U.S. Department
of Transportation

**Federal Aviation
Administration**

Advisory Circular

Subject: AIRWORTHINESS APPROVAL OF NAVIGATION OR FLIGHT MANAGEMENT SYSTEMS INTEGRATING MULTIPLE NAVIGATION SENSORS

Date: 6/14/95
Initiated By: AIR-130

AC No: 20-130A
Change:

1. PURPOSE. This advisory circular (AC) establishes an acceptable means, but not the only means, of obtaining airworthiness approval of multi-sensor navigation or flight management systems (hereafter referred to as multi-sensor equipment) integrating data from multiple navigation sensors for use as a navigation system for oceanic and remote, domestic en route, terminal, and non-precision instrument approach [except localizer, localizer directional aid (LDA) and simplified directional facility (SDF)] operations. This document does not address systems incorporating differential GPS capability. Like all advisory material, this AC is not mandatory and does not constitute a requirement. As such, the terms "shall" and "must" used in this AC pertain to an applicant who chooses to follow the method presented. The criteria of AC 90-45A, Approval of Area Navigation Systems for Use in the U.S. National Airspace System, does not apply to certification of equipment described in this AC. This AC supersedes previous GPS installation guidance contained in: FAA Notice 8110.48, Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors, and FAA Interim Guidance Memoranda dated February 25, 1991; April 5, 1991; March 20, 1992; July 20, 1992; and September 21, 1993. The appropriate information contained in those documents is incorporated in this AC.

2. CANCELLATION. Advisory Circular 20-130, Airworthiness Approval of Multi-Sensor Navigation Systems for use in the U.S. National Airspace System (NAS) and Alaska, dated September 12, 1988, is canceled.

3 RELATED FEDERAL AVIATION REGULATIONS. 14 CFR parts 21, 23, 25, 27, 29, 43, 91, 121, and 135.

4. RELATED READING MATERIALS.

a. Federal Aviation Administration (FAA) Technical Standard Order (TSO) C115a & b, Area Navigation Equipment Using Multi-Sensor Inputs; C129, Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS); C120, Airborne Area Navigation Equipment Using Omega/VLF Inputs; C94, Omega Receiving Equipment Operating Within the Radio Frequency Range 10.2 to 13.6 Kilohertz; and C60b, Airborne Area Navigation Equipment Using Loran-C Inputs. Copies may be obtained from the Department of

Transportation, FAA, Aircraft Certification Service, Aircraft Engineering Division, AIR-130, 800 Independence Avenue, SW., Washington, DC 20591.

b. RTCA, Inc. Document No. DO-160C, Environmental Conditions and Test Procedures for Airborne Equipment; Document No. DO-164A, Airborne Omega Receiving Equipment; Document No. DO-178B, Software Considerations in Airborne Systems and Equipment Certification; Document No. DO-180A, Minimum Operational Performance Standards for Airborne Area Navigation Equipment Using a Single Collocated VOR/DME Sensor Input; Document No. DO-187, Minimum Operational Performance Standards for Airborne Area Navigation Equipment Using Multi-Sensor Inputs; Document No. DO-190, Minimum Operational Performance Standards for Airborne Area Navigation Equipment Using Omega/VLF Inputs; Document No. DO-194, Minimum Operational Performance Standards for Airborne Area Navigation Equipment Using Loran-C Inputs; Document No. DO-200, Preparation, Verification and Distribution of User-Selectable Navigation Data Bases; Document No. DO-201, User Recommendations for Aeronautical Information Services; and Document No. DO-208, Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Position System (GPS). Copies may be purchased from RTCA, Inc., 1140 Connecticut Avenue, NW., Suite 1020, Washington, DC 20036.

c. Department of Defense, Global Positioning System Standard Positioning Service Signal Specification, November 5, 1993. Copies of this document may be requested from OASD (C3I) / T&TC3, 6000 Defense Pentagon, Washington, DC 20301-6000.

d. Advisory Circular 20-101C, Airworthiness Approval of Omega/VLF Navigation Systems for use in the U.S. National Airspace System (NAS) and Alaska; Advisory Circular 20-121A, Airworthiness Approval of Loran-C Navigation Systems for use in the U.S. National Airspace System (NAS) and Alaska; Advisory Circular 20-129, Airworthiness Approval of Vertical Navigation (VNAV) Systems for use in the U.S. National Airspace System (NAS) and Alaska; Advisory Circular 20-138, Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for use as a VFR and IFR Supplemental Navigation System; Advisory Circular 23-8A, Flight Test Guide for Certification of Part 23 Airplanes; Advisory Circular 25-4, Inertial Navigation Systems (INS); Advisory Circular 25-7, Flight Test Guide for Certification of Transport Category Airplanes; Advisory Circular 25-11, Transport Category Airplane Electronic Display Systems; Advisory Circular 25-15, Approval of Flight Management Systems in Transport Category Airplanes; Advisory Circular 27-1, Certification of Normal Category Rotorcraft; Advisory Circular 29-2A, Certification of Transport Category Rotorcraft; Advisory Circular 90-79, Recommended Practices and Procedures for the use of Electronic Long-Range Navigation Equipment; Advisory Circular 90-82B, Direct Routes in the Conterminous United States; Advisory Circular 91-49, General Aviation Procedures for Flight in North Atlantic Minimum Navigation Performance Specification Airspace; and Advisory Circular 120-33, Operational Approval of Airborne Long-Range Navigation Systems for Flight Within the North Atlantic Minimum Navigation Performance Specification Airspace. Copies may be obtained from the Department of Transportation, General Services Section, M-443.2, Washington, DC 20590.

e. Defense Mapping Agency (DMA) Technical Report DMA TR 8350.2, Department of Defense World Geodetic System 1984, Its Definition and Relationship With Local Geodetic Systems. Copies of this document may be requested from the Defense Mapping Agency, Systems Center, 8613 Lee Highway, Fairfax, VA 22031-2138.

5. BACKGROUND.

a. System Description. Navigation or flight management systems that determine aircraft position by integrating data from multiple navigation sensors are considered multi-sensor equipment. Aircraft position may be determined by various methods, depending on factors such as availability of sensor inputs, accuracy, signal parameters, location and/or flight phase, signal integrity, etc. Position determination may utilize data from various sensors, such as: distance measurements from two or more distance measuring equipment (DME) ground stations (DME-DME), bearing and distance from very high frequency omnidirectional range (VOR)/DME stations, bearing and distance from tactical air navigation (TACAN) stations, Omega/very low frequency (VLF), Loran-C, inertial navigation system (INS), inertial reference unit (IRU), and the global positioning system (GPS). The various sensor inputs are normally combined to determine a best computed aircraft position, but may be used individually in appropriate circumstances. A more detailed description of the various types of sensors is contained in the related AC and TSO for that type sensor. The coordinate system used is the Cartesian earth-centered earth-fixed coordinates as specified in the Department of Defense World Geodetic System 1984 (WGS-84). Navigational values such as distance and bearing to a waypoint, and ground speed are computed from the aircraft's latitude/longitude and the location of the waypoint. Course guidance is usually provided as a linear deviation from the desired track of a Great Circle course between defined waypoints.

b. System Availability and Reliability. Since multi-sensor equipment determines aircraft position by integrating data from multiple navigation sensor inputs, system availability and reliability is dependent upon the characteristics of the sensors incorporated in the system.

(1) Global Positioning System (GPS).

(i) Although basic GPS position determination capability from the 24 satellite constellation is expected to be available world-wide twenty-four hours a day, the satellite measurement redundancy required to ensure integrity of the GPS position will be neither world-wide nor continuous. With fewer than 24 satellites operating, GPS navigation capability may not be available at particular geographic locations at certain times. At least 21 satellites are expected to be operational with a probability of 98 percent.

(ii) The status of GPS is broadcast as part of the data message transmitted by the GPS satellites. Additionally, system status is planned to be available through the Notice to Airmen (NOTAM) system. GPS status information is also available by means of a telephone data service, (703) 313-5910, or voice, (703) 313-5907, from the U.S. Coast Guard.

(iii) GPS signal integrity monitoring shall be provided by the GPS navigation receiver using receiver autonomous integrity monitoring (RAIM) or an equivalent level of integrity provided by the multi-sensor equipment. This monitoring is necessary because delays up to two hours may occur before an erroneous satellite transmission can be detected and corrected by the satellite control segment. Availability of RAIM detection capability to meet non-precision approach requirements in the United States (with 24 satellites operating, barometric altitude aiding, and a 5 degree mask angle) is expected to exceed 99 percent.

(iv) Only the GPS satellite/ground control system operated by the U.S. Department of Defense is addressed in this AC. Utilization of other satellite navigation systems (i.e., GLONASS) is not covered.

(2) Omega/VLF.

(i) Omega system status is available from the U.S. Naval Observatory, telephone (703) 313-5906. Omega status messages are also broadcast by the National Bureau of Standards on stations WWV and WWVH at 16 minutes past each hour (WWV) and 47 minutes past each hour (WWVH). Omega/VLF ground station reliability is high, however reception of the Omega/VLF signals is susceptible to effects of precipitation static and atmospheric noise, especially when using an E-field antenna. Omega/VLF signals are generally usable 24-hours a day anywhere in the world.

(ii) The VLF communications system operated by the U.S. Navy is not primarily intended for navigation use. The Navy may shut stations down, add new stations, change frequencies, etc., with no advance notice. Information on current VLF system status is not published for the aviation user.

(iii) Omega/VLF navigation sensors, while they may use VLF communications stations to supplement and enhance the Omega system (improve performance, etc.), must be capable of accurate navigation using Omega signals alone.

(3) Loran-C.

(i) Loran-C ground transmitter reliability exceeds 99 percent annually, excluding momentary (less than 60 seconds) ground station outages which occur more frequently (e.g., transmitter switching, adjustments, antenna lightning protection circuitry). These momentary outages can result in loss of Loran-C navigation capability for several minutes, depending upon the particular conditions and design of the Loran-C sensor. Airborne reception of the Loran-C signal (normally using an E-field antenna) is highly susceptible to adverse effects caused by precipitation static and atmospheric noise. Loran-C signal coverage is available throughout the continental United States, southern Alaska, southern and eastern Canada, most of the Gulf of Mexico, the North Atlantic, and various other areas of the world.

(ii) Loran-C navigation predicated on hyperbolic lines of position originating from a single chain may not be suitable for IFR use throughout the entire continental United States and northern Alaska. Equipment utilizing master independent, cross chain, and/or multiple chain receivers has been approved for IFR use in areas where single chain receivers are unacceptable.

(iii) Loran-C system status is available through the NOTAM system and is also available by means of telephone data service (300 or 1200 baud, ASCII) from the U.S. Naval Observatory, telephone (202) 653-1079.

(4) VOR, VOR/DME, VORTAC, TACAN, and Multiple DME.

(i) Ground station availability of these navigation aids exceeds 99 percent annually.

(ii) Coverage of these navigation aids is limited to within line-of-sight of the ground station.

(iii) VOR, VOR/DME, VORTAC, TACAN, and DME system status is available through the NOTAM system.

(5) Inertial Navigation System (INS) and Inertial Reference Unit (IRU).

(i) Inertial navigation/reference systems are self contained and do not rely upon external navigation aids.

(ii) Some inertial systems are not suitable for alignment and/or operation at high north and south latitudes (polar regions).

c. System accuracy. Accuracy of multi-sensor equipment is dependent upon the sensor or combination of sensors in use at a particular time. Various navigation sensor inputs are integrated, considering signal quality, station geometry, integrity, estimated position error, etc. for each sensor and computing a best position based upon all available data. Required system navigational accuracy is specified later in this AC. Individual sensor capabilities are summarized below:

(1) Global Positioning System. The GPS equipment determines its position by precise measurement of the distance from selected satellites in the system and the satellites' known location. The accuracy of GPS position data can be affected by equipment characteristics and various geometric factors. Many of these errors can be reduced or eliminated with sophisticated mathematical modeling, while other sources of error cannot be corrected. Accuracy measurements are affected by satellite geometry, frequently modeled by a geometric

dilution of position (GDOP), which translates the effect of pseudorange errors to the position domain. The following are sources of pseudorange errors:

(i) Atmospheric propagation delays can cause relatively small measurement errors, typically less than 100 feet. Both tropospheric and ionospheric propagation delays can be partially corrected by sophisticated error correction capabilities.

(ii) Slight inaccuracies in the atomic clocks on the satellites can cause a small position error of approximately two feet.

(iii) Receiver processing (mathematical rounding, electrical interference, etc.) may cause errors that are usually either very small (which may add a few feet of uncertainty into each measurement) or very large (which are easy to detect). Receiver errors are typically on the order of four feet.

(iv) Conditions that cause signal reflections (multipath) of the satellites' transmitted signal to the receiver can cause small errors in position determination or momentary loss of the GPS signal. While advanced signal processing techniques and sophisticated antenna design can be used to minimize this problem, some uncertainty can still be added to a GPS measurement.

(v) Satellite ephemeris data can contain a small error of approximately four feet.

(vi) Selective Availability (SA) is essentially a method by which the Department of Defense can artificially create a significant clock and ephemeris error in the satellites. This feature is designed to deny an enemy the use of precise GPS positioning data. Selective Availability is the largest source of error in the GPS system. When SA is active, the DOD guarantees horizontal position accuracy will not be degraded beyond 100 meters 95 percent of the time and 300 meters 99.99 percent of the time. System performance specifications contained in this AC assume SA is active.

(vii) Block II GPS satellites incorporate an anti-spoofing alert flag to advise the user that the user range accuracy may be degraded. GPS navigation systems should recognize the presence of this flag.

(2) Omega/VLF. Omega/VLF equipment determines its present position by adding incremental changes in position calculated from the continuously measured phase of each received Omega signal to the initial position established at the time of system initialization. VLF signals may be used in conjunction with Omega and therefore navigation may be based on an Omega/VLF mix. The accuracy of Omega/VLF position data can be affected by equipment and geometry. Typically, Omega/VLF position determination can be expected to be within 3.0 nmi of the true position. Omega signals must be used to provide integrity to a VLF/Omega system, since VLF is not an approved navigation system and does not provide integrity. Consequently,

when no Omega signals are available, the equipment may continue to provide a navigation solution with no integrity using only the VLF system. This condition requires a unique indication from the sensor. The multi-sensor equipment may either provide the requisite integrity using an alternate approved sensor, or provide a unique annunciation to the pilot that the navigation solution does not have integrity. If integrity is not provided, the system does not meet IFR navigation certification criteria.

(i) Omega and VLF navigation can be degraded by errors due to phase disturbances of the signals as they propagate from the station to the aircraft.

(ii) Improper modeling of the signal propagation changes caused by diurnal shift surface conductivity, etc. can cause errors in position determination.

(iii) Accuracy measurements are affected by station geometry, which magnifies the effect of other errors in the system.

(3) Loran-C. Loran-C equipment determines its present position using multiple hyperbolic lines of position established by precise measurement of the time of arrival of synchronized pulsed signals from a series of ground transmitting stations. The accuracy of Loran-C navigation can be affected by various factors, including equipment, signal propagation, and geometric factors. Typically, Loran-C position determination within approved operating areas will be within 1.0 nmi and within 0.3 nmi (for systems receiving triad corrections for approach operations) of the true position.

(i) Position errors can be caused by slower signal propagation over land and fresh water than over sea water. These errors appear to be quite constant over distances of several miles. The effect of these errors is a shift or bias in the computed position in the local area. Area calibration or more sophisticated propagation models can be used to reduce the effect of these bias errors.

(ii) Position errors can be caused by abrupt changes in terrain and weather fronts which affect the propagation of the signal from the ground station.

(iii) Atmospheric noise and precipitation static adversely affect the ability of the equipment to precisely track the synchronized pulsed signals. Incorrect cycle tracking or loss of signal can result in significant position determination errors.

(iv) Accuracy measurements are affected by ground station geometry, which magnifies the effect of other errors in the system.

(4) VOR, VOR/DME, TACAN. Equipment utilizing VOR, VOR/DME, or TACAN sensors determines its present position by measuring the bearing or bearing and distance from a reference ground station. Typically, position determination using this type of

sensor will be within 1.0 nmi of the true position, however accuracy is highly dependent upon distance from the reference station.

(5) Multiple DME. Equipment utilizing a multiple DME sensor determines its present position by precise distance measurements from two or more reference ground stations. With good geometry, systems using high quality DME sensors are capable of position determination within 0.2 nmi of the true position.

(6) Inertial. Equipment utilizing an inertial navigation or inertial reference sensor(s) determines its present position by precise tracking of all movement of the aircraft from a known starting point. Accuracy of inertial sensors degrades over time. Position determination with an inertial system can degrade at a rate of 2 nmi per hour for flights up to 10 hours in duration.

d. General Operational Limitations.

(1) Sensor Requirements. Depending upon the particular sensors incorporated into the system, multi-sensor equipment can be approved for oceanic and remote, en route, terminal, and instrument approach use. This document assumes that each sensor used in the multi-sensor equipment has been demonstrated to meet the applicable design criteria for that sensor (i.e. TSO, MOPS, etc.), or that the multi-sensor system is shown to have equivalent performance.

(i) A system may be approved for oceanic and remote navigation provided at least one of the following sensors is utilized in the multi-sensor equipment: GPS, Omega/VLF, Loran-C (in limited areas), INS/IRU.

(ii) A system may be approved for en route use as a supplemental navigation system provided at least one of the following sensors is used by the multi-sensor equipment: GPS, Omega/VLF, Loran-C (in limited areas), VOR/DME, Multiple DME, TACAN, INS/IRU.

(iii) A system may be approved for terminal area use as a supplemental navigation system provided at least one of the following sensors is used by the multi-sensor equipment: GPS, Loran-C (in limited areas), VOR/DME, Multiple DME, TACAN.

(iv) A system may be approved for instrument approach navigation (except ILS, LOC, LOC-BC, LDA, SDF, and MLS) provided the required sensor(s) outlined in Table 1 is used by the multi-sensor equipment.

(v) All sensor accuracy and integrity requirements must be met without the need for operator input of required data, except that operator entry of Loran-C time difference correction values shown on a charted Loran-C instrument approach procedure may be used in satisfying approach accuracy requirements.

Table 1
Instrument Approach Sensor Requirements

Type of Instrument Approach	Required Sensor*
Published RNAV approaches	GPS or VOR/DME
Published Loran-C approaches	GPS or Loran-C
Published VOR or VOR/DME approaches	GPS or VOR/(DME)
Published TACAN approaches	GPS or TACAN
Published GPS approaches	GPS
Published NDB or NDB/DME approaches	GPS or NDB/(DME)

*The required sensor identifies a single sensor/sensor combination which, when demonstrated to meet the accuracy requirements of this AC, can be used to conduct these approaches. Alternatively, multi-sensor equipment can be shown to meet the accuracy requirements with a combination of sensors.

(2) IFR Navigation Equipment. Aircraft employing multi-sensor equipment for IFR navigation must also be equipped with an approved and operational alternate means of navigation appropriate to the intended route to be flown. Within the contiguous United States, Alaska, Hawaii, and surrounding coastal waters, this requirement can be met with an operational, independent VOR receiver, although data from this receiver can provide an input to the multi-sensor equipment. For oceanic and remote operations, an alternate means of navigation is required unless the multi-sensor equipment incorporates within itself a sensor approved individually for the particular area of operations (some oceanic airspace may require additional redundancy).

(3) Operating Limitations. Particular multi-sensor equipment may require operational areas be limited to those areas in which the equipment has been demonstrated to meet the performance specifications of this AC because of system characteristics and other factors affecting system operation. Operating limitations that may affect the approved operating area for particular multi-sensor equipment must be specified in the operating limitations section of the Airplane/Rotorcraft Flight Manual Supplement (AFMS/RFMS) (i.e., extreme north and south latitudes, data base coverage, sensor coverage, etc.). FAA approval of GPS navigation equipment does not constitute approval to conduct GPS-based navigation in airspace controlled by foreign airworthiness authorities. Systems that do not provide for coordinate reference system conversions of the displayed navigation information should not be used in airspace that is not referenced to the WGS-84 or NAD-83 geodetic datums. Operating limitations relating to geodetic datums for particular GPS navigation equipment should be included in the limitations section of the AFMS/RFMS.

e. Equipment Classes. GPS sensors installed in accordance with the guidance provided by this AC for IFR operations shall meet the requirements for Class B() or C() equipment as defined in TSO-C129 (hereafter referred to as Class B() or C() GPS sensor). GPS sensors integrated in multi-sensor equipment limited to VFR only shall meet the accuracy requirements in paragraph 7 of this AC.

f. Future Air Navigation System (FANS) Concept. Information in this AC is not intended to restrict the development, certification, or operational approval of current or future multi-sensor equipment installations designed to comply with required navigation performance (RNP) or other FANS design requirements.

6. DEFINITIONS. Any terms used in this AC that have a meaning specific to the context of this AC are contained in APPENDIX 3. GLOSSARY.

7. SYSTEM ACCURACY.

a. 2D Accuracy Requirements (95 percent probability).

(1) For equipment incorporating a Class B() or C() GPS sensor, the total position fixing error of the multi-sensor equipment shall be equal to or less than that shown in Table 2 when GPS data is used in the position/navigation computation:

Table 2
2D Accuracy Requirements, Equipment Incorporating Class B() or C() GPS Sensor

Error Type	Oceanic and remote (nmi)	En Route (Domestic) (nmi)	Terminal (nmi)	Non-Precision Approach * (nmi)
Position Fixing Error **	0.124	0.124	0.124	0.056
CDI Centering ***	0.2	0.2	0.2	0.01

* Non-precision approach criteria only applies to equipment incorporating a Class B1, B3, C1, or C3 GPS sensor.

** Equipment error assumes an average GPS HDOP of 1.5, GPS equipment waypoint input resolution of 0.01 minute, and output resolution of 0.01 minute for approach and 0.1 minute otherwise.

*** The maximum difference between the displayed cross track deviation and the computed cross track deviation.

(2) For equipment not incorporating a GPS sensor (or when GPS data is not used in a system including a GPS sensor), the total position fixing error of the multi-sensor equipment shall be equal to or less than that shown in Table 3:

Table 3
2D Accuracy Requirements, Equipment Not Incorporating a GPS Sensor

Error Type	Oceanic and remote (nmi)	En Route (Domestic) (nmi)	Terminal (nmi)	Non-Precision Approach (nmi)
Position Fixing Error *	12.0	2.8	1.7	0.3 (0.5 if navigation data derived from a single collocated VOR/DME station)
CDI Centering **	0.2	0.2	0.2	0.1

* Equipment error assumes multi-sensor equipment waypoint input resolution of 0.01 minute, and output resolution of 0.01 minute for approach and 0.1 minute otherwise.

** The maximum difference between the displayed cross track deviation and the computed cross track deviation.

(3) For times when the equipment is using data from only a single collocated VOR/DME station (such as during an RNAV approach) and no other sensor input is contributing to the position solution, the total maximum position fixing error of the airborne multi-equipment shall be equal to or less than that shown in Table 4. To find the cross track and along track error at this point, enter the table with the tangent distance and distance along track from the tangent point.

Table 4
2D Accuracy Requirements, Equipment Utilizing Only a Single Collocated VOR/DME

			Along-Track Distance																	
			0	5	10	15	20	25	30	35	40	50	60	70	80	90	100	110	120	130
Tangent Distance	0	xtk		0.6	0.8	1.1	1.4	1.7	2.0	2.3	2.6	3.2	3.9	4.5	5.2	5.8	6.4	7.1	7.7	8.4
		atk		0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.6
	5	xtk	0.6	0.6	0.8	1.1	1.4	1.7	2.0	2.3	2.6	3.3	3.9	4.5	5.2	5.8	6.4	7.1	7.7	8.4
		atk	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7
	10	xtk	0.6	0.7	0.9	1.1	1.4	1.7	2.0	2.3	2.6	3.3	3.9	4.5	5.2	5.8	6.5	7.1	7.7	8.4
		atk	0.8	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8
	15	xtk	0.6	0.7	0.9	1.1	1.4	1.7	2.0	2.3	2.6	3.3	3.9	4.5	5.2	5.8	6.5	7.1	7.7	8.4
		atk	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9
	20	xtk	0.6	0.7	0.9	1.2	1.4	1.7	2.0	2.3	2.7	3.3	3.9	4.6	5.2	5.8	6.5	7.1	7.7	8.4
		atk	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2.0	2.1
	25	xtk	0.7	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.7	3.3	3.9	4.6	5.2	5.8	6.5	7.1	7.8	8.4
		atk	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.7	1.7	1.7	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3
	30	xtk	0.7	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.7	3.3	3.9	4.6	5.2	5.9	6.5	7.1	7.8	8.4
		atk	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	2.0	2.0	2.1	2.1	2.2	2.2	2.3	2.4	2.4	2.5
	35	xtk	0.8	0.8	1.0	1.3	1.5	1.8	2.1	2.4	2.7	3.3	4.0	4.6	5.2	5.9	6.5	7.1	7.8	8.4
		atk	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.7	2.7
	40	xtk	0.8	0.9	1.1	1.3	1.5	1.8	2.1	2.4	2.7	3.3	4.0	4.6	5.2	5.9	6.5	7.1	7.8	8.4
		atk	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.5	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0
	50	xtk	0.9	1.0	1.1	1.3	1.6	1.9	2.2	2.5	2.8	3.4	4.0	4.6	5.3	5.9	6.5	7.2	7.8	8.4
		atk	2.9	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.1	3.2	3.2	3.3	3.3	3.4	3.4	3.5
	60	xtk	1.0	1.0	1.2	1.4	1.7	1.9	2.2	2.5	2.8	3.4	4.0	4.7	5.3	5.9	6.6	7.2	7.8	8.5
		atk	3.5	3.5	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.9	3.9	4.0
	70	xtk	1.0	1.1	1.3	1.5	1.7	2.0	2.3	2.6	2.9	3.5	4.1	4.7	5.3	6.0	6.6	7.2	7.9	8.5
		atk	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.2	4.2	4.2	4.2	4.3	4.3	4.4	4.4	4.4	4.5	4.5
	80	xtk	1.1	1.2	1.4	1.6	1.8	2.1	2.3	2.6	2.9	3.5	4.1	4.7	5.4	6.0	6.6	7.3	7.9	8.5
		atk	4.6	4.7	4.7	4.7	4.7	4.7.	4.7	4.7	4.7	4.8	4.8	4.8	4.9	4.9	5.0	5.0	5.0	5.1
	90	xtk	1.2	1.3	1.4	1.6	1.9	2.1	2.4	2.7	3.0	3.5	4.2	4.8	5.4	6.0	6.7	7.3	7.9	8.6
		atk	5.2	5.2	5.2	5.2	5.2	5.3	5.3	5.3	5.3	5.3	5.4	5.4	5.4	5.5	5.5	5.5	5.6	5.6
	100	xtk	1.3	1.4	1.5	1.7	1.9	2.2	2.4	2.7	3.0	3.6	4.2	4.8	5.4	6.1	6.7	7.3	7.9	8.6
		atk	5.8	5.8	5.8	5.8	5.8	5.8	5.9	5.9	5.9	5.9	5.9	6.0	6.0	6.0	6.1	6.1	6.1	6.2
	110	xtk	1.4	1.5	1.6	1.8	2.0	2.3	2.5	2.8	3.1	3.6	4.2	4.9	5.5	6.1	6.7	7.3	8.0	8.6
		atk	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.5	6.5	6.5	6.5	6.6	6.6	6.6	6.7	6.7	6.7
	120	xtk	1.5	1.6	1.7	1.9	2.1	2.3	2.6	2.8	3.1	3.7	4.3	4.9	5.5	6.1	6.8	7.4	8.0	8.6
		atk	6.9	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.1	7.1	7.1	7.1	7.2	7.2	7.2	7.3	7.3
	130	xtk	1.6	1.7	1.8	2.0	2.2	2.4	2.6	2.9	3.2	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.0	8.7
		atk	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.7	7.7	7.7	7.7	7.8	7.8	7.8	7.9

NOTE 1: Equipment error assumes a waypoint input resolution of 0.01 minute, and output resolution of 0.01 minute for approach and 0.1 minute otherwise.

NOTE 2: Equipment error assumes the maximum allowable difference between the displayed cross track deviation and the computed cross track deviation.

NOTE 3: Multi-sensor equipment accuracy shown in the above table does not necessarily satisfy accuracy requirements for operation in certain airspace. For example, navigation on published J and V routes requires the distance along-track from the tangent point and distance from the tangent point to VOR/DME to be less than approximately 50 nmi to meet airway width criteria.

NOTE 4: The above table is a result of an RSS combination of the below error elements. The accuracy tables are computed assuming that the waypoint is always at the tangent point and the aircraft is at the along-track distance measured from the same tangent point. This is important in the test procedures because the resulting cross-track error from the course setting is a function of distance to waypoint.

Ground Equipment Error:
VOR 1.4 degrees
DME 0.1 nmi

Airborne Equipment Error:
VOR 3.0 degrees
DME 0.2 nmi + 1%
CSE 1.6 degrees
Computation Error 0.5 nmi

b. Flight Technical Error (FTE). Since FTE factors are normally beyond the control of equipment manufacturers or installers, these error sources are not included in the accuracy specifications of paragraphs 7(a)(1) and (2). The FAA has determined that when properly installed in an aircraft, multi-sensor equipment (except equipment incorporating a Class C() GPS sensor) meeting the operational and display characteristics contained in this AC, related discrete sensor AC's, TSO-C115b, and related discrete sensor TSO's, provides for acceptable values of FTE. FTE should not exceed 1.0 nmi for en route, 1.0 nmi for terminal or approach transition, or 0.25 nmi (for equipment using GPS data) or 0.5 nmi (for equipment not using GPS data) for approach operating modes on a 95 percent basis. Equipment integrating a Class C() GPS sensor must include display and system integration capabilities that provide an acceptable value of FTE, and is evaluated based upon the particular installation to determine the suitability of proposed operational and display characteristics.

c. VNAV Accuracy Requirements. For equipment that includes a vertical navigation capability (VNAV), see AC 20-129 for Vertical Navigation Requirements.

8. AIRWORTHINESS CRITERIA FOR MULTI-SENSOR EQUIPMENT LIMITED TO VISUAL FLIGHT RULES (VFR) ONLY.

a. Application Process. Persons wishing to use multi-sensor equipment for operations limited to VFR only may obtain approval of the installation by Type Certificate (TC) or Supplemental Type Certificate (STC). For equipment that has already obtained installation approval via the TC or STC process, approval may also be obtained via data approved by the FAA (responsible Flight Standards District Office) on FAA Form 337 (Major Repair and Alteration). The approval for return to service must be signed by one of the entities noted in 14 CFR part 43; i.e., repair station, manufacturer, holder of an inspection authorization, etc.

b. Airworthiness Considerations. Multi-sensor equipment approved for VFR use only does not require TSO-C115b authorization, however it must at least meet the en route/terminal system accuracy criteria contained in paragraph 7a of this AC. Each individual sensor must also meet any additional performance criteria (besides accuracy) applicable to VFR only approval that is contained in the respective AC applicable to that type sensor. The installation verification should ensure, but is not limited to, the following:

(1) Electromagnetic Compatibility. The multi-sensor equipment installation does not interfere with the normal operation of other equipment installed in the aircraft.

(2) Environmental Conditions. The multi-sensor equipment is appropriate to the environmental categories (or criteria) in which it is installed.

(3) Equipment Mounting. The installation of the multi-sensor equipment, including antenna, must be sufficient to meet all structural mounting, dynamic, and emergency landing loads appropriate to the aircraft category. It is acceptable to use the criteria in AC 43.13-2A, "Acceptable Methods, Techniques, and Practices - Aircraft Alterations."

(4) Navigation Source Annunciator. A navigation source annunciator is provided on or adjacent to each affected display if the multi-sensor equipment installation supplies any information to displays such as a horizontal situation indicator (HSI), course deviation indicator (CDI), distance display, electronic map, etc., that can also display information from other systems normally used for aircraft navigation.

(5) Computer Software. The AC 20-115B, which refers to RTCA/DO-178B, provides an acceptable means for showing that software complies with applicable airworthiness requirements. The applicant should substantiate software levels in the safety assessment. As an alternative to substantiating software level(s) in a safety assessment, the applicant may develop all software that contains or affects navigation and integrity functions to at least the Level D criteria, as defined in RTCA/DO-178B. The FAA recommends that the standards for IFR equipment contained in paragraph 8b(1) be followed if the system is intended to be upgraded to IFR use in the future.

(6) Failure Protection. Any probable failure of the multi-sensor equipment must not degrade the normal operation of other required equipment or create a flight hazard. Likewise, normal operation of the multi-sensor equipment cannot adversely affect the performance of other aircraft equipment. The interfaces with other aircraft equipment must be designed such that normal or abnormal multi-sensor equipment operation does not adversely affect the operation of other equipment. Operation of other equipment shall not adversely affect the multi-sensor equipment operation.

(7) System Controls, Displays and Annunciators. All displays, controls, and annunciators must be readable under all normal cockpit conditions and expected ambient light conditions (total darkness to bright reflected sunlight). Night light provisions must be consistent with other cockpit lighting. All displays and controls should be arranged to facilitate equipment usage. Controls that are normally adjusted in flight shall be accessible and properly labeled as to their function. System controls and displays should be designed to maximize operational suitability and minimize pilot workload. System controls should be arranged to provide

protection against inadvertent system turnoff. Reliance on pilot memory for operational procedures shall be minimized.

(8) Navigation/Integrity Annunciation. The multi-sensor equipment should indicate, independent of any operator action:

(i) The following conditions by means of a navigation warning flag on the navigation display:

(A) The absence of power required for the navigation function.

(B) Probable equipment malfunctions or failures affecting the navigation function.

(C) Loss of navigation function.

(ii) If an integrity monitoring function (such as GPS RAIM) is provided, an appropriately located annunciator shall be provided to indicate loss of the integrity monitoring function.

NOTE 1: For equipment not incorporating an external navigation display (CDI, HSI, etc.), complete blanking of the control display is acceptable.

NOTE 2: Presentation of a failure/status annunciation (flag or integrity annunciation) does not require removal of navigation information from the navigation display.

(9) Autopilot/Flight Director Coupling. The multi-sensor equipment may be coupled to an autopilot and/or flight director provided the multi-sensor equipment has a deviation or steering output that is compatible with the autopilot/flight director system and no unusual interface is required.

(10) VFR Limitation Placard. A placard stating " GPS not approved for IFR" must be installed in clear view of, and readable by, the pilot.

(11) Pressure/Barometric Altitude Inputs. If the multi-sensor equipment incorporates Class B1, B2, C1, or C2 GPS sensor(s) and uses a barometric pressure altitude input, that input must be appropriate to the equipment.

(12) Manufacturer's Instructions. The multi-sensor equipment, including antenna(e), must be installed in accordance with the instructions and limitations provided by the manufacturer of the equipment.

c. VFR Airworthiness Approval. There are two types of VFR airworthiness approval which differ significantly as to test requirements and data analysis.

(1) First-Time VFR Airworthiness Approval (for a Particular Type of Multi-Sensor Equipment). This type of approval refers to the first time an applicant presents a particular (hardware and software configuration) model of multi-sensor equipment integrating multiple navigation sensors for FAA airworthiness installation approval and certification for VFR navigation use. The first approval of particular multi-sensor equipment must be accomplished through the TC or STC process. Each new model of multi-sensor equipment or significant changes (hardware or software) to existing equipment shall undergo the same approval process as the original equipment unless it can be shown by analysis and tests acceptable to the Administrator that the new model will function as well or better than the approved equipment. A first-time approval is conducted in four phases:

(i) Lab/Bench Tests and Equipment Data Evaluation. This phase consists of the following:

(A) Review of the manufacturer's procedures for development of software and review of supporting documentation in accordance with the guidelines of paragraph 8b(5) of this AC.

(B) Analysis of failure modes and annunciations.

(C) Review of reliability data to establish that all probable failures are detected and that hazardously misleading failures are shown to be improbable.

(D) Review of installation and maintenance manuals.

(E) Evaluation of the operator's manual (pilot's guide).

(ii) Aircraft Installation Data Evaluation. Normally the manufacturer of the multi-sensor equipment will provide an aircraft as a test bed for the first time installation approval. This approval may serve as a basis for subsequent installation approvals. The following assessments are made:

(A) Review of the equipment installation in the aircraft.

(B) Verification that the multi-sensor equipment is appropriate to the environment in which it was installed. (DO-160C testing is acceptable to meet this requirement.)

(C) Analysis of a data flow diagram in order to review which equipment provides what data to which other equipment.

(D) Verification that the installation of the multi-sensor equipment, including antenna, is sufficient to meet all structural mounting, dynamic, and emergency landing loads appropriate to the aircraft category.

(E) Verification that a placard stating "GPS not approved for IFR" is installed in clear view of, and readable, by the pilot.

(F) Verification that the multi-sensor equipment does not interfere with the normal operation of other equipment installed in the aircraft. (May interface with IFR equipment.)

(G) Evaluation of the antenna installation. A critical aspect of many multi-sensor equipment installations is the installation of the antenna(e). It is important that the antenna for each sensor be one that is approved for the particular type (make and model) sensor installed.

(iii) Ground Test Evaluations. For multi-sensor equipment incorporating a Class B() or C() GPS sensor, static ground tests are conducted to verify the installed GPS equipment configuration (including antenna) provides position data meeting the accuracy criteria specified in paragraph 7a(1) of this AC. These tests shall cover a continuous period of 12 hours with a maximum sample interval of five minutes.

NOTE: The 12-hour ground accuracy test may be performed on the aircraft or by use of a representative mock-up configuration. If a mock-up test fixture is used, the entire installed multi-sensor equipment configuration, including antenna(e), must consist of the hardware to be used in the installation and be representative of the installed system configuration.

(iv) Flight Test Evaluations. Flight tests are conducted to verify proper operation and accuracy of the multi-sensor equipment as installed in the aircraft. Flight tests should include at least the following:

NOTE: Required flight evaluations for the first-time airworthiness approval of particular multi-sensor equipment are accomplished by the cognizant Aircraft Certification Office unless specific tests are delegated by the ACO to a flight test pilot designated engineering representative (DER).

(A) Evaluation of installed multi-sensor equipment to verify that it is functioning safely, and operates in accordance with the manufacturer's specifications.

(B) If coupled to an autopilot, evaluation of steering response while autopilot and/or flight director is coupled to the multi-sensor equipment during a variety of different track and mode changes. Additionally, all available display sensitivities shall be evaluated.

(C) Evaluation to verify the multi-sensor equipment installation does not adversely affect other onboard equipment (this test may be partially accomplished as a ground test).

(D) Evaluation of the accessibility of all controls pertaining to the multi-sensor equipment installation.

(E) Evaluation of the visibility of the controls, displays, and annunciators relating to the multi-sensor equipment installation during day and night lighting conditions. No distracting cockpit glare or reflections may be introduced, and all controls must be illuminated for identification and ease of use. Night lighting shall be consistent with other cockpit lighting.

(F) Validate multi-sensor equipment navigational accuracy in each operating mode (e.g. oceanic, en route, and terminal) for which approval is requested. In addition to overall system navigation performance, particular test requirements for navigational accuracy will vary depending upon the particular sensors integrated in the multi-sensor equipment and whether sensor accuracy performance data has previously been obtained. As an alternative to demonstrating the required accuracy with each specific sensor noted below, the multi-sensor equipment can be shown to have the requisite accuracy with various combinations of sensors.

(1) GPS sensor accuracy should be verified in each operating mode by at least 5 low altitude over flights of one or more surveyed locations (ensure survey point coordinates are relative to WGS-84 or NAD-83). An acceptable method of conducting this accuracy demonstration is to accomplish low altitude (less then 100 feet AGL) overflight of a runway threshold and record the GPS position as the aircraft crosses the threshold. The system accuracy is the distance between the coordinate position determined by the GPS and the coordinate position of the surveyed location (runway threshold). Runway threshold coordinates may be obtained from the airport operator or regional flight procedures office. If coordinate data conversion to WGS-84/NAD-83 is necessary, contact the National Flight Data Center at (202) 267-9277.

(2) Initial certification for systems including an Omega/VLF, Loran-C, VOR/DME, multiple (scanning) DME, INS or IRU sensor that has not previously been certified shall be based upon a demonstration of system accuracy by recording (at not greater than 15 minute intervals) the sensor position and comparing it to the actual

position during evaluation flights representative of the area in which approval is desired. This flight test should be at least two hours in duration in order to provide a sufficient data set.

(2) Follow-On VFR Airworthiness Installation Approvals. This type of approval refers to installation approvals in any model or type of aircraft after a first time airworthiness approval of the particular multi-sensor equipment has been issued. Follow-on approvals may use the first time airworthiness approval, which was either a TC or an STC, as a basis for installation approval. Follow-on installation approvals may be accomplished by TC, STC, or data approved on FAA Form 337, if the flight standards inspector determines that there are no design changes as a result of the installation. The determination of a design change will be dependent upon the integration with other avionics and not on the basis of aircraft make and model. Since the GPS equipment operates on principles that are not dependent upon the aircraft make and model, the engineering evaluation of one aircraft model is applicable to a different aircraft provided the integration with the other equipment is equivalent.
The applicant or installing agency requesting a follow-on multi-sensor equipment installation utilizing this method of data approval should:

(i) Unless otherwise provided, contact either the manufacturer or organization responsible for obtaining the first time airworthiness approval of the multi-sensor equipment in order to:

(A) Obtain a sample airplane or rotorcraft flight manual supplement (or supplemental flight manual, if appropriate), if required for the aircraft.

(B) Obtain verification of the equipment approval status, including antenna, software, autopilot/flight director interface, and system integration requirements, etc.

(C) Discuss any problem areas and seek assistance in their solution.

(D) Verify that the maximum operating speed for which the multi-sensor equipment is qualified is compatible with the maximum expected ground speed of the aircraft.

(ii) Conduct a similar data evaluation as outlined in paragraph 8c(1)(ii) of this AC.
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(iii) Conduct a functional flight evaluation covering the items listed in paragraphs 8c(1)(iv)A through 8c(1)(iv)E of this AC. In addition, the flight test should demonstrate multi-sensor equipment navigational performance (including, as applicable to the sensors integrated in the system, Loran-C chain selection/switching, P-static protection, etc.) has not been affected by the installation in the aircraft.

NOTE: Required flight evaluations for follow-on equipment installations approved via the Form 337 process may be conducted by the installer.

9. AIRWORTHINESS CRITERIA MULTI-SENSOR EQUIPMENT USED UNDER INSTRUMENT FLIGHT RULES (IFR)

a. Application Process. Persons wishing to obtain approval of multi-sensor equipment integrating any combination of GPS, Omega/VLF, Loran-C, VOR/DME, Multiple DME, or INS/IRU sensors for IFR operations may do so via the Type Certificate (TC) or Supplemental Type Certificate (STC) process. For equipment approved via the TC or STC process, approval may also be obtained via data approved by the FAA (responsible Flight Standards District Office) on FAA Form 337 (Major Repair and Alteration). The approval for return to service must be signed by one of the entities noted in 14 CFR part 43; i.e., repair station, manufacturer, holder of an inspection authorization, etc.

(1) The initial (first-time airworthiness approval) certification of multi-sensor equipment requires extensive engineering and flight test evaluations and must be accomplished via the TC or STC approval process.

(2) Subsequent (follow-on) installations of the same multi-sensor equipment (hardware and software) in other aircraft are approved using a less extensive evaluation process since the basic engineering design has already been evaluated. Approval of follow-on installations may be accomplished via the TC, STC, or FAA Form 337 process. The extent of required evaluations depends upon the degree of integration of the navigation system with other aircraft systems, the similarity between the initial and follow-on aircraft models, and other changes that may have been incorporated in the multi-sensor equipment. The decision to allow an applicant to use FAA approved engineering data in support of an FAA Form 337 approval is left to the field inspector's judgment. The FAA Airworthiness Inspector's Handbook (FAA Order 8300.10) provides guidance applicable to multi-sensor equipment installations. Changes to software accomplishing navigation, integrity, or availability functions; changes in the number, type, or mix of sensors integrated in the system; changes to/addition of approved operating areas; or significant changes to operating limitations cannot be accomplished using the FAA Form 337 process and must use TC or STC procedures.

(3) Approval of multi-sensor equipment integrating a Class C() GPS sensor with any other combination of sensors for IFR operations must use the TC or STC process. Because of the unique enhanced display and system integration requirements applicable to this integration of sensors and displays, appropriate test requirements and procedures must be determined based upon the particular application. These tests must establish the equivalent display capability of the installation and the display requirements for Class A() sensors. Reference AC 20-138 for the specific requirements.

b. Airworthiness Considerations. Multi-sensor equipment to be approved for oceanic and remote, domestic en route, terminal, and non-precision instrument approach (except localizer, LDA and SDF) operations must meet the minimum navigation performance and operation standards for the appropriate equipment specified in TSO-C115b and this AC (including GPS equipment classes in TSO-C129 as referenced in TSO-C115b for multi-sensor equipment incorporating a GPS sensor). Additionally, each individual sensor must at least meet the navigation performance and operation criteria (besides accuracy) contained in the respective TSO and AC applicable to that type sensor.

(1) System Integrity and Software Development. Loss of navigation or flight management information is considered to be a major failure condition for the aircraft as defined in AC 25.1309-1A, AC 23.1309-1A, AC 27-1, or AC 29-2A, as applicable to the aircraft. Hazardously misleading information to the flight crew is also considered to be a major failure condition for the aircraft. Navigation data is considered to be hazardously misleading when unannunciated position errors exist that are greater than those specified by the multi-sensor equipment or individual sensor requirements (e.g., GPS position integrity performance requirements in Table 2-1 of RTCA/DO-208). The applicant should conduct a system safety assessment to verify that design errors and failure modes that produce major failure conditions are improbable.

(i) AC 25.1309-1A, AC 23.1309-1A, AC 27-1, or AC 29-2A, as applicable, provides an acceptable means for showing that the hardware complies with pertinent airworthiness requirements.

(ii) AC 20-115B, which refers to RTCA/DO-178B, provides an acceptable means for showing that software complies with pertinent airworthiness requirements. The applicant should substantiate software levels in the safety assessment. As an alternative to substantiating software level(s) in a safety assessment, the applicant may develop all software that contains or affects navigation and integrity functions to at least the Level C criteria, as defined in RTCA/DO-178B.

(iii) The cognizant Aircraft Certification Office may grant a deviation to TSO-C115a or TSO C-129 (Classes B and C) to permit the applicant to use the procedures of RTCA/DO-178B instead of RTCA/DO-178A.

(iv) If software was developed using RTCA/DO-178A procedures (as is specified in TSO-C115a), the applicant may need to further evaluate some features of the software. RTCA/DO-178A does not address some applications of digital technology commonly found in multi-sensor equipment (e.g., use of user-modifiable software including data bases, option-selectable software, software development and verification tools, previously developed software in modular architectures, and field loadable software capabilities). In these cases RTCA/DO-178A does not provide adequate procedures and the applicant must include in the software aspects of certification plan the means for showing that these features comply with pertinent airworthiness requirements. One acceptable means for demonstrating such features comply with the pertinent airworthiness requirements is to comply with pertinent portions of the criteria contained in RTCA/DO-178B, which would supplement the basic criteria contained in RTCA/DO-178A.

(v) The FAA strongly recommends that the applicant use the procedures described in RTCA/DO-178B (or later revision), as referenced in AC 20-115B, to show that the software aspects of a system comply with pertinent airworthiness requirements. For software developed prior to the availability of RTCA/DO-178B, Section 12.1.4 of RTCA/DO-178B provides a method for upgrading a baseline for software development so that changes can be made in accordance with the criteria contained in RTCA/DO-178B.

(vi) If application specific integrated circuits (ASIC's) or other complex logic devices are used, they must be developed using a structured process similar to that used for software developed under RTCA/DO-178B. If deterministic tests exhaustively consider all possible input values and verify that the ASIC completely meets all pertinent requirements, then a structured development process is not required. Either methodology should be approved in advance by the cognizant ACO.

(2) Display Format/Operating Procedure Changes. Changes to navigational display formats and navigation/function operating procedures (implemented through hardware or software) may constitute major changes requiring additional evaluation.

(3) Location of System Displays. Each display element (i.e., the course deviation indicator (CDI), horizontal situation indicator (HSI), map display, etc.), used as a primary flight instrument in the guidance and control of the aircraft, for maneuver anticipation, or for failure/status/integrity annunciation, shall be located where it is visible to the pilot (in the pilot's primary field of view) with the least practicable deviation from the pilot's normal position and line of vision when looking forward along the flight path.

NOTE 1: CDI displays contained in the CDU will most likely not be acceptable for IFR operations.

NOTE 2: Flight technical error (FTE) can be reduced when numeric display information is integrated with the non-numeric display or is located within the pilot's primary field of view. Both digital cross track and track angle error have been shown to reduce FTE. This information should be displayed together (either within the CDU or remotely displayed near the non-numeric display) for better tracking performance. The use of non-numeric cross track data integrated with non-numeric track angle error data into one display may provide the optimum of situation and control information for the best overall tracking performance.

(4) Failure Protection. Any probable failure of the multi-sensor equipment shall not degrade the normal operation of other required equipment or create a flight hazard. Likewise, normal operation of the multi-sensor equipment installation shall not adversely affect

the performance of other aircraft equipment. The interfaces with other aircraft equipment must be designed such that normal or abnormal multi-sensor equipment operation shall not adversely affect the operation of other equipment nor shall operation of other equipment adversely affect the multi-sensor equipment operation.

(5) Environmental Conditions. The aircraft environment in which the multi-sensor equipment is installed shall be found to be compatible with the environmental categories (or criteria) in RTCA/DO-160C to which the equipment was tested.

(6) Electromagnetic Compatibility. The multi-sensor equipment installation should not be the source of objectionable electromagnetic interference, nor be adversely affected by electromagnetic interference from other equipment in the aircraft.

(i) For systems incorporating a GPS sensor, the GPS equipment should be shown to meet the 2D accuracy requirements of paragraph 7a(1) of this AC when subjected to a radiated signal with continuous wave (cw) modulation at a frequency of 1.57542 GHz and an electric field strength of 20 mv/meter measured at the exterior case of the GPS receiver. The radiated susceptibility test procedures of RTCA/DO-160C, Section 20, should be followed when conducting this test. The test should be conducted with simulated satellite inputs and should not result in the loss of track of any satellite used for navigation. The duration of the test must be sufficient to determine if tracking has been lost (20 seconds should normally be long enough, depending on the coasting features used by the GPS equipment). This test will usually be conducted by the GPS equipment manufacturer, but if not, the applicant is responsible for conducting the test.

(ii) For systems incorporating a GPS sensor, intermodulation effects are possible between multiple channel SATCOM installations and GPS. GPS equipment should not be installed in aircraft with multiple SATCOM channels unless the SATCOM equipment is modified to prevent simultaneous use of interfering frequencies. Current multi-channel SATCOM equipment (as of 1/1/94) has not been modified in this manner and should not be installed with GPS equipment. In addition, certain GPS manufacturers have been granted a deviation to the requirements of TSO-C129 and will include a limitation in their installation instructions that states that the GPS equipment can not be installed in aircraft with SATCOM equipment. If such GPS equipment is installed in an aircraft the TC, STC, or FAA Form 337 should appropriately limit the future installation of SATCOM equipment in the aircraft.

(iii) For systems incorporating a GPS sensor, harmonic interference from VHF transmissions on 121.150, 121.175, 121.200, 131.250, 131.275, and 131.300 MHz may adversely affect reception of the GPS signal if less than 100 dB isolation is provided. Low pass or notch filters installed at the output of the VHF transmitter to attenuate the undesired VHF signal should have an insertion loss of 2 dB or less to preclude the need for reevaluation of installed VHF transceiver performance.

(7) P-Static Protection. If an E-Field antenna (whip, plate, or blade type) is used (such as with an Omega/VLF or Loran-C sensor), the aircraft should be protected by acceptable bonding techniques and installation of static dischargers. These protective devices should be specified as part of the approved design data for the multi-sensor installation. The capability to provide satisfactory P-static protection for the system should be demonstrated as part of the initial certification program. This testing may be accomplished by ground or static testing if sufficient data is provided to demonstrate that the proposed technique is equivalent to flight testing. If a flight demonstration is selected it must be conducted at speeds up to Vne, Vmo, or Mmo through known P-static conditions such as a cloud of ice crystals. Momentary loss of signal when encountering heavy P-static conditions may be acceptable provided the equipment is capable of providing acceptable navigation information during such conditions. P-static charging of the aircraft can cause degradation of the signal-to-noise ratio by one of three major mechanisms:

(i) Sparkover of Isolated Metal Panels. Sparkover of isolated metal panels can be handled by appropriate bonding. This bonding needs to occur on all control and trim surfaces as well as isolated access panels. Bonding should be evaluated by a careful ohmic survey (an electrical bonding limit of 10 milliohms is considered acceptable) of techniques.

(ii) Streamer currents. The effects caused by streamer currents can be reduced by placing the receiving antenna as far as possible from any nonconductive surfaces such as windshields. The nonconductive surfaces may be coated with a conductive coating. Temporary spray coatings are not satisfactory.

(iii) Corona discharge. Corona discharge can be reduced by the appropriate placing of orthodecoupled static dischargers on the extremities of the aircraft. A number of recent studies have shown that the frayed-wick types of dischargers constructed with a high resistance rod and metal pins are recommended although other types may also be used if they can demonstrate ability to provide protection from radio frequency (RF) coupling to the sensor antenna. The number, type, and location of these static dischargers to be installed on a particular aircraft model should be determined by following the instructions provided by the manufacturer of the static discharger for P-static protection.

(8) Anti-Ice Protection. If the aircraft in which the multi-sensor equipment is installed is approved for flight into known icing conditions, any antennae must have anti-ice protection or be found not to be susceptible to ice buildup (i.e., is installed in a non-icing location on the aircraft, or is of a sufficiently low profile that ice does not accumulate on the antenna). Alternatively, the equipment can be shown to operate satisfactorily when the antenna is subject to icing provided there are no harmful effects, such as possible ingestion of accumulated ice or degradation in aerodynamic performance. (The effects of ice accumulation on the antenna, if any, can be found in the manufacturer's installation instructions.)

(9) System Controls. All displays, controls, and annunciators must be readable under all normal cockpit conditions and expected ambient light conditions (total darkness to bright reflected sunlight). Night lighting provisions must be compatible with other cockpit lighting. All displays and controls must be arranged to facilitate equipment usage. Controls that are normally adjusted in flight shall be accessible and properly labeled as to their function. System controls and displays shall be designed to maximize operational suitability and minimize pilot workload. System controls shall be arranged to provide protection against inadvertent system turnoff. Reliance on pilot memory for operational procedures shall be minimized.

(10) Navigation Data Base. For equipment incorporating a TSO-C129 GPS sensor, the multi-sensor equipment shall incorporate an appropriately updatable navigation data base (in the WGS-84 or NAD-83 coordinate datum). This data base must contain at least the following location information in terms of latitude and longitude with a resolution of 0.01 minute or better for the area(s) in which IFR operations are to be conducted: all airports, VOR's (and VORTAC's), NDB's, and all named waypoints and intersections shown on en route charts. For equipment including a terminal mode, the data base shall also contain all named waypoints and intersections shown on terminal area charts, Standard Instrument Departures (SID's) and Standard Terminal Arrival Routes (STAR's). For equipment including an approach mode, the navigation data base must also include all waypoints and intersections included in published non-precision instrument approach (except localizer, LDA, and SDF) procedures. Instrument approaches must be conducted using a current database. User entry or modification of navigation data base data shall not be possible. (This does not preclude the storage of "user defined data" within the equipment.) Additional data base coding, storage, and approach waypoint presentation requirements as specified in the applicable TSO's must be provided. Navigation data bases shall meet the standards specified in sections 3, 4, and 5 of RTCA/DO-200, "Preparation, Verification and Distribution of User Selectable Navigation Data Bases" and sections 2 through 7 of RTCA/DO-201, "User Recommendations for Aeronautical Information Services."

(11) Pressure/Barometric Altitude Inputs. If the multi-sensor equipment incorporates a Class B1, B2, C1, or C2 GPS sensor(s) and uses a barometric pressure/altitude input, that input must be appropriate to the equipment.

(12) Manufacturer's Instructions. The multi-sensor equipment, including required antenna(s), shall be installed in accordance with the instructions and limitations provided by the manufacturer of the equipment.

c. IFR Airworthiness Approval. There are two types of IFR airworthiness approval which differ significantly as to test requirements and data analysis.

(1) First-Time IFR Airworthiness Approval (for a Particular Type of Multi-Sensor Equipment). This type of approval refers to the first time an applicant presents a particular (hardware and software configuration) model multi-sensor equipment integrating

multiple navigation sensors for FAA airworthiness installation approval and certification for IFR navigation use. The first approval of particular multi-sensor equipment must be accomplished through the TC or STC process. Each new model of multi-sensor equipment by the same manufacturer or significant changes (hardware or software) to existing equipment shall undergo the same approval process as the original equipment unless it can be shown by analysis and tests acceptable to the Administrator that the new model will function as well or better than the approved equipment. A first-time approval is conducted in four phases:

(i) Lab/Bench Tests and Equipment Data Evaluation. This phase consists of the following:

(A) Analysis of the manufacturer's procedures for development of software and review of supporting documentation in accordance with the guidelines of paragraph 9b(1) of this AC.

(B) Verification of compliance with the appropriate environmental qualification standards and tests specified in the individual sensor TSO's and in RTCA/DO-160C.

(C) Verification of compliance with the applicable minimum performance and operation standards specified in TSO-C115b and other TSO's applicable to the individual sensors incorporated in the system.

(D) Analysis of failure modes and annunciations.

(E) Review of reliability data to establish that all probable failures are detected and that failure rates meet acceptable criteria (e.g. as detailed in AC 25.1309-1A).

(F) Evaluation of the ease of use of the controls and of the viewing ease (e.g. brightness, contrast, intensity, dimming, etc.) of the displays and annunciations from a human factors point of view.

(G) Review of installation and maintenance manuals. Special attention should be given to the manufacturer's instructions for locating all antennas on the aircraft. Refer to paragraph 9.c.(1)(ii)(G) of this AC for specific information that should be included in these instructions.

(H) Evaluation of the operator's manual (pilot's guide).

(ii) Aircraft Installation Data Evaluation. Normally the manufacturer of the multi-sensor equipment will provide an aircraft as a test bed for the first time installation approval. This approval may serve as a basis for subsequent installation approvals. The following assessments are to be made:

(A) Review of installation drawings, wiring diagrams, and descriptive wiring routing.

(B) Evaluation of the cockpit layout of the installed equipment with emphasis on equipment controls, applicable circuit breakers (labels and accessibility), switching arrangement, and related indicators, displays, annunciators, etc.

(C) Analysis of a data flow diagram in order to review which equipment provides what data to which other equipment.

(D) Review of a structural analysis of the equipment installation, including antenna(e), in order to ascertain whether structural mounting, dynamic, and crash load requirements are satisfied.

(E) Review of an electrical load analysis in order to verify that the total electrical load requirements are within the capabilities of the aircraft's electrical generating system. Determine that the supplied electrical power is consistent with applicable equipment reliability requirements.

(F) Verification that the aircraft environment in which the multi-sensor equipment is installed is appropriate to the environmental categories (or criteria) as identified in 9.c.(1)(i)(B) or the individual TSO to which the equipment has been tested.

(G) Evaluation of the antenna installation. A critical aspect of many multi-sensor equipment installations is the installation of the antenna(e). It is important that the antenna for each sensor is approved for the particular type (make and model) sensor installed.

(1) Adequate isolation must be provided between a GPS antenna and any other transmitting antenna(s) installed on the aircraft in order to prevent interference. Shadowing by aircraft structure can adversely affect the operation of GPS equipment. Typically, a GPS antenna is located forward of the wings on the top of the fuselage to minimize effects of the wings, tail, etc. during aircraft maneuvering. For installations on helicopters, the effects of the rotor blades on antenna performance must be considered.

NOTE: The GPS signal is typically below the value of the background noise. Electrical noise in the vicinity of the antenna can adversely affect the performance of the system. Antenna installation in close proximity to traffic alert and collision avoidance system (TCAS), satellite communication (SATCOM), and other transmitting antennas (particularly "L" band) should be carefully evaluated for potential mutual interference.

(2) E-field antennas (whip, plate, or blade type) are typically used with Loran-C sensors and many Omega/VLF sensors. Precipitation static has an adverse effect upon the signal receiving capability of this type of antenna. The adverse effects of P-static can be minimized by use of the proper antenna type and location, by proper installation of high-quality static dischargers, and by proper bonding of airframe surfaces. The manufacturer's installation or maintenance manual usually describes acceptable E-field antenna installation practices. Each aircraft should be subjected to a careful ohmic survey of electrical airframe bonding (an electrical bonding limit of 10 milliohms is considered acceptable). P-static protection is a required part of the system installation and must be maintained for proper system operation.

(3) H-field antennas (loop type) are typically used with Omega/VLF sensors. The signal receiving quality of this type of antenna is adversely affected by aircraft electrical skin currents, particularly by 400 Hz ac. P-static has no appreciable effect on an H-field antenna, and its effects are usually not observed. A procedure called skin mapping is normally employed to determine a good mounting location for H-field antennas. It should be noted that shifting major aircraft electrical components to different locations within the aircraft or installing new equipment subsequent to antenna installation may render a previously determined skin map location unsuitable. A simple test to verify the effectiveness of an H-field antenna installation located by skin mapping is to park the aircraft away from any external electrical noise source. Then, using only the aircraft's battery, and with all other electrical equipment off, activate the multi-sensor equipment and record signal-to-noise values (or quality factors) for all receivable stations of the appropriate sensor. Repeat this process of recording signal-to-noise values (or quality factors) with engine(s) running and all electrical/electronic equipment operating on aircraft power. If the antenna installation is satisfactory, there should not be any significant degradation in signal reception.

(iii) Ground Test Evaluations. For multi-sensor equipment incorporating a Class B() or C() GPS sensor, static ground tests are conducted to verify the installed GPS equipment configuration (including antenna) provides position data meeting the accuracy criteria specified in paragraph 7a(1) of this AC. These tests shall cover a continuous period of 24 hours with a maximum sample interval of five minutes.

> NOTE: The 24-hour ground accuracy test may be performed on the aircraft or by use of a representative mock-up configuration. If a mock-up test fixture is used, the entire installed GPS equipment configuration, including antenna, must consist of the hardware to be used in the installation and be representative of the installed system configuration.

(iv) Flight Test Evaluations. Flight tests are conducted to verify proper operation and accuracy of the multi-sensor equipment as installed in the aircraft. Flight tests should include at least the following:

NOTE 1: Required flight evaluation for any new sensor should be conducted according to the AC for installation of that sensor (Reference 4.d).

NOTE 2: Required flight evaluations for the first-time airworthiness approval of a particular multi-sensor equipment are accomplished by the cognizant Aircraft Certification Office unless specific tests are delegated by the ACO to a Flight Test Pilot Designated Engineering Representative (DER).

(A) Evaluation of all operating modes of the multi-sensor equipment. Particular attention should be given to mode switching and transition requirements associated with the approach mode for equipment incorporating Class B1, B3, C1, and C3 GPS sensors.

(B) Evaluation of the interface (function) of other equipment connected to the multi-sensor equipment.

(C) Review of various failure modes and associated annunciations, such as loss of electrical power, loss of signal reception, equipment failure, individual sensor failure, autopilot/flight director response to system flags, etc.

(D) Evaluation of steering response while autopilot and/or flight director is coupled to the multi-sensor equipment during a variety of different track and mode changes. This evaluation shall include, as applicable, transition from en route to approach transition to approach modes and vice-versa. Additionally, all available display sensitivities shall be evaluated.

(E) Evaluation of displayed multi-sensor equipment parameters on interfaced cockpit instruments such as HSI, CDI, distance display, electronic flight instruments system (EFIS), moving maps, fuel management systems, etc.

(F) Assessment of all switching and transfer functions, including electrical bus switching, pertaining to the multi-sensor equipment installation.

(G) Evaluation to determine satisfactory electromagnetic compatibility (EMC) between the multi-sensor equipment installation and other onboard equipment (this test may be partially accomplished as a ground test).

NOTE 1: For systems incorporating a GPS sensor, particular attention should be given to other "L" band equipment, such as TCAS or SATCOM equipment, VHF transmissions on the frequencies stated in paragraph 9b(6)(iii) of this AC, high frequency (HF) communications systems, and other transmitting equipment (ACARS, AFIS, Flightfone, etc.).

NOTE 2: Installation instructions for each GPS receiver installation shall include the requirement for verification of adequate isolation from the harmonic interference of VHF communication transceivers. These tests shall be conducted on the completed GPS installation by tuning each VHF transmitter to the frequencies listed below and transmitting for a period of 20 seconds while observing the signal status of each satellite being received. Degradation of individually received satellite signals below a point where navigation is no longer possible is not acceptable and will require that additional isolation measures (low pass or notch filters installed at the output of the VHF transmitter, additional spacing between the VHF transmitter and the GPS antenna, replacement of the VHF transmitter with a unit having no excessive harmonic emissions, etc.) be included in the aircraft installation. Reevaluation of installed VHF transceiver performance is not necessary if the filter insertion loss is 2 dB or less.

The following VHF frequencies shall be evaluated:

121.150 MHz	131.250 MHz
121.175 MHz	131.275 MHz
121.200 MHz	131.300 MHz

Proper radio regulations (FCC Rules) must be observed.

NOTE 3: For Omega/VLF and Loran-C systems that incorporate an E-Field antenna, testing should be conducted in accordance with paragraph 9.b.(7).

(H) Evaluation of the accessibility of all controls pertaining to the multi-sensor equipment installation.

(I) Evaluation of the visibility of the controls, displays, and annunciators relating to the multi-sensor equipment installation during day and night lighting conditions. No distracting cockpit glare or reflections may be introduced, and all controls must be illuminated for identification and ease of use. Night lighting shall be consistent with other cockpit lighting.

(J) Analysis of crew workload when operating the multi-sensor equipment in association with other piloting requirements.

(K) Validate multi-sensor equipment navigational accuracy in each operating mode. In addition to overall system navigation performance, particular test requirements for navigational accuracy will vary depending upon the particular sensors integrated in the multi-sensor equipment and whether sensor accuracy performance data has previously been obtained. The performance of each navigation sensor should be evaluated separately and in combination with other sensors as applicable. Note that the accuracy associated with a GPS sensor must be demonstrated to enable potential operating benefits.

(1) GPS sensor accuracy should be verified in each operating mode by at least 5 low altitude over flights of one or more surveyed locations (ensure survey point coordinates are relative to WGS-84). An acceptable method of conducting this accuracy demonstration is to accomplish low altitude (less then 100 feet AGL) overflight of a runway threshold and record the GPS position as the aircraft crosses the threshold. The system accuracy is the distance between the coordinate position determined by the GPS and the coordinate position of the surveyed location (runway threshold). Runway threshold coordinates may be obtained from the airport operator. If coordinate data conversion to WGS-84/NAD-83 is necessary, contact the National Flight Data Center at (202) 267-9277.

(2) Initial certification for systems including an Omega/VLF sensor that has not previously been certified shall be based upon a demonstration of system accuracy by recording (at not less than 15 minute intervals) the Omega/VLF sensor position and comparing it to the actual position during evaluation flights representative of the area in which approval is desired. Suitable accuracy and navigation capability must be demonstrated using Omega only. VLF signals may be used to augment and expand areas of coverage, but the system must be demonstrated to be capable of meeting all navigation performance requirements using Omega signals only in an area of nominal Omega coverage. Recorded data should include sufficient signal parameters and sensor performance data to provide a clear indication of satisfactory sensor performance. The particular flight paths should be selected based upon an analysis of critical signal characteristics, station geometry, aircraft movement, time of day, etc. The system should demonstrate its ability to re-acquire Omega/VLF signals after power interruptions of less than seven minutes and more than seven minutes, as well as in areas of marginal performance. It should demonstrate its ability to detect inadequate navigation capability, poor signal quality, etc.

(3) Initial certification for systems including a Loran-C sensor that has not previously been certified shall be based upon a demonstration of system accuracy by recording (at not less than 15 minute intervals) the Loran-C sensor position and comparing it to the actual position during evaluation flights representative of the area in which approval is desired. Recorded data should include sufficient signal parameters and sensor performance data to provide a clear indication of satisfactory sensor performance. The particular flight paths should be selected based upon an analysis of critical signal characteristics, station geometry, chain/station selection criteria, known poor signal areas, aircraft movement, seasonal effects (i.e., snow pack vs. trees, water vs. ice, etc.), time of day,

etc. The system should demonstrate its ability to detect poor signal conditions, inadequate navigation capability, operations outside approved operating areas, and the ability to reacquire the Loran-C signal following momentary signal interruptions and prolonged (more than 5 minutes) in-flight power failure, etc.

(4) Initial certification for systems including a VOR/DME or multiple (scanning) DME sensor that has not been previously certified shall be based upon a demonstration of system accuracy by recording (at not greater than 15 minute intervals) the VOR/DME and/or DME/DME sensor position and comparing it to the actual position during evaluation flights. Recorded data should include sufficient signal parameters and sensor performance data to provide a clear indication of satisfactory sensor performance, The particular flight paths should be selected based upon an analysis of critical signal characteristics, station geometry, signal coverage (including limited station availability with acceptable range), aircraft movement, etc. The system should demonstrate its ability to detect poor signal conditions, inadequate navigation capability, recovery from in-flight power failure, etc. The VOR/DME auto-tune logic should be reviewed and tested to verify that all three types of VOR/DME ground stations are identified and tuned correctly.

(5) Initial certification for systems including an inertial navigation system (INS) or inertial reference unit (IRU) that has not been previously certified shall be based upon a demonstration of system accuracy by recording (at no greater than 15 minutes intervals) the INS/IRU sensor position and comparing it to the actual position during evaluation flights representative of the area in which approval is desired. Recorded data should include sufficient sensor performance parameters to provide a clear indication of satisfactory sensor performance and drift rates. The system should demonstrate its ability to detect inadequate navigation capability, operations outside approved operating areas, recovery from power failure, reinitialization in flight, alignment in limiting areas, etc. This demonstration should include 150 system flights at greater than 3 hours. At the end of the flight, the systems must exhibit less than 2.0 nmi drift rates. For systems that will be operated for more then 10 hours, the system must stay within 20 nmi x 25 nmi for the maximum deviation allowed (See AC 25-4).

(L) Verify continuity of navigation data during normal aircraft maneuvering, including holding patterns and turns at up to at least 30 degrees of bank for a 360 degree turn left and right.

(M) Verify that flight technical error (FTE) can be maintained at less than 1.0 nmi for en route, 1.0 nmi for terminal (approach transition), and 0.25 nmi (for equipment that is seeking credit for GPS data) or 0.5 nmi (for equipment not using or not seeking credit for GPS data) for approach operating modes, both with and without autopilot and/or flight director, as applicable.

(N) For equipment including an approach mode, conduct a sufficient number of approaches using the navigation data base to verify the proper operation of annunciations, waypoint sequencing, and display sensitivity changes, as appropriate, in accordance with the requirements specified in TSO-C115b and other TSO's applicable to the specific sensors incorporated in the multi-sensor equipment. This evaluation should include at least: turn anticipation, waypoint sequencing, display sensitivity changes, annunciations, procedure turns at the final approach fix (FAF), holding patterns at the missed approach holding fix, transitions from TO-FROM operation to TO-TO operation, heading legs after the initial approach fix (IAF) to intercept the final approach course both before and after the FAF, and DIRECT TO operation before and after the IAF.

(2) Follow-On IFR Airworthiness Installation Approvals. This type of approval refers to installation approvals in any model or type of aircraft after a first time airworthiness approval of the particular multi-sensor equipment has been issued. Follow-on approvals may use the first time airworthiness approval, which was either a TC or an STC, as a basis for installation approval, if the flight standards inspector determines that there are no design changes as a result of the installation. The determination of a design change will be dependent upon the integration with other avionics and not on the basis of aircraft make and model. Since the GPS equipment operates on principles that are not dependent upon the aircraft make and model, the engineering evaluation of one aircraft model is applicable to a different aircraft provided the integration with the other equipment is equivalent.

(i) Unless otherwise provided, contact either the manufacturer or organization responsible for obtaining the first time airworthiness approval of the multi-sensor equipment in order to:

(A) Obtain a sample airplane or rotorcraft flight manual supplement (or supplemental flight manual, if appropriate).

(B) Obtain verification of the equipment approval status, including antenna, software, autopilot/flight director interface, and system integration requirements, etc.

(C) Discuss any problem areas and seek assistance in their solution.

(D) Verify that the maximum operating speed for which the multi-sensor equipment is qualified is compatible with the maximum expected ground speed of the aircraft.

(ii) If the aircraft is approved for flight in known icing conditions, verify the suitability of the antenna installation in accordance with the guidance specified in paragraph 9b(8) of this AC.

(iii) Conduct a similar data evaluation as outlined in paragraph 9c(1)(ii) of this AC.

(iv) Conduct a functional flight evaluation covering at least the following items:

NOTE: Required flight evaluations will be conducted by the cognizant Aircraft Certification Office (ACO) or, when authorized, by a flight test pilot designated engineering representative (DER) in accordance with the procedures used by the cognizant ACO. Depending upon the level of similarity between the initial and follow-on installations, including aircraft type, the Flight Standards District Office (FSDO) Inspector may accept flight evaluations conducted by the installer.

(A) Overall operation of the installed multi-sensor equipment, including interface with other equipment in the aircraft.

(B) The effect(s) of multi-sensor equipment and sensor failure (open circuit breaker), including autopilot /flight director response, if applicable.

(C) If interfaced with an autopilot or flight director, steering response while the autopilot or flight director is coupled to the multi-sensor equipment.

(D) Displayed navigation parameters on all interfaced cockpit instruments.

(E) The effect(s), if any, of switching and transfer functions, including electrical bus switching, pertaining to the multi-sensor installation.

(F) Evaluation to determine satisfactory electromagnetic compatibility (EMC) between the multi-sensor equipment installation and other equipment as specified in paragraph 9c(1)(ii)(G) of this AC.

NOTE: Verification of adequate isolation from harmonic interference of VHF communication transceivers in each individual aircraft is required for installation of multi-sensor equipment using GPS. This test should be repeated if a VHF transceiver is replaced or added, or if a new or replacement VHF communications antenna is installed.

(G) Evaluation of the accessibility and visibility of all controls and displays pertaining to the multi-sensor equipment installation.

(H) Validate multi-sensor equipment navigational accuracy in each operating mode. Previously approved sensors need only be evaluated to the extent necessary to verify accuracy has not been degraded by the equipment installation in the particular aircraft.

(1) GPS sensor accuracy is evaluated as specified in paragraph 9c(1)(iv)(K)(1) of this AC.

(2) Omega/VLF sensor accuracy is evaluated by conducting a short flight (approximately 100 nmi) and verifying position accuracy by overflight of at least 3 reference locations or comparison to a valid GPS, Loran-C, or DME/DME position.

(3) Loran-C sensor accuracy can be evaluated in the same manner as that specified for GPS sensors, except that five different locations should be used.

(4) VOR/DME and DME/DME sensor accuracy can be evaluated in the same manner as that specified for GPS sensors, except that five different locations should be used.

(5) INS/IRU sensor accuracy can be evaluated as an average drift over the entire flight (should be less than 2.0 nmi/hr.)

(I) Verify continuity of navigation data during normal aircraft maneuvering, including holding patterns and turns at up to at least 30 degrees of bank for left and right 360 degree turns.

(J) Monitor displayed cross-track error to verify that flight technical error (FTE) is less than 1.0 nmi for en route, 1.0 nmi for terminal (approach transition), and 0.25 nmi (for equipment using GPS data) or 0.5 nmi (for equipment not using GPS data) for approach operating modes, both with and without autopilot and/or flight director, as applicable.

(K) For equipment including an approach mode, conduct at least three published instrument approaches (retrieved from the database) to verify the proper operation of the equipment in the approach environment. This test should be conducted separately for each sensor, for which approach approval is sought. If multiple sensors are to be used, then all combinations should also be tested.

10. OPERATIONAL CONSIDERATIONS.

a. Flight Manual Supplement. An appropriate Airplane or Rotorcraft Flight Manual Supplement (or, for aircraft without an FAA Approved Flight Manual, a Supplemental Flight Manual) containing the limitations and operating procedures applicable to the equipment installed should be provided for each installation of multi-sensor equipment for IFR approval. A Flight Manual Supplement or Supplemental Flight Manual may be necessary for installations limited to VFR use only, depending upon the complexity of the installation and need to identify necessary limitations and operating procedures.

b. Other Navigation Equipment Required. Aircraft employing multi-sensor equipment for IFR navigation must also be equipped with an approved and operational alternate means of navigation appropriate to the intended route to be flown. Within the contiguous United States, Alaska, Hawaii, and surrounding coastal waters, this requirement may be met with an operational, independent VOR receiver, although data from this receiver can provide an input to the multi-sensor equipment. For oceanic and remote operations, an alternate means of navigation is required unless the multi-sensor equipment incorporates within itself a sensor approved individually for the particular area of operations (some oceanic airspace may require additional redundancy).

c. Alternate Airport Requirements. An alternate airport (if required by the applicable operating rules) must be served by an approved instrument approach procedure based on a navigation system other than GPS or Loran-C and the aircraft must be properly equipped to conduct that approach.

d. Operational Area. Operators and their flight crews must consult the approved flight manual supplement for their aircraft to determine approved operational areas that may apply to particular systems and/or sensors. Flight crews must be aware that operational areas for different systems/sensors may be different, and the appropriate operating area(s) for a particular system can only be determined by reference to the approved flight manual supplement or other FAA approved documents.

JOHN K. McGRATH
Manager, Aircraft Engineering Division

APPENDIX 1. PROCEDURES FOR OBTAINING FAA APPROVAL OF FOLLOW-ON MULTI-SENSOR EQUIPMENT INSTALLATIONS FOR IFR/VFR OPERATIONS BY FAA FORM 337

1. FOLLOW-ON MULTI-SENSOR EQUIPMENT INSTALLATIONS LIMITED TO VFR USE ONLY. Approval of follow-on multi-sensor equipment installations limited to VFR use only (where the initial approval was accomplished using the TC or STC process) are normally obtained using FAA Form 337 approved by the responsible Flight Standards District Office (FSDO). Such installations can usually be approved for return to service by one of the entities noted in 14 CFR part 43; i.e., repair station, manufacturer, holder of an inspection authorization, etc., provided the installation:

a. General Installation Methods. Conforms to the acceptable methods, techniques, and practices contained in AC 43.13-1A, Acceptable Methods, Techniques and Practices - Aircraft Inspection and Repair, and AC 43.13-2A, Acceptable Methods, Techniques, and Practices - Aircraft Alterations.

b. Installation Criteria. Is in accordance with the criteria specified in paragraph 8c(1)(ii) of this AC. A certification from the manufacturer to confirm that the en route/terminal accuracy requirements of paragraph 6 and ground accuracy test requirements of paragraph 8c(1)(iii) have been met should be provided. This certification can be accomplished by reference to the first time TC/STC approval.

NOTE: Limited test data may be required to verify/demonstrate that the applicable requirements have been satisfied.

c. Aircraft Flight Manual Supplement/Placard(s). Except for those installations where placards address required limitations, an airplane or rotorcraft flight manual supplement (or supplemental flight manual) prepared by the applicant and containing at least the following information must be presented for FAA approval. The proposed flight manual supplement (or supplemental flight manual) is submitted for approval along with the other data associated with the installation.

(1) Equipment operating limitations.

(2) Emergency/abnormal operating procedures (if applicable).

(3) Normal procedures for operating the multi-sensor equipment and any interfaced equipment. (May be provided in a pilot's guide that is referenced in the flight manual supplement.)

(4) General description of system (or reference to a pilot's guide that provides an equipment description).

d. Functional Flight Evaluation. A functional flight evaluation covering the items listed in paragraph 8c(2)(iii) is accomplished by the installer. The results of this evaluation are included with the data provided to the FSDO.

2. FOLLOW-ON MULTI-SENSOR EQUIPMENT INSTALLATIONS FOR IFR USE. Approval of follow-on multi-sensor equipment installations for IFR use (where the initial approval was accomplished using the TC or STC process) may be obtained using an FAA Form 337 approved by the responsible FSDO.

a. Data Submitted by the Applicant. Alteration data for the equipment installation is submitted with a properly executed FAA Form 337, and a certification from the manufacturer to confirm that the accuracy requirements of paragraph 7a and ground accuracy test requirements of paragraph 9c(1)(iii) of this AC and system performance specifications of TSO-C115a or b have been met. (This certification can be accomplished by reference to TSO-C115a or b approval and the original TC/STC approval.) The FAA Form 337, along with all required data pertaining to the installation, should be submitted to the responsible FSDO

b. Additional Data That May be Required. If required by the FSDO (or an ACO when consulting with the FSDO when reviewing the data/conducting necessary tests requested by the FSDO) approving the technical data/installation, the applicant may also be required to furnish a copy of the equipment data (for equipment not produced under TSO-C115a or b authorization), manufacturer's operating and installation instructions, fault analysis for installation, installation details and/or photographs, structural substantiation, system wiring diagrams, and ground test evaluation results.

c. Aircraft Flight Manual Supplement. An airplane or rotorcraft flight manual supplement (or supplemental flight manual) prepared by the applicant and containing at least the following information must be presented for FAA approval. The proposed flight manual supplement (or supplemental flight manual) is prepared using the guidance contained in Appendix 2 and submitted to the FSDO.

(1) Equipment operating limitations.

(2) Emergency/abnormal operating procedures.

(3) Normal procedures for operating the multi-sensor equipment and any interfaced equipment. (May be provided in a pilot's guide that is referenced in the flight manual supplement.)

(4) General description of system (or reference to a pilot's guide that provides an equipment description).

d. Functional Flight Evaluation. A functional flight evaluation covering the items listed in paragraph 9.c.(2)(iv) is accomplished. The inspector may authorize the installer to conduct the flight evaluation. In situations where additional FAA evaluation is necessary, required flight evaluations will be conducted by the cognizant ACO or, when authorized, by a Flight Test Pilot Designated Engineering Representative (DER) in accordance with the procedures used by the ACO.

APPENDIX 2. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (FAA Form 337 Approval Process).

1. The following sample Airplane Flight Manual Supplement (AFMS) is provided as an example of the format to be used and information to be included when preparing required supplements. An AFMS must follow the organization of the flight manual being supplemented.

FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX Multi-Sensor
Navigation System

FAA APPROVED AIRPLANE FLIGHT MANUAL SUPPLEMENT
ABC MODEL XXX MULTI-SENSOR NAVIGATION SYSTEM

AIRPLANE MAKE:

AIRPLANE MODEL:

AIRPLANE SERIAL NO.:

REGISTRATION NO.:

This document must be carried in the airplane at all times. It describes the operating procedures for the ABC Model XXX Multi-Sensor navigation system when it has been installed in accordance with <manufacturer's installation manual number and date> and FAA Form 337 dated <insert date>.

For airplanes with an FAA Approved Airplane Flight Manual, this document serves as the FAA Approved ABC Model XXX Multi-Sensor navigation system Flight Manual Supplement. For airplanes that do not have an approved flight manual, this document serves as the FAA Approved ABC Model XXX Multi-Sensor navigation system Supplemental Flight Manual.

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

FAA APPROVED

____
Title
Office
Federal Aviation Administration
City, State

FAA Approved
Date: Page < > of < >

FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX Multi-Sensor
Navigation System

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FAA Approved
Date: Page < > of < >

FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX Multi-Sensor
Navigation System

SECTION 1 - GENERAL

1. <Provide a very brief (i.e., one paragraph) general description of the multi-sensor navigation system installed in the aircraft.>
2. Provided the ABC Model XXX multi-sensor navigation system is receiving usable signals, it has been demonstrated capable of and has been shown to meet the accuracy specifications of:

VFR/IFR en route oceanic and remote, en route domestic, terminal, and instrument approach (GPS, Loran-C, VOR, VOR-DME, TACAN, NDB, NDB-DME, RNAV) operation (specify operations, i.e., en route oceanic and remote, en route domestic, terminal, instrument approach, etc., as applicable to the particular approval.) within the U. S. National Airspace System and latitudes bounded by < > North and < > South using the WGS-84 (or NAD 83) coordinate reference datum in accordance with the criteria of AC 20-130A, AC 91-49, AC 120-33, and <list additional applicable ACs>. Satellite navigation data is based upon use of only the Global Positioning System (GPS) operated by the United States.

SECTION 2 - LIMITATIONS

1. The ABC Model XXX Multi-Sensor Navigation System Pilot's Guide, P/N <insert part number>, dated <insert date> (or later appropriate revision) must be immediately available to the flight crew whenever navigation is predicated on the use of the system. The software status stated in the Pilot's Guide must match that displayed on the equipment.
2. The system must utilize software version <insert version identification>.
3. IFR en route and terminal navigation is prohibited unless the pilot verifies the currency of the data base or verifies each selected waypoint for accuracy by reference to current approved data.
4. Instrument approaches must be accomplished in accordance with approved instrument approach procedures that are retrieved from the multi-sensor equipment data base. The multi-sensor equipment data base must incorporate the current update cycle.

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FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX Multi-Sensor
Navigation System

(a) Instrument approaches must be conducted in the approach mode and GPS integrity monitoring (for systems incorporating a GPS sensor) must be available at the Final Approach Fix.
(b) Accomplishment of ILS, LOC, LOC-BC, LDA, SDF, and MLS approaches are not authorized.
(c) When an alternate airport is required by the applicable operating rules, it must be served by an approach based on other than GPS or Loran-C navigation, the aircraft must have operational equipment capable of using that navigation aid, and the required navigation aid must be operational.
(d) <if applicable> This system has been demonstrated to meet the accuracy and availability requirements of the MNPS airspace.

5. The aircraft must have other approved navigation equipment installed and operating appropriate to the route of flight.
6. <Specify any airspace limitations that may be applicable to systems that do not provide for coordinate reference system conversions of the displayed navigation information for airspace that is not referenced to the WGS-84 or NAD-83 geodetic datums.
7. <Specify any additional limitations applicable to the particular installation.>

SECTION 3 - EMERGENCY/ABNORMAL PROCEDURES
EMERGENCY PROCEDURES
No Change

ABNORMAL PROCEDURES
1. If ABC Model XXX multi-sensor equipment navigation information is not available or invalid, utilize remaining operational navigation equipment as required.

2. If “GPS INTEGRITY NOT AVAILABLE” message is displayed, continued navigation using the GPS equipment or reversion to an alternate means of navigation appropriate to the route and phase of flight is necessary. When continuing to use GPS navigation, position should be verified every 15 minutes using another IFR-approved navigation system.

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FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX Multi-Sensor
Navigation System

SECTION 4 - NORMAL PROCEDURES

NOTE: Transmission on VHF communication frequencies 121.150, 121.175, 121.200, 131.250, 131.275, and 131.300 MHz may adversely affect reception of the GPS signal. Transmissions in excess of approximately 15 seconds may result in loss of GPS signal reception. Navigation will be restored within 5 seconds after the completion of the transmission.

1. Normal operating procedures are outlined in the ABC Model XXX Multi-Sensor Equipment Pilot's Guide, P/N <insert part number>, dated <insert date> (or later appropriate revision).
2. <Describe approach mode sequencing and signal integrity capability.>
3. System Annunciators

a. Waypoint - <describe each annunciator>
b. Message - <describe each annunciator>
c. Approach - <describe each annunciator>
d. <describe any other annunciators>

4. System Switches

a. Nav/FMS - <describe switch use and function>

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FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX Multi-Sensor
Navigation System

b. RMI Switch - <describe switch use and function>
c. <describe any other switches>

5. Pilot's Display <describe the pilot's multi-sensor navigation data display(s)>
6. Flight Director/Autopilot Coupled Operation <describe the procedures for coupling multi-sensor equipment navigation information to the flight director and/or autopilot system(s)>
7. <include any other normal operating procedures necessary>

SECTION 5 - PERFORMANCE

No Change

SECTION 6 - WEIGHT AND BALANCE

<Refer to revised weight and balance data, if applicable.>

SECTION 7 - SYSTEM DESCRIPTION

<Provide a brief description of the system, its operation, installation, etc.>

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APPENDIX 3. GLOSSARY

1. Availability. The availability of the overall system or a particular sensor is the percentage of time that the services of the system/sensor are usable. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from the satellites or ground stations are available for use.

2. Area Calibration. Area calibration is a procedure where time measurement correction factors are input into the Loran-C system to reduce the effect of propagation anomalies.

3. Barometric altitude. Altitude in the earth's atmosphere above mean standard sea level pressure datum plane, measured by a pressure (barometric) altimeter and corrected for local barometric pressure setting.

4. Differential GPS. A technique used to improve GPS system accuracy by determining positioning error from the GPS satellites at a known fixed location and subsequently transmitting the determined error, or corrective factors, to GPS users operating in the same area.

5. Distance Root Mean Square (DRMS). The root-mean-square value of the distances between the measured and true location in a collection of measurements. The two dimensional circular error distribution, where 95 percent of the position solutions must lie within the defined radius of the circle, is represented by two times the DRMS (2DRMS).

6. En Route Operations. The phase of navigation covering operations between departure and termination phases. The en route phase of navigation has two subcategories: en route domestic and en route oceanic/remote.

7. En Route Domestic. The phase of flight between departure and arrival terminal phases, with departure and arrival points within the U.S. National Airspace System (NAS).

8. En Route Oceanic and Remote. The phase of flight between the departure and arrival terminal phases, with an extended flight path over an ocean.

9. Flight Technical Error (FTE). Navigation error introduced by the pilot's (or autopilot's) capability to utilize displayed guidance information to track the desired flight path.

10. Geometric Dilution of Precision (GDOP). A measure of the satellite geometric effects that degrade a user's position determination.

11. GPS Equipment Classes A(), B(), and C(). GPS equipment is categorized into the following classes (ref. TSO-C129):

a. Class A(). Equipment incorporating both the GPS sensor and navigation capability. This equipment incorporates Receiver Autonomous Integrity Monitoring (RAIM). Class A1 equipment includes en route, terminal, and non-precision approach navigation capability. Class A2 equipment includes en route and terminal navigation capability only.

b. Class B(). Equipment consisting of a GPS sensor that provides data to an integrated navigation system (i.e., flight management system, multi-sensor navigation system, etc.). Class B1 equipment includes RAIM and provides en route, terminal, and non-precision approach capability. Class B2 equipment includes RAIM and provides en route and terminal capability only. Class B3 equipment requires the integrated navigation system to provide a level of GPS integrity equivalent to RAIM and provides en route, terminal, and non-precision approach capability. Class B4 equipment requires the integrated navigation system to provide a level of GPS integrity equivalent to RAIM and provides en route and terminal capability only.

c. Class C(). Equipment consisting of a GPS sensor that provides data to an integrated navigation system (i.e., flight management system, multi-sensor navigation system, etc.), which provides enhanced guidance to an autopilot or flight director in order to reduce flight technical error. Installation of Class C() equipment is limited to aircraft approved under 14 CFR part 121 or equivalent criteria. Class C1 equipment includes RAIM and provides en route, terminal, and non-precision approach capability. Class C2 equipment includes RAIM and provides en route and terminal capability only. Class C3 equipment needs the integrated navigation system to provide a level of GPS integrity equivalent to RAIM and provides en route, terminal, and non-precision approach capability. Class C4 equipment requires the integrated navigation system to provide a level of GPS integrity equivalent to RAIM and provides en route and terminal capability only.

12. Horizontal Dilution of Precision (HDOP). The satellite geometric effects which perturb a user's horizontal error (east and north). Combination of east dilution of precision and north dilution of precision.

13. Integrity. The probability that the system will provide accurate navigation as specified or timely warnings to users when navigation data from a particular sensor should not be used for navigation.

14. Mask Angle. A fixed elevation angle referenced to the user's horizon below which GPS satellites are ignored by the receiver software. The mask angle is driven by the receiver antenna characteristics, the strength of the transmitted signal at low elevations, receiver sensitivity and acceptable low elevation errors.

15. Non-Precision Approach Operations. Those flight phases conducted on charted non-precision Instrument Approach Procedures (IAP's) commencing at the initial approach fix and concluding at the missed approach point or the missed approach holding fix, as appropriate.

16. Operating Modes. Multi-sensor equipment modes associated with various phases of flight: i.e., oceanic, en route, terminal, and non-precision approach.

17. Precipitation Static (P-Static). P-static is electromagnetic noise generated by the dissipation of an electrical charge from an aircraft into the atmosphere. The aircraft becomes charged by flight through particles suspended in the atmosphere such as dust, ice, rain, or snow. Unprotected aircraft may create so much noise that the Loran-C or Omega/VLF sensor can no longer detect the transmitted signal.

18. Pressure Altitude. Altitude in the earth's atmosphere above mean standard sea level pressure datum plane, measured by a pressure (barometric) altimeter set to standard pressure (29.92 inches of mercury).

19. Receiver Autonomous Integrity Monitoring (RAIM). A technique whereby a civil GPS receiver/processor determines the integrity of the GPS navigation signals using only GPS signals or GPS signals augmented with altitude. This determination is achieved by a consistency check among redundant measurements. At least one satellite in addition to those required for navigation must be in view for the receiver to perform the RAIM function.

20. Stand-Alone Navigation System. Stand-alone equipment is equipment that is not combined with other navigation sensors or navigation systems. Stand-alone GPS equipment can, however, include other augmentation features such as altimeter smoothing, clock coasting, etc.

21. Standard Positioning Service (SPS). The standard specified level of positioning, velocity and timing accuracy that is available, without qualifications or restrictions, to any user of the GPS system on a continuous worldwide basis. The navigation service associated with SPS is specified to be 100 meters 2 DRMS horizontal error. 2 DRMS is defined to represent 95 percent.

22. Supplemental Air Navigation System. An FAA-approved navigation system that can be used for navigation provided an alternate navigation system, which meets all of the regulatory requirements for the route of flight, is also installed on the aircraft.

23. Terminal Area Operations. Those flight phases conducted on charted Standard Instrument Departures (SID's), on Standard Terminal Arrivals (STAR's), or other flight operations between the last en route fix/waypoint and an initial approach fix/waypoint.

24. Time Difference (TD). The elapsed time, in microseconds, measured at the receiver, between the arrival of a set of pulses from one Loran-C station's signal to the arrival of a set of pulses from another Loran-C stations signal.

25. Track Angle Error. Track angle error is the difference between the desired track and actual track (magnetic or true).

26. Triad. The collective name given to the three stations from a Loran-C chain from which navigational information is being derived.