



U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: AIRWORTHINESS APPROVAL OF
GLOBAL POSITIONING SYSTEM (GPS)
NAVIGATION EQUIPMENT FOR USE AS A
VFR AND IFR SUPPLEMENTAL NAVIGATION
SYSTEM

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Change:

1. PURPOSE. This advisory circular (AC) establishes an acceptable means, but not the only means, of obtaining airworthiness approval of Global Positioning System (GPS) equipment for use as a supplemental 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 addresses the approval of stand-alone (e.g., TSO-C129 Class A()) GPS equipment only (AC 90-45A, Approval of Area Navigation Systems for Use in the U.S. National Airspace System, does not apply). Approval of navigation or flight management systems integrating Classes B() and C() GPS equipment in a multi-sensor navigation system is addressed in AC 20-130A, Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors. This document does not address GPS equipment incorporating differential GPS capability. Like all advisory material, this advisory circular is not mandatory and does not constitute a requirement. As such, the terms "shall" and "must" used in this advisory circular pertain to an applicant who chooses to follow the method presented. This AC supersedes previous GPS installation guidance contained in: FAA Notice 8110.47, Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for User as a VFR and IFR Supplemental Navigation System, 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. RELATED FEDERAL AVIATION REGULATIONS 14 CFR parts 21, 23, 25, 27, 29, 43, 91, 121, and 135.

3. RELATED READING MATERIALS

a. Federal Aviation Administration (FAA)/Technical Standard Order (TSO) C129, Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS). 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-178B, Software Considerations in Airborne Systems and Equipment Certification; 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 Positioning System (GPS). Copies may be purchased from RTCA, Inc., 1140 Connecticut Avenue, NW., Suite 1020, Washington, DC 20036.

c. Department of Defense Interface Control Document (ICD) ICD-GPS-200B, Navstar GPS Space Segment/Navigation User Interface. Copies of the civil version of this document may be requested from the GPS Joint Program Office, SSD/CZ, Los Angeles AFB, CA 90006.

d. 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; Advisory Circular 20-129, Airworthiness Approval of Vertical Navigation (VNAV) Systems for Use in the U.S. National Airspace System (NAS) and Alaska; 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 Relationships With Local Geodetic Systems. Copies of this document may be requested from the Defense Mapping Agency, Systems Center (SG), 8613 Lee Highway, Fairfax, VA 22031-2138.

4. BACKGROUND

a. System Description The Global Positioning System is a satellite based radio navigation system which utilizes precise range measurements from the GPS satellites to determine precise position anywhere in the world. The GPS constellation assumed in this AC consists of 24 satellites in various orbital planes approximately 11,000 nmi above the earth broadcasting a pseudo-random code timing signal and data message that the airborne equipment processes to obtain satellite position and status data as well as a measurement of how long a radio signal takes to reach the receiver from each satellite. System performance specifications contained in this AC are based upon that achieved with the above constellation configuration once declared operational and with selective availability (SA) active. By knowing the precise location of each satellite and precisely matching timing with the atomic clocks on the satellites, the receiver can accurately measure the time the signal takes to arrive at the receiver and thus determine precise position. A minimum of three satellites must be in view to determine a two dimensional position, if altitude is known, and four are necessary to establish an accurate three dimensional position. To provide integrity monitoring based on GPS information, five satellites with good geometry are necessary. The Department of Defense (DOD) is responsible for operating the GPS satellite constellation and monitors the GPS satellites to ensure proper operation. Every satellite's exact measured orbital parameters (ephemeris data) are sent to each satellite for broadcast as part of the data message sent in the GPS signal. The GPS coordinate system 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, ground speed, etc., 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

(1) 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 necessary to ensure integrity of the GPS position will be neither world-wide nor continuous. With less 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.

(2) 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.

c. GPS Signal Integrity GPS signal integrity monitoring shall be provided by the GPS navigation receiver using receiver autonomous integrity monitoring (RAIM) 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.

d. GPS System Accuracy The GPS equipment determines its position by precise measurement of the distance from selected satellites in the system and the satellite's 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 mathematics and sophisticated modeling, while other sources of error cannot be corrected. Accuracy measurements are affected by satellite geometry or geometric dilution of position (GDOP), which multiplies the effect of pseudo-range errors in the system. The following are sources of pseudo-range errors:

(1) Atmospheric propagation delays can cause relatively small measurement errors, typically less than 100 feet. Ionospheric propagation delays can be partially corrected by sophisticated error correction capabilities.

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

(3) 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.

(4) 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 are used to minimize this problem, some uncertainty can still be added to a GPS measurement.

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

e. Selective Availability 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 (2 drms) 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.

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

g. General Operational Limitations

(1) En Route Domestic, Terminal, and Non-Precision Approach (except Localizer, LDA, and SDF) Use as a Supplemental Navigation System A GPS system that meets the requirements of Class A1 equipment as specified in TSO-C129 may be approved for en route, terminal, and non-precision instrument approach (except localizer, LDA, and SDF) supplemental navigation. A GPS system that meets the requirements of Class A2 equipment as specified in TSO-C129 may be approved for en route and terminal supplemental navigation. All GPS accuracy and integrity requirements must be met without the need for operator input of necessary data.

(2) En Route Oceanic and Remote Operation A GPS system that meets the requirements of Class A() equipment as specified in TSO-C129 may be approved as one of the means, but not the only means, for oceanic and remote navigation.

(3) IFR Navigation Equipment GPS equipment for IFR navigation is for use as a supplemental navigation system. The installation of GPS equipment does not affect the requirement for a primary means of navigation appropriate to the route intended 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. Additional navigation equipment redundancy may be required for operation in oceanic and remote airspace.

(4) Operating Limitations The design of particular GPS equipment will require operational areas be limited to those areas in which the equipment has been demonstrated to meet the performance specifications of this advisory circular because of system characteristics and other factors affecting system operation. Operating limitations that may affect the approved operating area for particular GPS equipment (i.e., extreme north and south latitudes, data base coverage, etc.) must be specified in the operating limitations section of the Airplane/Rotorcraft Flight Manual Supplement (AFMS/RFMS). 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.

h. Equipment Classes Equipment installed in accordance with the guidance provided by this AC for IFR operations shall meet the requirements for Class A() equipment as defined in TSO-C129.

i. 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 GPS equipment installations designed to comply with required navigation performance (RNP) or other FANS design requirements.

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

6. SYSTEM ACCURACY

a. 2D Accuracy Requirements (95 percent probability)

(1) The total position fixing error of the airborne GPS equipment shall be equal to or less than the following:

Error Type	Oceanic/ 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 Class A1 equipment.

** Equipment error assumes an average HDOP of 1.5, GPS equipment waypoint input resolution of 0.01 minute, and coordinate 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) The reference datum shall use latitude/longitude values corresponding to the WGS-84 ellipsoid (Defense Mapping Agency (DMA) Technical Report DMA TR 8350.2, Department of Defense World Geodetic System 1984, Its Definition and Relationships With Local Geodetic Systems).

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 paragraph 6a(1). The FAA has determined that when properly installed in an aircraft, Class A() equipment meeting the operational and display characteristics contained in this AC and TSO-C129 provides for acceptable values of FTE. FTE should not exceed 1.0 nmi for en route, 1.0 nmi for approach transition, or 0.25 nmi for approach operating modes on a 95 percent basis.

7. AIRWORTHINESS CRITERIA FOR GPS INSTALLATIONS USED AS A SUPPLEMENTAL NAVIGATION SYSTEM LIMITED TO VISUAL FLIGHT RULES (VFR) ONLY

a. Application Process Operators wishing to obtain approval of Class A() GPS equipment limited to VFR use only may do so via the type certificate (TC), supplemental type certificate (STC), or, for equipment previously approved via the TC or STC process, 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 a GPS navigation system should be accomplished via the TC or STC approval process.

(2) Subsequent (follow-on) installations of the same GPS navigation system (hardware and software) in other aircraft are approved using a less extensive evaluation process since the basic engineering design of the GPS equipment 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 GPS 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 GPS navigation system. 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 GPS equipment installations.

b. Airworthiness Considerations GPS equipment approved for VFR use only does not require TSO-C129 authorization, however it must at least meet the en route/terminal system accuracy criteria (0.124 nmi, 95 percent probability) contained in paragraph 6a of this AC. Airworthiness considerations should include the following:

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

(2) Environmental Conditions The GPS equipment is appropriate to the aircraft environment in which it is installed.

(3) Equipment Mounting The installation of the GPS equipment, including antenna, must be sufficient to meet all structural mounting, dynamic, and emergency landing loads appropriate to

the aircraft. It is acceptable to use the methods in AC 43.13-2A, "Acceptable Methods, Techniques, and Practices - Aircraft Alterations."

(4) Navigation Source Annunciator A navigation source annunciator is provided on or near each affected display if the GPS installation supplies any information to displays such as a horizon situation indicator (HSI), course deviation indicator (CDI), distance display, electronic map, etc., which 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 airborne GPS navigation system must not degrade the normal operation of other required equipment or create a flight hazard. Likewise, normal operation of the GPS equipment must not adversely affect the performance of other aircraft equipment. The interfaces with other aircraft equipment must be designed such that normal or abnormal GPS equipment operation does not adversely affect the operation of other equipment. Operation of other equipment shall not adversely affect the GPS equipment operation.

(7) System Controls, Displays and Annunciators All displays, controls, and annunciators must be easily readable under all normal cockpit conditions and expected ambient light conditions (total darkness to bright reflected sunlight). Night lighting 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 adequate protection against inadvertent system turnoff. Reliance on pilot memory for operational procedures shall be minimized.

(8) Navigation/Integrity Annunciation The GPS 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 necessary 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 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 Unit (CDU) 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 GPS navigation system may be coupled to an autopilot and/or flight director system, if a deviation or steering output that is compatible with the autopilot/flight director system is provided and no unusual interface is required.

(10) VFR Limitation Placard A placard stating "GPS limited to VFR use only" must be installed in clear view of, and readable by, the pilot.

(11) Manufacturer's Instructions The GPS equipment, including antenna, 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 Criteria (for a Particular Type of GPS Equipment) This type of approval refers to the very first time an applicant presents a particular (hardware and software configuration) model GPS navigation system for FAA airworthiness installation approval and certification for VFR navigation use. The first approval of a particular GPS navigation system must be accomplished through the TC or STC process. Each new model of GPS 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. The 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 7b(5) of this AC.

(B) Analysis of failure modes and annunciations.

(C) Review of reliability data to establish that all probable failures affecting the navigation function are detected.

(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 GPS equipment will provide an aircraft as a test bed for the first-time installation approval. This approval will serve as a basis for subsequent installation approvals regardless of aircraft type or model. The following assessments are made:

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

(B) Verification that the GPS equipment is appropriate to the aircraft environment in which it is installed.

(C) Verification that the installation of the GPS equipment, including antenna, is sufficient to meet all structural mounting, dynamic, and emergency landing loads appropriate to the aircraft.

(D) Verification that a placard stating "GPS limited to VFR use only" is installed in clear view of and readable by the pilot.

(E) Verification that the GPS equipment installation does not interfere with the normal operation of other equipment installed in the aircraft.

(iii) Ground Test Evaluation Static ground tests are conducted to verify the installed GPS equipment configuration (including the antenna) provides position data meeting the en route/terminal accuracy criteria specified in paragraph 6a 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 using 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 GPS 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 a particular GPS system are accomplished by the cognizant Aircraft Certification Office (ACO) unless specific tests are delegated by the ACO to a flight test pilot designated engineering representative (DER).

(A) Evaluation of installed GPS navigation system to verify that it is functioning properly, safely, and operates in accordance with the manufacturer's specifications.

(B) Evaluation of steering response while the autopilot and/or flight director is coupled to the GPS equipment during a variety of different track and mode changes. All available display sensitivities should be evaluated.

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

(D) Validate GPS navigation system accuracy by at least 5 low altitude overflights 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 than 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.

(E) Evaluation of the accessibility of all controls pertaining to the GPS installation.

(F) Evaluation of the visibility of the controls, displays, and annunciators relating to the GPS 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.

(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 GPS equipment has been issued via the TC or STC process. Follow-on approvals may use the first time airworthiness approval as a basis for installation approval. The applicant or installing agency requesting a follow-on GPS equipment installation limited to VFR use should:

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

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

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

(C) Verify that the maximum operating speed for which the GPS equipment is qualified is compatible with the maximum expected ground speed of the aircraft.

(ii) Conduct a similar data evaluation as outlined in paragraph 7c(1)(ii) of this AC.

(iii) Conduct a functional flight evaluation covering the items specified in paragraph 7c(1)(iv) of this AC.

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

8. AIRWORTHINESS CRITERIA FOR GPS INSTALLATIONS USED AS A SUPPLEMENTAL NAVIGATION SYSTEM UNDER INSTRUMENT FLIGHT RULES (IFR)

a. Application Process Operators wishing to obtain approval of Class A() GPS equipment for IFR operations may do so via the type certificate (TC) or supplemental type certificate (STC) process. For equipment produced under TSO-C129 authorization that has previously obtained initial 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. 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 a GPS navigation or sensor system 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 GPS navigation system (hardware and software) in other aircraft are approved using a less extensive evaluation process since the basic engineering design of the GPS equipment 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 GPS 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 GPS navigation system. 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 GPS equipment installations. Changes to software accomplishing navigation, integrity, or availability functions or significant changes to operating limitations cannot be accomplished using the FAA Form 337 process.

b. Airworthiness Considerations GPS navigation equipment approved as a supplemental navigation system for oceanic and remote en route, domestic en route, terminal, and non-precision instrument approach (except localizer, LDA, and SDF) operations does not require TSO-C129 authorization, however it must meet the minimum navigation performance and operation standards of Class A1 or A2 equipment, as applicable, specified in TSO-C129 and this AC. Airworthiness considerations should include the following:

(1) System Integrity and Software Development Loss of navigation information is considered to be a major failure condition for the aircraft as defined in AC 1309-1A; AC 23.1309-1A; AC 27-1; or AC 29-2A, as applicable to the aircraft. Providing/presenting hazardously misleading information to the flight crew is also considered to be a major failure condition for the aircraft. GPS

navigation data is considered to be hazardously misleading when unannounced position errors exist that are greater than those specified by the GPS position integrity performance requirements in Table 2-1 of RTCA/DO-208. The applicant should conduct a safety assessment of the GPS equipment installation 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, provide an acceptable means for showing that the hardware complies with pertinent airworthiness requirements.

(ii) The 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-C129 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-C129), 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 GPS navigation systems (e.g., use of user-modifiable software, 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) 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 the GPS Display Each display element (i.e., the cross track deviation display (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 airborne GPS navigation system shall not degrade the normal operation of other required equipment or create a flight hazard. Likewise, normal operation of the GPS 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 GPS equipment operation shall not adversely affect the operation of other equipment nor shall normal or abnormal operation of other equipment adversely affect the GPS equipment operation.

(5) Environmental Conditions The aircraft environment in which the GPS system 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 GPS navigation system should not be the source of objectionable electromagnetic interference, nor be adversely affected by electromagnetic interference from other equipment in the aircraft.

(i) The GPS equipment should be shown to meet the 2D accuracy requirements of paragraph 6a 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) 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) 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) Anti-Ice Protection If the aircraft in which the GPS equipment is installed is approved for flight into known icing conditions, the antenna must 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 GPS 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.)

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

(9) Navigation Data Base The GPS equipment shall incorporate an appropriately updatable navigation data base (in the WGS-84 or NAD-83 coordinate datum) containing 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 and terminal area charts, Standard Instrument Departures (SID's) and Standard Terminal Arrival Routes (STAR's). For Class A1 equipment, 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 data base. 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 TSO-C129 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."

(10) Pressure/Barometric Altitude Inputs An appropriate input of pressure and/or barometric altitude must be provided to the GPS equipment.

(11) Manufacturer's Instructions The GPS equipment, including antenna, 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 GPS Equipment)
This type of approval refers to the very first time an applicant presents a particular (hardware and software configuration) model GPS navigation system for FAA airworthiness installation approval and certification for IFR navigation use. The first approval of a particular GPS navigation system must be accomplished through the Type Certificate (TC) or Supplemental Type Certificate (STC) process. Each new model of GPS 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 test 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 8b(1) of this AC.

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

(C) Verification of compliance with the minimum performance and operation standards applicable to Class A() equipment specified in TSO-C129.

(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 the GPS antenna on the aircraft. Refer to paragraph 8c(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 GPS equipment will provide an aircraft as a test bed for the first time installation approval. This approval will serve as a basis for subsequent installation approvals regardless of aircraft type or model. 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, 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 GPS equipment is installed is appropriate to the environmental categories (or criteria) in RTCA/DO-160C to which the equipment has been tested.

(G) Evaluation of the antenna installation. It is important that the antenna be one that is approved for the particular type of GPS equipment installed. A critical aspect of any GPS installation is the installation of the antenna. Adequate isolation must be provided between the GPS antenna and any other transmitting antenna(s) installed on the aircraft. Shadowing by aircraft structure can adversely affect the operation of the 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.

(iii) Ground Test Evaluations Static ground tests are conducted to verify the installed GPS equipment configuration (including the antenna) provides position data meeting the accuracy criteria specified in paragraph 6a 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 GPS system in the aircraft. Flight tests should include at least the following:

NOTE: Required flight evaluations for the first-time airworthiness approval of a particular GPS system 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 the overall operation of the GPS equipment to include at least the following: the ability to readily create and modify a flight plan, perform "DIRECT TO" functions, hold at a designated waypoint, intercept and track to or from a waypoint on a selected course, turn anticipation, waypoint sequencing, and the general presentation of navigational data (depiction of the "TO" waypoint, distance to waypoint, estimated time of arrival, estimated time en route, ground speed, etc.).

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

(C) Evaluation of steering response while autopilot and/or flight director is coupled to the GPS 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.

(D) Evaluation of displayed GPS navigation parameters on interfaced cockpit instruments such as HSI, CDI, distance display, electronic flight instruments system (EFIS), moving maps, fuel management systems, etc.

(E) Assessment of all switching and transfer functions, including electrical bus switching, pertaining to the GPS installation.

(F) Evaluation to determine satisfactory electromagnetic compatibility (EMC) between the GPS installation and other onboard equipment (this test may be partially accomplished as a ground test)

NOTE 1: Particular attention should be given to other "L" band equipment, such as TCAS or SATCOM equipment, VHF transmissions on the frequencies stated in paragraph 8b6(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 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

Please use proper radio regulations when conducting this test.

(G) Evaluation of the accessibility of all controls pertaining to the GPS installation.

(H) Evaluation of the visibility of the controls, displays, and annunciators relating to the GPS 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.

(I) Analysis of crew workload when operating the GPS equipment in association with other piloting requirements.

(J) Validate GPS accuracy in each operating mode by at least 5 low altitude overflights 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 than 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.

(K) Verify continuity of navigation data during normal aircraft maneuvering, including holding patterns and turns at up to at least 30 degrees of bank for one minute.

(L) Verify that flight technical error (FTE) can be maintained at less than 1.0 nmi for en route, 1.0 nmi for approach transition, and 0.25 nmi for approach operating modes both with and without autopilot and/or flight director use, as applicable.

(M) For equipment approved for approach, conduct a sufficient number of approaches and transitions from en route to terminal to approach operations using the navigation data base to verify proper operation of the GPS navigation system in the approach environment. 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 after a first time airworthiness approval of the particular GPS 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.

(i) Unless otherwise provided, contact either the manufacturer or organization responsible for obtaining the first time airworthiness approval of the GPS 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, system integration requirements, etc.

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

(D) Verify that the design maximum operating speed for the GPS equipment 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 8b(7) of this AC.

(iii) Conduct a data evaluation similar to that outlined in paragraph 8c(1)(ii) of this AC.

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

- (A) Overall operation of the installed GPS equipment, including interface with other equipment in the aircraft.
- (B) The effect(s) of GPS equipment failure (open circuit breaker), including autopilot/flight director response, if applicable.
- (C) If interfaced with an autopilot and/or flight director, steering response while the autopilot and/or flight director is coupled to the GPS equipment.
- (D) Displayed GPS 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 GPS installation.
- (F) Evaluation to determine satisfactory EMC between the GPS installation and other equipment as specified in paragraph 8c(1)(iv)(F) of this AC.

NOTE: Verification of adequate isolation from harmonic interference of VHF communication transceivers is required for installation of GPS navigation equipment in each individual aircraft. 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) Accessibility and visibility (day and night conditions) of all controls pertaining to the GPS installation.
- (H) Validate GPS accuracy in each operating mode as specified in paragraph 8c(1)(iv)(J) of this AC.
- (I) Verify continuity of navigation data during 360 degree left and right turns at 30 degrees of bank.
- (J) Monitor displayed cross-track error during en route, and, if applicable, approach transition and approach operations to verify FTE is less than 1.0 nmi (en route and approach transition) and 0.25 nmi (approach), both with and without use of the autopilot and flight director (if installed).
- (K) For equipment approved for approach, conduct at least three published instrument approaches (retrieved from the data base) to verify proper operation of the equipment in the approach environment.

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 ACO may accept flight evaluations conducted by the installer.

9. 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 GPS navigation 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 GPS equipment for IFR navigation is for use as a supplemental navigation system. The installation of GPS equipment does not affect the requirement for primary means of navigation appropriate to the route intended 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. Additional navigation equipment redundancy may be required for operation in oceanic and remote airspace.

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 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. Flight crews must be aware that operational areas for different systems 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 FOR IFR/VFR OPERATIONS
BY FAA FORM 337 FOR FOLLOW-ON GPS EQUIPMENT INSTALLATIONS

1. FOLLOW-ON GPS EQUIPMENT INSTALLATIONS LIMITED TO VFR USE ONLY Approval of follow-on GPS 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 The installation criteria should be in accordance with the criteria specified in paragraph 7c(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 7c(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 adequately 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 GPS system 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 7c(1)(iv) of this AC is accomplished by the installer. The results of this evaluation are included with the data provided to the FSDO.

2. FOLLOW-ON GPS EQUIPMENT INSTALLATIONS FOR IFR USE Approval of follow-on GPS 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 6a and ground accuracy test requirements of paragraph 8c(1)(iii) of this AC and system performance specifications of TSO-C129 have been met. (This certification can be accomplished by reference to TSO-C129 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 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-C129 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 GPS system 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)(iv) is accomplished. If the criteria specified in appendix 1, paragraph 2a(2) above is satisfied, the installer conducts 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 GPS Navigation System
FAA APPROVED AIRPLANE FLIGHT MANUAL SUPPLEMENT ABC MODEL XXX GPS NAVIGATION SYSTEM	
AIRPLANE MAKE: AIRPLANE MODEL: AIRPLANE SERIAL NO.: REGISTRATION NO.:	
<p>This document must be carried in the airplane at all times. It describes the operating procedures for the ABC Model XXX GPS navigation system when it has been installed in accordance with <i><manufacturer's installation manual number and date></i> and FAA Form 337 dated <i><insert date></i>.</p> <p>For airplanes with an FAA Approved Airplane Flight Manual, this document serves as the FAA Approved ABC Model XXX GPS Flight Manual Supplement. For airplanes that do not have an approved flight manual, this document serves as the FAA Approved ABC Model XXX GPS Supplemental Flight Manual.</p> <p>The information contained herein supplements or supersedes the basic Airplane Flight Manual dated <i><insert date></i> only in those areas listed herein. For limitations, procedures, and performance information not contained in this document, consult the basic Airplane Flight Manual.</p>	
FAA APPROVED	
<hr/> <p>Title Office Federal Aviation Administration City, State</p>	
FAA Approved Date: _____	Page <> of <>

FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

Installation Center/Repair Station 123 Fourth Street Anytown, USA	Model XXX GPS Navigation System
<u>Table of Contents</u>	
<u>Section</u> <u>Page</u>	
1 General..... < >	
2 Limitations..... < >	
3 Emergency/Abnormal Procedures..... < >	
4 Normal Procedures..... < >	
5 Performance..... < >	
6 Weight and Balance..... < >	
7 System Description..... < >	
FAA Approved Date: _____	Page < > of < >

FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

Installation Center/Repair Station 123 Fourth Street Anytown, USA	Model XXX GPS Navigation System
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SECTION 1 - GENERAL

1. <Provide a very brief (i.e., one paragraph) general description of the GPS navigation system installed in the aircraft>

2. Provided the ABC Model XXX GPS navigation system is receiving adequate 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, North Atlantic Minimum Navigation Performance Specification (MNPS) Airspace 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-XXX, AC 91-49, AC 120-33, and ~~list~~ *list additional applicable AC's*. 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 GPS 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 GPS equipment data base. The GPS equipment data base must incorporate the current update cycle.

FAA Approved
Date: _____

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FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

Installation Center/Repair Station 123 Fourth Street Anytown, USA	Model XXX GPS Navigation System
<p>(a) Instrument approaches must be conducted in the approach mode and RAIM must be available at the Final Approach Fix.</p> <p>(b) Accomplishment of ILS, LOC, LOC-BC, LDA, SDF, and MLS approaches are not authorized.</p> <p>(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.</p> <p>5. The aircraft must have other approved navigation equipment installed and operating appropriate to the route of flight.</p> <p>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.></p> <p>7. <Specify any additional limitations applicable to the particular installation>.</p>	
<p><u>SECTION 3 - EMERGENCY/ABNORMAL PROCEDURES</u></p>	
<p><u>EMERGENCY PROCEDURES</u></p>	
<p>No Change</p>	
<p><u>ABNORMAL PROCEDURES</u></p>	
<p>1. If ABC Model XXX GPS navigation information is not available or invalid, utilize remaining operational navigation equipment as required.</p> <p>2. If "RAIM NOT AVAILABLE" message is displayed, continue to navigate using the GPS equipment or revert to an alternate means of navigation appropriate to the route and phase of flight. When continuing to use GPS navigation, position must be verified every 15 minutes using another IFR-approved navigation system.</p>	
FAA Approved Date: _____	Page <> of <>

FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

Installation Center/Repair Station 123 Fourth Street Anytown, USA	Model XXX GPS Navigation System
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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 GPS Pilot's Guide, P/N *<insert part number>*, dated *<insert date>* (or later appropriate revision).
2. *<Describe approach mode sequencing and RAIM prediction 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/GPS - *<describe switch use and function>*
 - b. RMI Switch - *<describe switch use and function>*
 - c. *<describe any other switches>*
5. Pilot's Display *<describe the pilot's GPS display(s)>*

FAA Approved
Date: _____

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FIGURE 1. SAMPLE AIRPLANE FLIGHT MANUAL SUPPLEMENT (continued)

<p>Installation Center/Repair Station 123 Fourth Street Anytown, USA</p>	<p>Model XXX GPS Navigation System</p>
<p>6. Flight Director/Autopilot Coupled Operation <i><describe the procedures for coupling GPS to the flight director and/or autopilot system(s)></i></p>	
<p>7. <i><include any other normal operating procedures necessary></i></p>	
<p><u>SECTION 5 - PERFORMANCE</u></p>	
<p>No Change</p>	
<p><u>SECTION 6 - WEIGHT AND BALANCE</u></p>	
<p><i><Refer to revised weight and balance data, if applicable.></i></p>	
<p><u>SECTION 7 - SYSTEM DESCRIPTION</u></p>	
<p><i><Provide a brief description of the system, its operation, installation, etc.></i></p>	
<p>FAA Approved Date: _____</p>	<p>Page <> of <></p>

APPENDIX 3. GLOSSARY

1. Availability The availability of the GPS system is the percentage of time that the services of the GPS system 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 are available for use.
2. Barometric Altitude Altitude in the earth's atmosphere above mean standard sea level pressure datum, measured by a pressure (barometric) altimeter and corrected for local barometric pressure setting.
3. 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.
4. 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 (2 DRMS).
5. En Route Operations The phase of navigation covering operations between departure and arrival terminal phases. The en route phase of navigation has two subcategories: en route domestic and en route oceanic/remote.
6. 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).
7. En Route Oceanic and Remote The phase of flight between the departure and arrival terminal phases, with an extended flight path over an ocean.
8. 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.
9. Geometric Altitude Altitude above the surface of the WGS-84 ellipsoid.
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) A measure of the satellite geometric effects which degrade a user's horizontal position determination.

13. Integrity. The probability that the system will provide accurate navigation as specified or timely warnings to users when GPS data 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.

15. Non-Precision Approach Operations Those flight phases conducted on charted 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. 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).

17. Pseudorange The distance from the user to a satellite plus an unknown user clock offset distance. With four satellite signals it is possible to compute position and offset distance.

18. 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 pseudorange measurements. At least one satellite in addition to those required for navigation must be in view for the receiver to perform the RAIM function.

19. Stand-Alone GPS Navigation System Stand-alone GPS equipment is equipment that is not combined with other navigation sensors or navigation systems such as DME, Loran-C, Omega, Inertial, etc. Stand-alone GPS equipment can, however, include other augmentation features such as altimetry smoothing, clock coasting, etc.
20. 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.
21. System Availability The percentage of time (specified as 98 percent) that at least 21 of the 24 GPS satellites must be operational and providing a usable navigation signal.
22. 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.
23. Track Angle Error Track angle error is the difference between the desired track and actual track (magnetic or true).