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MINIMUM OPERATIONAL PERFORMANCE STANDARDS FOR GLOBAL POSITIONING SYSTEM/WIDE AREA AUGMENTATION SYSTEM AIRBORNE EQUIPMENT

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Prepared by SC-159

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FOREWORD

This report was prepared by Special Committee 159 (SC-159) and approved by the RTCA Program Management Committee (PMC) on November 28, 2001.

RTCA, Incorporated, is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Federal Advisory Committee and develops consensus-based recommendations on contemporary aviation issues. RTCA's objectives include but are not limited to:

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

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1 PURPOSE AND SCOPE

1.1 Introduction

This document contains minimum operational performance standards (MOPS) for airborne navigation equipment (2D and 3D) using the Global Positioning System (GPS) augmented by the Wide Area Augmentation System (WAAS). Throughout this document, the term “WAAS” is used as a generic reference to Satellite-Based Augmentation Systems (SBAS). These standards are intended to be applicable to other SBAS providers, such as European Geostationary Navigation Overlay Service (EGNOS) and Japan’s Multi-functional Transport Satellite (MTSAT) Satellite -based Augmentation System (MSAS).

In this document, the term “shall” is used to indicate requirements. An approved design should comply with every requirement, which can be assured by inspection, test, analysis, or demonstration. The term “must” is used to identify items which are important but are either duplicated somewhere else in the document as a “shall”, or are considered to be outside the scope of this document. The term “should” is used to denote a recommendation that would improve the WAAS equipment, but does not constitute a requirement.

The standards define minimum performance, functions and features for WAAS-based sensors that provide position information to a multi-sensor system or separate navigation system. They also address WAAS-based Area Navigation (RNAV), and optionally Vertical Navigation (VNAV), equipment to be used for the en route, terminal area, and non-precision approach phases of flight. These standards are based upon a nominal allocation of the aircraft-level requirements in RTCA/DO-236A, *Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation*, accounting for the unique issues associated with WAAS and GNSS navigation service and minimizing the need for pilot training. These standards also define performance, functions and features for equipment that satisfies the requirements for approach procedures with vertical guidance APV and Global Navigation Satellite System (GNSS) Landing System (GLS). The standards cover WAAS-based equipment which is designed to serve combinations of the above phases of flight; updated standards for multi-sensor systems are being developed by RTCA Special Committee 181.

Compliance with these standards by manufacturers, installers and users is recommended as one means of assuring that the equipment will satisfactorily perform its intended functions under conditions encountered in routine aeronautical operations, and will ensure a basic compatibility with the requirements defined in RTCA/DO-236A. Manufacturers and operators who elect to comply directly with the requirements of RTCA/DO-236A as part of an aircraft certification (type certificate or supplemental type certificate) may bypass these RNAV standards, but are not expected to be eligible for a Class Gamma TSO authorization.

The regulatory application of these standards is the responsibility of appropriate government agencies. In the United States, the Federal Aviation Administration (FAA) has published a Technical Standard Order (TSO) for GPS/WAAS equipment to reference the requirements and bench test procedures in Section 2.

The word "equipment", as used in this document, includes all components or units necessary (as determined by the equipment manufacturer or installer) to properly perform its intended function. For example, the airborne "equipment" may include: sensor(s), a computer unit, an input-output unit which interfaces with existing aircraft displays/systems, a control unit, a display, shock mount(s), etc. In the case of this example, all of the foregoing components or units constitute the "equipment". It should not be inferred from this example, however, that all GPS/WAAS navigation equipment will necessarily include all of the foregoing components or units. The particular components of GPS/WAAS equipment will depend upon the design used by the equipment manufacturer, subject to the constraint that the equipment must meet the applicable requirements of this MOPS.

Section 1 of this document provides information and assumptions needed to understand the rationale for equipment characteristics and requirements stated in the remaining sections. It describes typical equipment applications and operational goals and forms the basis for the standards stated in Sections 2 through 4.

Sections 2 through 4 contain the performance requirements. When measured values of equipment performance could be a function of the measurement method, these sections also define standard test conditions as well as testing methods. Section 2 contains the minimum performance standards for the equipment. These standards define required performance under standard operating conditions and stressed physical environmental conditions. It also details the recommended test procedures necessary to demonstrate compliance.

Section 3 describes those additional requirements and tests that ensure that the equipment performs its intended function in a particular installation. Tests for the installed equipment are included when performance cannot be adequately determined through bench testing, as described Section 2.

Section 4 describes the characteristics of installed equipment, and the expected pilot reactions to specified displays.

Appendices A through D are normative. Specifically, Appendix A contains the WAAS signal specification, Appendix B contains GPS assumptions, Appendix C describes the standard interference environment, and Appendix D defines the database record for precision approach.

Appendix E includes a description of the baseline weighted least squares algorithm used to define the solution requirement for precision approach algorithms. It also includes an example means of implementing the navigation system error algorithm for precision approach.

Appendices F and G define the requirements for optional capabilities. Specifically, Appendix F describes vertical navigation (VNAV) capability which is optional under this MOPS for en route, terminal area and non-precision approach. Appendix G describes the requirements and test procedures for baro-aided FDE capability which is optional under this MOPS.

Appendices H, I, K and L contain example algorithms for implementing functions that are required by this MOPS. In other words, the GPS/WAAS equipment need not realize these algorithms. Appendix H is a recommended output standard. Appendix I describes a step detector algorithm. Appendix J describes required methods of calculating WAAS-based protection levels, based upon the data in the WAAS message. Appendix K provides a list of references concerning the fault detection and exclusion (FDE) algorithm which can be used during the en route, terminal area, and non-precision phases of flight as a reversionary mode for providing integrity. Appendix L describes an example method for making WGS-84 computations.

Appendices M through Q are informative. Appendix M contains background material for bench tests. A summary of the requirements for all classes of equipment can be found in Appendix N. Appendix O is a glossary and Appendix P provides flowcharts for the Ionospheric Grid Point (IGP) selection process. Appendix Q contains WAAS requirements for helicopters.

Appendix R contains requirements and test procedures for tightly integrated GPS/inertial systems when fault-detection and exclusion is used to provide integrity. Any equipment that uses integrated GPS/inertial must meet the requirements and accomplish the test procedures of this appendix.

Note: *Equations in Appendix A and R are labeled sequentially (i.e., [A-1], [A-2]) so that the equations may be referenced.*

1.2 System Overview

The WAAS is an augmentation to GPS which calculates GPS integrity and correction data on the ground and uses geostationary satellites (GEOs) to broadcast GPS integrity and correction data to GPS/WAAS users and to provide ranging signals. It is a safety critical system consisting of a ground network of reference and integrity monitor data processing sites to assess current GPS performance, as well as a space segment which broadcasts that assessment to Global Navigation Satellite System (GNSS) users to support en route through precision approach navigation. Users of the system include all aircraft applying the WAAS data and ranging signal.

1.2.1 Wide Area Augmentation System

A conceptual overview of the WAAS architecture is provided in Figure 1-1. The WAAS is made up of an integrity and reference monitoring network, processing facilities, geostationary satellites, and control facilities.

Wide area reference stations and integrity monitors are widely dispersed data collection sites that contain GPS/WAAS ranging receivers which monitor all signals from the GPS, as well as the WAAS geostationary satellites. The reference stations collect measurements from the GPS and WAAS satellites so that differential corrections, ionospheric delay information, GPS/WAAS accuracy, WAAS network time, GPS time, and UTC can be determined.

The wide area reference station and integrity monitor data are forwarded to the central data processing sites. These sites process the data in order to determine differential corrections, ionospheric delay information, and GPS/WAAS accuracy, as well as verify residual error bounds for each monitored satellite. The central data processing sites also generate navigation messages for the geostationary satellites and WAAS messages. This information is modulated on the GPS-like signal and broadcast to the users from geostationary satellites.

1.2.2 GNSS Satellite Signal Characteristics

GNSS refers to a world-wide position and time determination system that uses satellite ranging signals to determine user location. It encompasses all satellite ranging technologies, including GPS and additional satellites. Different components of the GNSS can have different signal characteristics (e.g., GPS, Global Orbiting Navigation Satellite System (GLONASS), WAAS satellites).

1.2.2.1 GPS Signal Characteristics

The GPS ranging signal is modulated with data at 50 symbols/second that defines the satellite's position, system time, clock correction parameters, as well as the health and accuracy of the transmitted data and ranging signal. The user computes a pseudorange to the satellite by timing the arrival of the GPS signal. The user equipment uses the pseudoranges from the satellites to compute the receiver's internal clock offset and a three dimensional position fix. A pseudo-random noise (PRN) code, known as the Coarse Acquisition (C/A) code, is generated at a rate of 1.023 MHz and modulated onto the GPS

L1 frequency (1575.42 MHz). All GPS satellites transmit at the same L-band frequency. The carrier is modulated with a specific C/A code for each GPS satellite.

The GPS coordinate system provided by the signal is the Cartesian earth-centered earth-fixed (ECEF) coordinates as specified in the World Geodetic System 1984 (WGS-84). The GPS position is determined in the WGS-84 coordinate system.

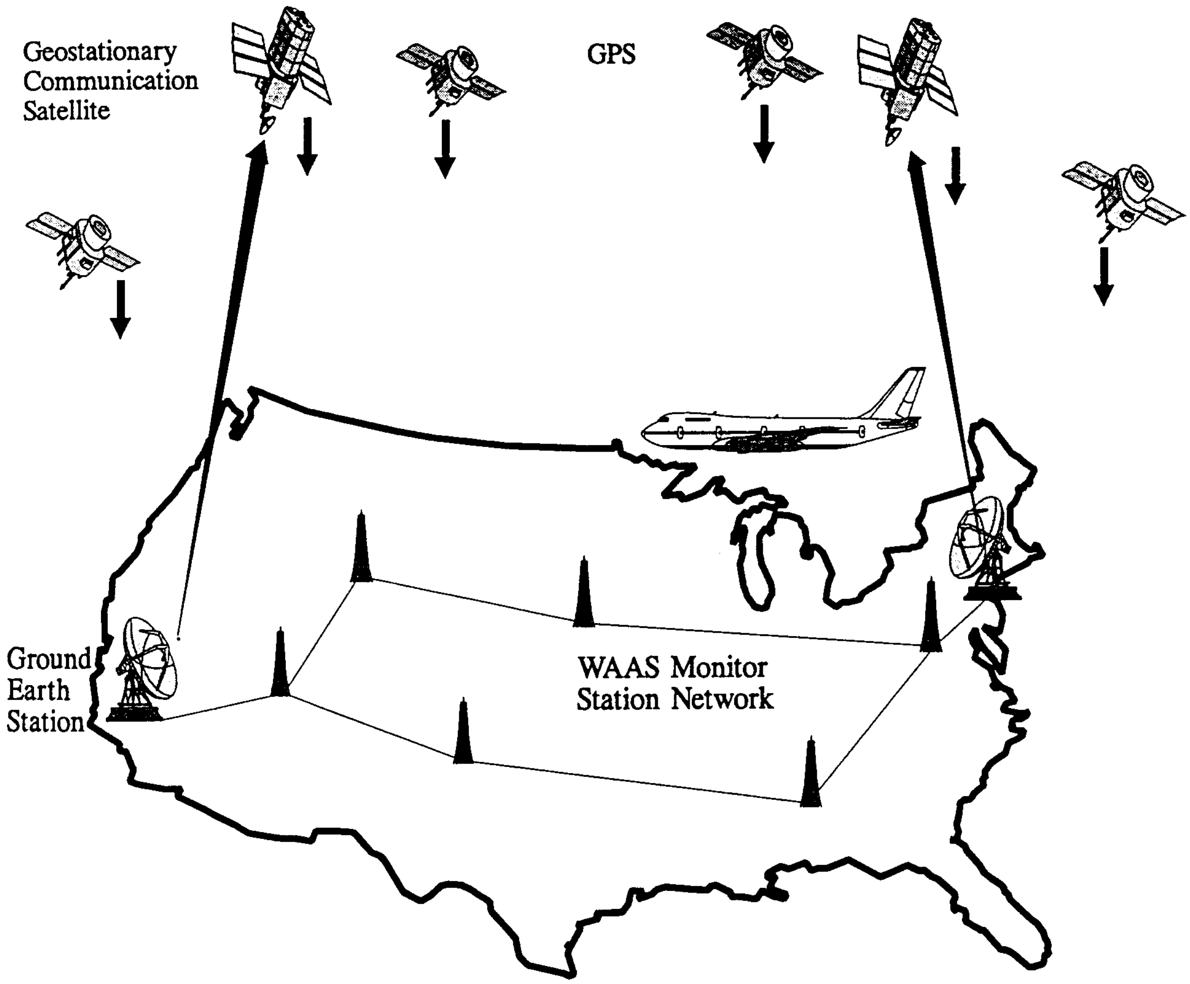


FIGURE 1-1 WAAS ARCHITECTURE

The GPS Control Segment consistently manages GPS time to within one microsecond of Universal Coordinated Time (UTC) (modulo one second). For time coordination purposes, an offset between GPS time and UTC is provided in the GPS navigation message and is specified to have an SPS accuracy of 40 nanoseconds 95% of time. Detailed GPS Standard Positioning Service (SPS) information is provided in the GPS SPS Performance Standard, October 2001, and ICD-GPS-200C, "Navstar GPS Space Segment / Navigation User Interfaces", April 2000.

1.2.2.2 WAAS Signal Characteristics

The WAAS signal is transmitted from a geostationary satellite on the GPS L1 frequency (1575.42 MHz). The 500 symbols/second WAAS data stream is added modulo-2 to a 1023-bit PRN code, which will then be biphase shift-keyed (BPSK) modulated onto the L1 carrier frequency at a rate of 1.023 Mega-chips/second (Mcps). Detailed WAAS signal characteristics, as well as formats and data contents, are provided in Appendix A. The WAAS network time (WNT) is maintained such that the offset from GPS is less than 50 nanoseconds. The WAAS network time offset from UTC after correction is less than 20 nanoseconds.

1.3 Operational Goals

The operational goal of the WAAS is to augment the Department of Defense (DOD) GPS SPS so that GPS/WAAS is the only radionavigation equipment required onboard the aircraft to meet aviation radionavigation performance requirements for oceanic, remote area and domestic en route, terminal, nonprecision approach, LNAV/VNAV, APV-II and GLS phases of flight.

The WAAS signal provides the augmentation to GPS to obtain the required accuracy improvement for precision approaches, as well as integrity, continuity, and availability of navigation for all phases of flight. Within the service volume, the level of service will be dependent on the user's equipment. When the aircraft is outside the WAAS service volume, the GPS/WAAS equipment will be suitable for supplemental navigation and may be suitable as a primary means of oceanic/remote area navigation.

Additional goals for GPS/WAAS are to provide:

a. flexibility for future enhancements;

b. worldwide primary (sole) means radionavigation;

c. positioning and time for automatic dependent surveillance;

d. ground movement monitoring (with augmentation);

e. growth to GPS/Local Area Augmentation System for Category III precision approach; and

f. replacement of other radionavigation systems.

1.3.1 Intended Operational Applications

This document describes airborne equipment that is capable of providing GPS/WAAS positioning function suitable for navigation in the en route, terminal, nonprecision approach and precision approach phases of flight. It also describes additional criteria that must be met for airborne equipment which provides flight guidance information based upon a desired flight plan. The equipment provides GPS/WAAS lateral navigation for en route through nonprecision approach, and optionally may provide vertical navigation based on barometric altimeter. For precision approach, both lateral and vertical GPS/WAAS navigation is provided. The positioning function is precise and reliable, and may ultimately support other applications such as dependent surveillance and surface navigation.

1.3.2 Operational Environment

The GPS/WAAS is intended to be a primary (sole) means of radionavigation within the U.S. National Airspace System (NAS). As such, it may be used by aircraft as the primary-means of navigation within designated airspace, so that other radionavigation equipment is not required on the aircraft. Operations and procedures that are designed to utilize the enhanced capabilities described in this document must be implemented to capture all the benefits of the GPS/WAAS. It is anticipated that the NAS will transition to increased reliance on GNSS and decreased emphasis on ground-based radionavigation aids.

The GPS/WAAS is a unique system in that it provides service to a very large area. Due to the increased impact of a failure of the GPS/WAAS infrastructure, the requirements on WAAS signal-in-space performance are more stringent than other conventional radionavigation aids. As with conventional aids, operational precautions will be used to mitigate a potentially hazardous situation in the event of a failure.

The GPS/WAAS may result in the decommissioning of other radionavigation aids on the ground and the removal of other radionavigation equipment from the cockpit. Although the ultimate degree to which these reductions can be made is not yet known, it is believed that they will result in significant savings both to the aviation authority and the aeronautical community. The operating environment is expected to evolve to capture the benefits of improved RNAV capabilities, resulting in increased operational efficiency. The GPS/WAAS is a radionavigation system which provides improved performance to support both existing and future operations.

1.3.3 International Compatibility

The operational concept for GNSS and Space-Based Augmentation System (SBAS) is predicated on the combination of the different GNSS elements without pilot intervention. As GNSS is a global system, there should be no flight crew interaction based on airspace, so that the flight crew should not be involved in the selection of different SBAS (e.g., WAAS, EGNOS, MSAS).

In order to support the designation of a particular SBAS service provider for a precision approach (the most stringent operation), the FAS data block contains an SBAS service provider ID that can be confirmed against the ID broadcast in a Type 17 message. This can be accomplished transparent to the flight crew, consistent with the operational concept.

For operations other than precision approach, it is expected that States will approve all combinations of GNSS elements, to include SBAS services provided by another State. If a State decides to approve a subset of GNSS elements for operations other than precision approach, there may be serious operational restrictions depending on the capability of the equipment. While all participating States are coordinating through ICAO to ensure that SBAS provides seamless global coverage, it is important to recognize the potential ramifications if it becomes necessary for a State to approve a subset of GNSS operations. These ramifications depend upon the capability of the user equipment. For example, if the U.S. FAA were to approve WAAS operations, but not EGNOS operations:

a. Equipment with deselection capability: Equipment which provides this optional capability could deselect EGNOS in U.S. airspace. Potential implementations of this capability could be realized through parameters stored in the updatable navigation database, software modifications, or pilot interface. A pilot interface provides the most flexibility to accommodate operational needs, but requires training and is contrary to the basic operational concept for GNSS. Database implementations could link approved SBAS providers to specific procedures or regions.

b. Equipment that is designed to only use WAAS: For equipment intended to be used only in the U.S. NAS, operational restrictions can be avoided by using WAAS alone. However, this equipment could not be used where WAAS is not approved, and the potential benefits of using EGNOS or MSAS, when they are approved, would not be realized.

c. Equipment that is designed to use all SBAS providers: The operation of this equipment is consistent with the basic operational concept, but could suffer severe restrictions in the event that a State does not approve the use of another service. Users of this equipment would be forced to revert to non-GNSS navigation, or VFR flight, in the event that EGNOS were not approved in the U.S. In an environment where GNSS is the only navigation service, the economic impacts to users of this equipment could be severe.

A similar operational issue can arise for the approval of SBAS operations outside the airspace of the SBAS service provider. Throughout most of South America, WAAS equipment could use WAAS to support nonprecision approaches whenever WAAS is available. If a State chose to approve GPS operations, but not WAAS, then any equipment that does not provide the capability described in item a) would not be usable in that State's airspace.

1.4 Equipment Classes

Equipment developed to this MOPS should be identified with the applicable functional and operational equipment class (e.g., Class Beta-3) which describe the equipment capabilities. These classes are defined below.

1.4.1 Functional Classes

Class Beta. Equipment consisting of a GPS/WAAS sensor that determines position (with integrity) and provides position and integrity data to an integrated navigation system (e.g., flight management system, multi-sensor navigation system). This equipment also provides integrity in the absence of the WAAS signal through the use of Fault Detection and Exclusion (FDE).

Class Gamma. Equipment consisting of both the GPS/WAAS position sensor (defined by Class Beta) and a navigation function, so that the equipment provides path deviations relative to a selected path. The equipment provides the navigation function required of a stand-alone navigation system. This equipment also provides integrity in the absence of the WAAS signal through the use of FDE. In addition, this class of equipment requires a database, display outputs and pilot controls.

Class Delta. Equipment consisting of both the GPS/WAAS position sensor (defined by Class Beta) and a navigation function, so that the equipment provides path deviations relative to a selected path, similar to Class Gamma. However, not all of the functions provided by Class Gamma equipment are provided. In particular, Class Delta does not provide a database or direct pilot controls. The Delta class of equipment is only applicable to Class 4 precision approach, providing an ILS replacement.

Figure 1-2 shows possible architectures for the three functional classes. Functions shown in the hatched region are required for that class of equipment. The shaded regions designate functions which may or may not be included in the GPS/WAAS equipment. For example, the shaded region shown for Class Gamma indicates that the actual displays may be part of the GPS/WAAS equipment, or the displays may be separate and the GPS/WAAS equipment simply provides electrical output(s).

Note: *There are a number of integration issues associated with the installation of Class Beta equipment (such as compatibility with the navigation computer). Compatibility will have to be established for each navigation computer; the appropriate standards for determining that compatibility are not included in this standard. Class Gamma and Delta equipment can interface directly with the pilot via a display. Thus Class Gamma and Delta equipment is capable of operating as stand-alone equipment, while Class Beta equipment must be integrated with other systems. Class Beta equipment, together with the navigation computer, database, controls, and display will provide equivalent performance to Class Gamma and Delta equipment.*

1.4.2 Operational Classes

Class 1. Equipment which supports oceanic and domestic en route, terminal, nonprecision approach, and departure operation. When in oceanic and domestic en route, terminal nonprecision approach, and departure operations, this class of equipment applies the long-term and fast WAAS differential corrections when they are available.

Class 2. Equipment which supports oceanic and domestic en route, terminal, nonprecision approach, LNAV/VNAV and departure operation. When in LNAV/VNAV, this class of equipment applies the long-term, fast, and ionospheric corrections. When in oceanic and domestic en route, terminal nonprecision approach, and departure operations, this class of equipment applies the long-term and fast WAAS differential corrections when they are available.

Class 3. Equipment which supports oceanic and domestic en route, terminal, nonprecision approach, LNAV/VNAV, precision approach (APV-II, and GLS), and departure operation. When in GLS, APV-II, or LNAV/VNAV, this class of equipment applies the long-term, fast, and ionospheric corrections. When in oceanic and domestic en route, terminal nonprecision approach, and departure operations, this class of equipment applies the long-term and fast WAAS differential corrections when they are available.

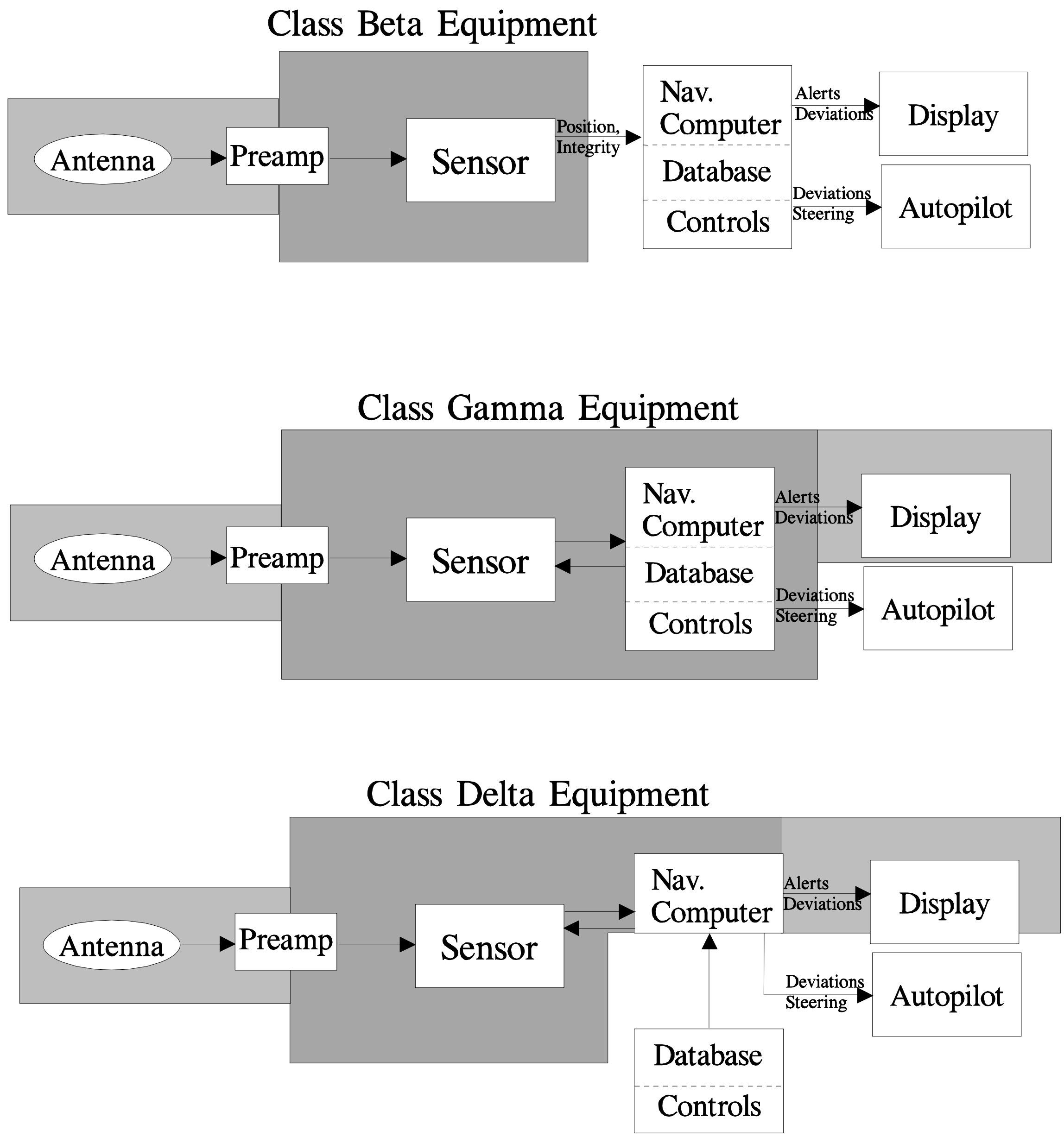


FIGURE 1-2 FUNCTIONAL CLASSES

Class 4. Equipment which supports precision approach operation. This class of equipment is intended to serve as a replacement to existing precision approach equipment such as ILS. Class 4 equipment is only applicable to functional Class Delta, and equipment which meets Class Delta-4 is also likely to meet the requirements for Class Beta-1, -2, or -3.

Note: *Class 1, 2, and 3 equipment provides navigation for both domestic and oceanic/remote area en route operation. The equipment can provide a single mode for both operations, which must satisfy all of the en route requirements. Alternatively, the equipment may provide two separate modes: an oceanic mode and a domestic en route mode. The only difference between these modes is the horizontal alert limit and the time-to-alert (Section 2.2.2.6). Unless otherwise specified, the term "en route" refers to the en route navigation mode, which can accommodate both domestic and oceanic/remote en route phases of flight.*

1.4.3 Relation of Classes to Document Organization

This MOPS addresses the requirements for Class Beta, Gamma, and Delta equipment as described by Table 1-1.

TABLE 1-1 EQUIPMENT CLASSES AND REQUIREMENTS ORGANIZATION

Section		Must be met for Equipment Class						
		Beta			Gamma			Delta
		1	2	3	1	2	3	4
2.1.1	General Requirements	Y	Y	Y	Y	Y	Y	Y
2.1.2	Requirements for En Route/ Terminal	Y	Y	Y	Y	Y	Y	
2.1.3	Requirements for Nonprecision Approach	Y	Y	Y	Y	Y	Y	
2.1.4	Requirements for LNAV/ VNAV		Y	Y		Y	Y	
2.1.5	Requirements for Precision Approach (APV-II, GLS)			Y			Y	Y
2.2.1	General Class Gamma Requirements				Y	Y	Y	
2.2.2	Class Gamma En Route/ Terminal				Y	Y	Y	
2.2.3	Class Gamma Nonprecision Approach				Y	Y	Y	
2.2.4	Class Gamma LNAV/VNAV					Y	Y	
2.2.5	Class Gamma Precision Approach (APV-II and GLS)						Y	Y
2.3	Class Delta Requirements							Y

1.5 Aiding and Multiple Sensors

As described in the last section, this MOPS describes three functional classes of GPS/WAAS equipment. Class Beta is simply a GPS/WAAS sensor. It determines pseudorange, WAAS corrected pseudorange, status of each satellite as determined by WAAS, position, and integrity on the position fix. It outputs receiver observables to be used as necessary by an integrated navigation system, such as a flight management system. Class Gamma includes all of the functions listed above, but it also includes a navigation capability and appropriate display/outputs. Class Delta consists of both the GPS/WAAS sensor and the navigation function so that the equipment provides path deviations relative to a selected path for precision approach.

A separate barometric altimeter is expected to provide vertical position during the en route, terminal area, and non-precision approach phases of flight. The altimeter will be independent of the GPS/WAAS equipment and display directly to the pilot. Optionally, the baro-altimeter may provide vertical position to the GPS/WAAS equipment as part of the vertical navigation (VNAV) capability described in Appendix F. In the case of VNAV, GPS altitude will not be factored into the vertical position solution.

Barometric altitude is expected to provide vertical position directly to the pilot for determination of the minimum descent altitudes and decision heights for both non-precision approach and precision approach. However, barometric altitude is not to be used for vertical guidance or deviation for precision approach. The use of barometric altitude and altitude rate to help insure integrity during precision approach is not precluded.

Although it is not required, the use of barometric altitude for the fault detection and exclusion (FDE) algorithm is highly recommended. Baro-aiding can significantly improve the system availability outside of the WAAS service volume (for the en route, terminal area, and non-precision phases of flight, FDE is required to be performed only when the WAAS is not providing integrity). Implementations which provide increased availability may be used and may obtain operational benefits in areas outside the WAAS service volume.

Other sensors, such as clock-aiding, Loran or inertial, may also be used as part of the FDE algorithm. Such an algorithm would need to meet all the FDE requirements. FDE algorithms which use other navigation signals external to the aircraft, such as Loran or VOR/DME, must satisfy the availability requirement without the use of the other navigation signals. The manufacturer must provide the means to test and analyze alternate FDE algorithms to demonstrate compliance.

1.6 Test Considerations

The test procedures specified in Sections 2 through 4 are intended to be used as recommended means of demonstrating compliance with the minimum acceptable performance parameters specified herein. Although specific test procedures are cited, it is recognized that other methods may be suitable. These alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

1.6.1 Environmental Tests

Environmental tests are specified in Section 2.4. These tests, like bench tests, are performed at the equipment level. The procedures and their associated limit requirements provide a laboratory means of determining the electrical and mechanical performance of the equipment under conditions expected to be encountered in actual aeronautical operations. Test results may be used by equipment manufacturers as design guidance, in preparation of installation instructions and, in certain cases, for obtaining formal approval of equipment design and manufacture.

1.6.2 Bench Tests

The test procedures specified in Section 2.5 provide a means to demonstrate equipment performance in a simulated environment. Test results may be used as design guidance for monitoring manufacturing compliance and, in certain cases, for obtaining formal approval of equipment design and manufacture.

Due to the number of possible sensor complements and position-fixing modes for this equipment, and the actual service to be provided, it is deemed impractical to define complete test procedures for all current and future equipment designs. Test procedures contained in Section 2.5 apply to the minimum system requirements in accordance with the minimum performance parameters specified in this standard.

1.6.3 Installed Tests

The installed test procedures and their associated limit requirements are in Section 3. Although bench and environmental test procedures are not a part of installed tests, their successful completion is normally a precondition to the completion of the installed tests. Installed tests are normally performed on the ground and in flight.

The test results may be used to demonstrate equipment functional performance in the environment in which it is intended to operate and with the minimum service to be provided.

1.7 Definition of Key Terms

Appendix O provides a glossary of the terms used in this document. This section expands upon the definitions of key terms in order to increase document clarity and establish a common foundation of terminology.

1.7.1 General Terms

Availability: The availability of a navigation system is the ability of the system to provide the required function and performance at the initiation of the intended operation. 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 external sources are available for use. Availability is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

Continuity: The continuity of a system is the ability of the total system (comprising all elements necessary to maintain aircraft position within the defined airspace) to perform its function without interruption during the intended operation. More specifically, continuity is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation and was predicted to operate throughout the operation.

Misleading Information: Within this standard, misleading information is defined to be any data which is output to other equipment or displayed to the pilot that has an error larger than the alert limit (HAL/VAL) or current protection level (HPL/VPL) , without any indication of the error (e.g., flag) within the time-to-alert for the applicable phase of flight. For equipment which is aware of the navigation mode, and therefore the alert limit, misleading information is defined relative to the alert limit. If the equipment is not aware of the mode, then misleading information is defined relative to the protection level, since the alert limit is not known. This includes all output data, such as position, non-numeric cross-track, numeric cross-track, and distance-to-waypoint as applicable.

Navigation Mode: The navigation mode refers to the equipment operating to meet the requirements for a specific phase of flight. The navigation modes are: oceanic/remote, en route, terminal, non-precision approach, and precision approach (including LNAV/VNAV, APV-II and GLS). The oceanic/remote mode is optional; if it is not provided, the en route mode can be substituted for the oceanic mode. In addition, departure guidance is provided by Class 1, 2 and 3 equipment in the terminal mode.

Planned Primary Means of Navigation: Planned primary means of navigation refers to the capability of planning an operation around scheduled outages so that the system is available for a particular flight and the operational continuity, integrity and accuracy requirements are met.

Primary Means of Navigation: The airborne navigation equipment that meets the requirements of radionavigation for the intended phase of flight (route to be flown). These requirements include satisfying the necessary level of accuracy, integrity, continuity, and availability for a particular area, route, procedure, or operation. Examples of systems which provide a primary means of navigation include:

a. VOR for domestic en route, terminal, and nonprecision approach where it is available;

b. VOR/DME for domestic en route above flight level 240, terminal, and nonprecision approach where it is available; and

c. INS for oceanic operation.

Required Navigation Performance (RNP): A statement of the navigation performance accuracy necessary for operation within a defined airspace. Note that there are additional requirements, beyond accuracy, applied to a particular RNP type. See RTCA/DO-236A.

1.7.2 Alert Limits and Protection Levels

Horizontal Alert Limit: The Horizontal Alert Limit (HAL) is the radius of a circle in the horizontal plane (the local plane tangent to the WGS-84 ellipsoid), with its center being at the true position, which describes the region which is required to contain the indicated horizontal position with the required probability for a particular navigation mode (e.g., $1-10^{-7}$ per flight hour for en route), assuming the probability of a GPS satellite integrity failure being included in the position solution is less than or equal to 10^{-4} per hour.

Vertical Alert Limit: The Vertical Alert Limit is half the length of a segment on the vertical axis (perpendicular to the horizontal plane of WGS-84 ellipsoid), with its center being at the true position, which describes the region which is required to contain the indicated vertical position with a probability of $1-10^{-7}$ per approach, for a particular navigation mode, assuming the probability of a GPS satellite integrity failure being included in the position solution is less than or equal to 10^{-4} per hour.

Horizontal Protection Level$_{Fault\ Detection}$: The Horizontal Protection Level$_{\text{Fault Detection}}$ (HPL_{FD}) is the radius of a circle in the horizontal plane (the local plane tangent to the WGS-84 ellipsoid), with its center being at the true position, which describes the region which is assured to contain the indicated horizontal position. It is a horizontal region for which the missed alert and false alert requirements are met for the chosen set of satellites when autonomous fault detection is used. It is a function of the satellite and user geometry and the expected error characteristics: it is not affected by actual measurements. Therefore, this value is predictable.

Vertical Protection Level$_{Fault\ Detection}$: The Vertical Protection Level$_{\text{Fault Detection}}$ (VPL_{FD}) is half the length of a segment on the vertical axis (perpendicular to the horizontal plane of WGS-84 ellipsoid), with its center being at the true position, which describes the region which is assured to contain the indicated vertical position when autonomous fault detection is used. It defines the vertical region for which the missed alert and false alert requirements are met for the chosen set of satellites when autonomous fault detection is used. It is a function of the satellite and user geometry and the expected error characteristics: it is not affected by actual measurements. Therefore, this value is predictable.

Horizontal Protection Level$_{WAAS}$: The Horizontal Protection Level$_{\text{WAAS}}$ (HPL_{WAAS}) is the radius of a circle in the horizontal plane (the plane tangent to the WGS-84 ellipsoid), with its center being at the true position, which describes the region which is assured to contain the indicated horizontal position. It is the horizontal region for which the missed alert requirement can be met. It is based upon the error estimates provided by WAAS.

Vertical Protection Level$_{WAAS}$: The Vertical Protection Level$_{\mathrm{WAAS}}$ (VPL$_{\mathrm{WAAS}}$) is half the length of a segment on the vertical axis (perpendicular to the horizontal plane of WGS-84 ellipsoid), with its center being at the true position, which describes the region which is assured to contain the indicated vertical position. It defines the vertical region for which the missed alert requirement can be met. It is based upon the error estimates provided by WAAS.

Horizontal Uncertainty Level: The Horizontal Uncertainty Level (HUL) is an estimate of horizontal position uncertainty, based on measurement inconsistency, which bounds the true error with high probability (at least 99.9 percent). This estimate will not be available if there are four or fewer measurements available (because there is no redundancy).

Vertical Uncertainty Level: The Vertical Uncertainty Level (VUL) is an estimate of vertical position uncertainty, based on measurement inconsistency, which bounds the true error with high probability (at least 99.9 percent). This estimate will not be available if there are four or fewer measurements available (because there is no redundancy).

Horizontal Exclusion Level$_{Fault\ Detection}$: The Horizontal Exclusion Level$_{\mathrm{Fault\ Detection}}$ (HEL$_{\mathrm{FD}}$) is the radius of a circle in the horizontal plane, for which the missed alert and failed exclusion requirements can be met when autonomous Fault Detection and Exclusion is used (i.e., exclusion is available). It is only a function of the satellite and user geometry and the expected error characteristics: it is not affected by actual measurements. Therefore, this value is predictable.

1.7.3 Fault Detection and Exclusion (FDE) Terms

Fault Detection and Exclusion (FDE): Fault detection and exclusion is a receiver processing scheme that autonomously provides integrity monitoring for the position solution, using redundant range measurements. The FDE consists of two distinct parts: fault detection and fault exclusion. The fault detection part detects the presence of an unacceptably large position error for a given mode of flight. Upon the detection, fault exclusion follows and excludes the source of the unacceptably large position error, thereby allowing navigation to return to normal performance without an interruption in service.

Figure 1-3 provides a diagram of the conditions associated with FDE. Figure 1-4 shows a Markov state diagram of the events associated with autonomous fault detection. Finally, Figure 1-5 shows several example scenarios that can lead to the FDE events defined below.

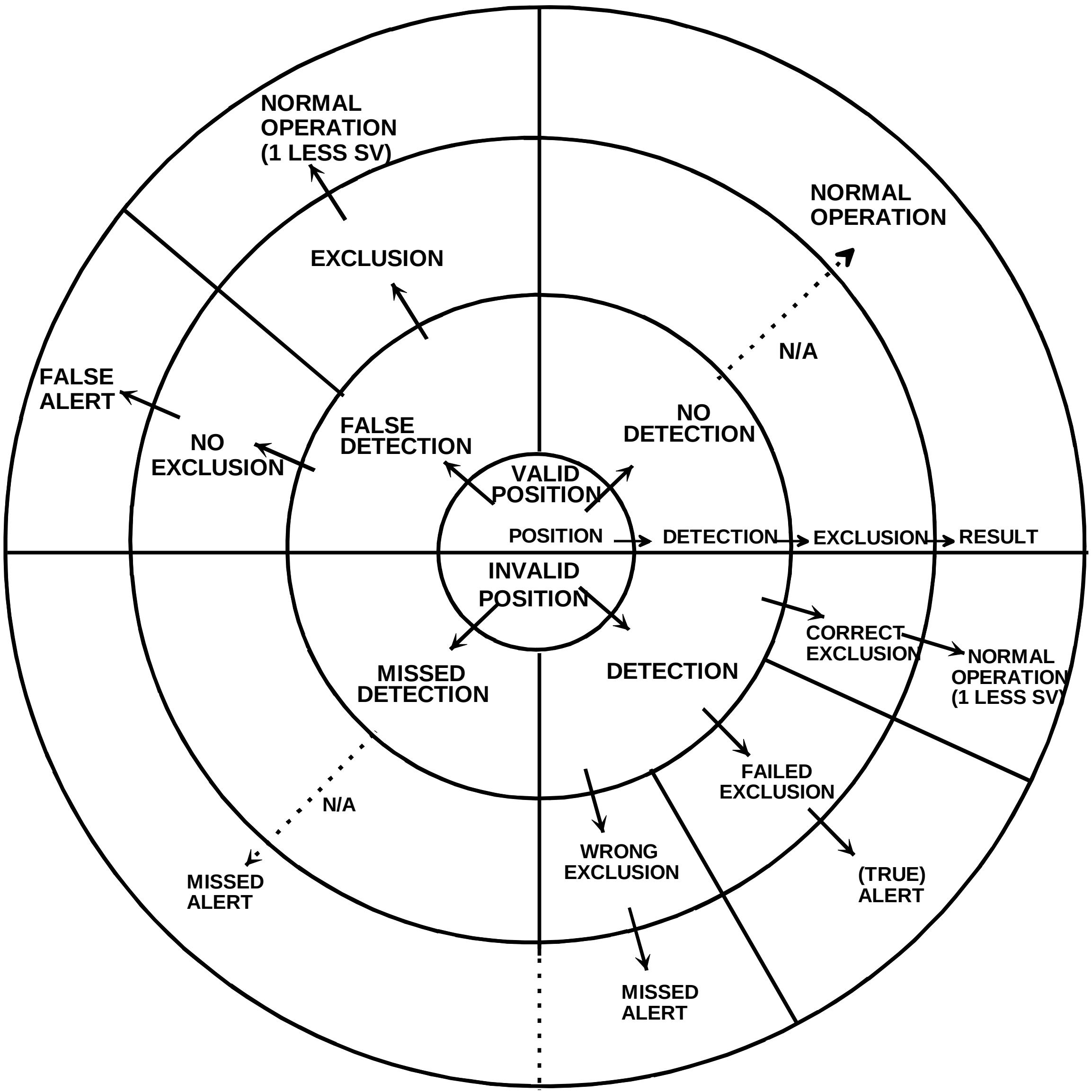
Alert: For the definitions of missed alert, false alert, and time-to-alert, an alert is defined to be an indication that is provided by the GPS/WAAS equipment when the positioning performance achieved by the equipment does not meet the integrity requirements. This alert is one of the conditions that would cause a navigation alert (ref. 2.1.1.13.2, item d).

Positioning Failure: If the equipment is aware of the navigation mode/alert limit, a positioning failure is defined to occur whenever the difference between the true position and the indicated position exceeds the applicable alert limit. If the equipment is not aware of the navigation mode/alert limit, a positioning failure is defined to occur whenever the difference between the true position and the indicated position exceeds the applicable protection level (either horizontal or vertical as applicable).

Note 1: *Additional system utility may be obtained by outputting the HUL after a positioning failure has been detected.*

Missed Detection: A missed detection is defined to occur when a positioning failure is not detected.

Note 2: *The term, missed detection, refers to internal processing of the FDE algorithm. It does not refer to an alert that is issued by the GPS/WAAS equipment.*



<u>FIGURE 1-3</u> DIAGRAM OF FDE CONDITIONS

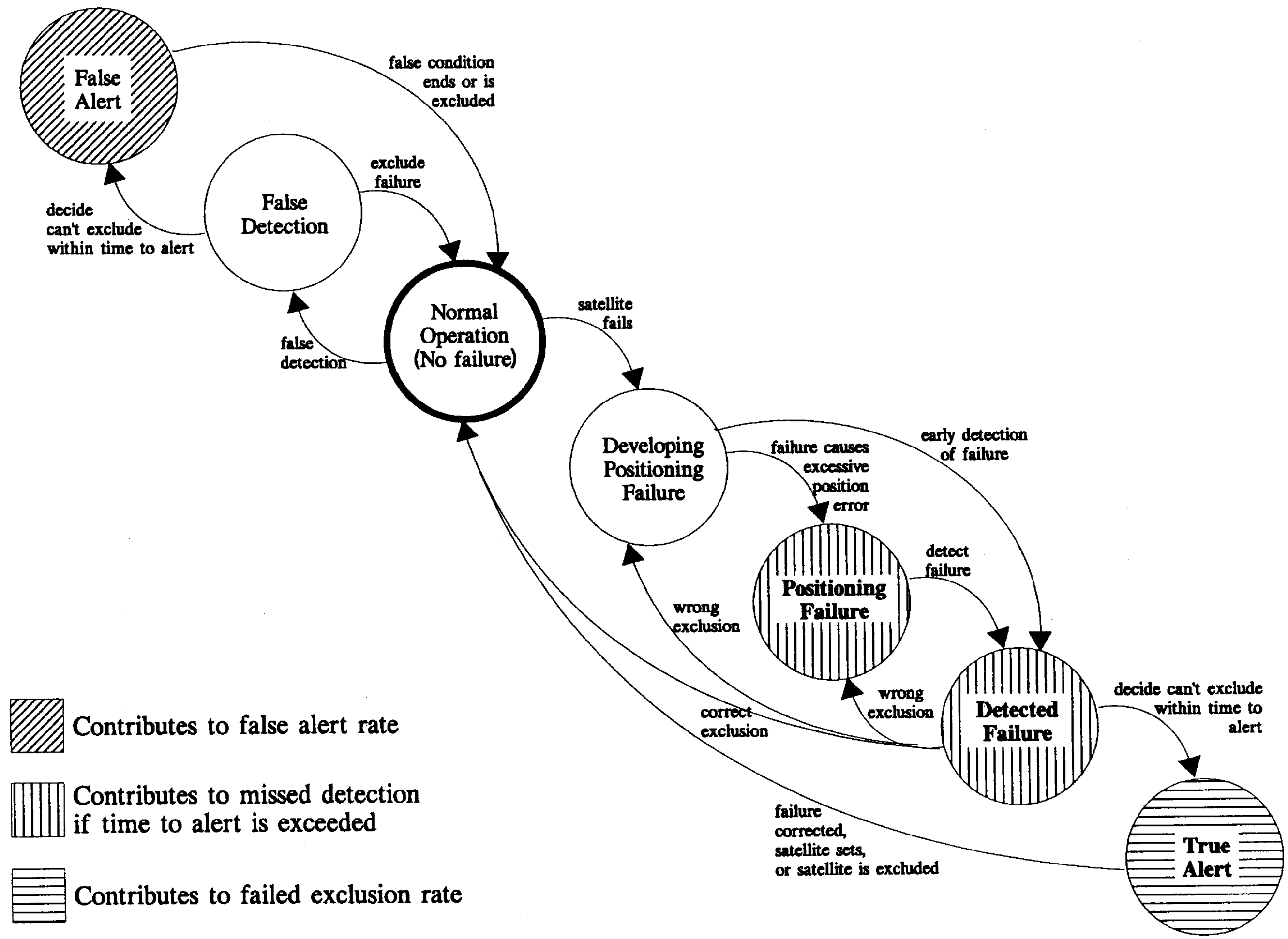
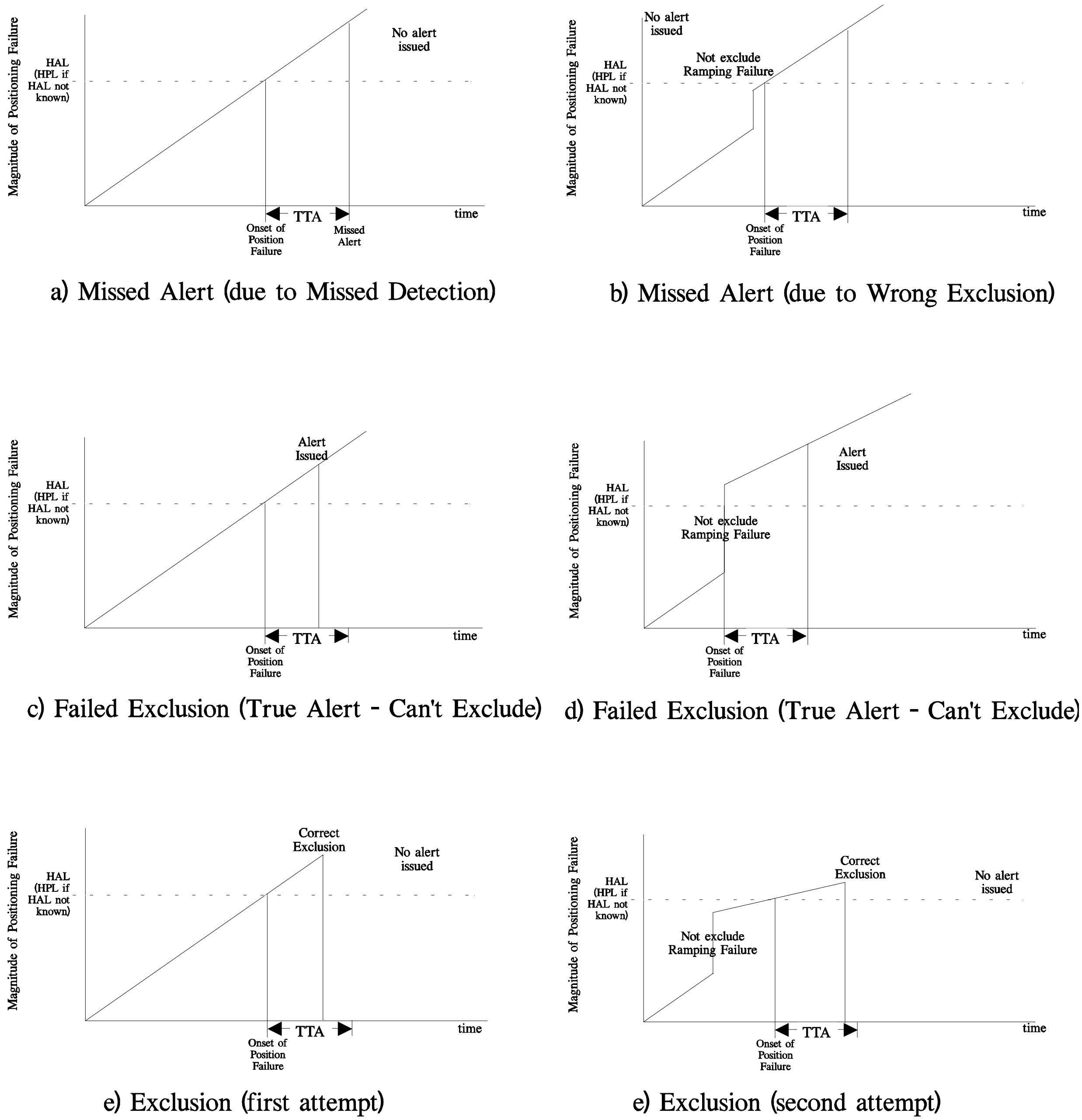


FIGURE 1-4 MARKOV CHAIN FOR FDE



<u>FIGURE 1-5</u> EXAMPLE FDE EVENTS

Time-To-Alert: Time-to-Alert is the maximum allowable elapsed time from the onset of a positioning failure until the equipment annunciates the alert.

Failed Exclusion (exclusion not possible): A failed exclusion is defined to occur when a true positioning failure is detected and the detection condition is not eliminated within the time-to-alert (from the onset of the positioning failure). A failed exclusion would cause a navigation alert.

Wrong Exclusion: A wrong exclusion is defined to occur when a detection occurs, and a positioning failure exists but is undetected after exclusion, resulting in a missed alert.

Missed Alert: Positioning failures which are not annunciated (as an alert) within the time-to-alert are defined to be missed alerts. Both missed detection and wrong exclusion conditions can cause missed alerts after the time-to-alert expires.

False Detection: A false detection is defined as the detection of a positioning failure when a positioning failure has not occurred. It is internal to the GPS/WAAS equipment.

False Alert: A false alert is defined as the indication of a positioning failure when a positioning failure has not occurred (a result of false detection). A false alert would cause a navigation alert.

Note 3: *The exclusion function may exclude a false detection internal to the GPS/WAAS equipment, which does not contribute to the false alert rate (if an alert is not issued by the GPS/WAAS equipment).*

Availability of Detection: The detection function is defined to be available when the constellation of satellites provides a geometry for which the missed alert and false alert requirements can be met on all satellites being used for the applicable alert limit and time-to-alert. When the constellation is inadequate to meet these requirements (Sections 2.1.2.2.2 and 2.1.3.2.2), the fault detection function is defined to be unavailable. Thus the availability of detection for a specific location, time, constellation and horizontal alert limit (HAL) is defined to be:

$$\text{Detection Availability (X, t, Const, HAL)} = \prod_{i=1}^{N} D(i)$$

where N = number of satellites being used by the GPS/WAAS equipment

D(i) = 1, if Pr(detection given error in ith satellite causing positioning error equal to HAL) ≥ the detection requirement and Pr (false alert) ≤ the false alert rate requirement.

0, otherwise.

Note that for a given geometry and navigation mode, the detection function is either available or unavailable.

Note 4: *The detection function is expected to operate whenever sufficient measurement redundancy exists, regardless of whether or not it is "available" for the selected navigation mode by the definition above. Therefore, it may temporarily operate when the missed alert rate is greater than required for the appropriate alert limit (i.e., HPL>HAL), but the false alert rate must continue to meet requirements.*

Availability of Exclusion: The exclusion function is defined to be available when the constellation of satellites provides a geometry for which the FDE algorithm can meet the failed exclusion requirement, and prevent the indication of a positioning failure or a loss of integrity monitoring function. Therefore, exclusion must occur before the duration of a positioning failure exceeds the time-to-alert, and the detection function as defined above must be available after exclusion.

Note that for a given geometry and a given failed satellite, the success of the exclusion function to prevent an alert condition (duration of positioning failure exceeds time-to-alert) may be probabilistic. For example: given a particular exclusion algorithm, a satellite geometry, and a failed satellite, the algorithm could have a 99% probability of successfully preventing a warning condition. However, the exclusion function is only defined to be available if the probability of excluding a satellite and preventing an alert (given a satellite failure has occurred and has been detected) satisfies the failed exclusion requirement.

Thus the availability of exclusion for a specific location, time, constellation and HAL is defined to be:

$$\text{Exclusion Availability (X, t, Const, HAL)} = \prod_{i=1}^{N} E(i)$$

where N = the number of satellites being used by the GPS/WAAS equipment

E(i) = 1, if Pr(Failed exclusion) $\leq 10^{-3}$ and detection still available after exclusion, given i^{th} satellite failed,

0, if Pr(Failed exclusion) > 10^{-3} or detection not available given i^{th} satellite failed.

Note that for a given geometry and navigation mode, the exclusion function is either available or unavailable.

Note 5: *The fact that the definition of exclusion availability states that detection is required to be available after exclusion occurs is only intended to be used as a comparison of algorithmic availability. There may be significant operational benefit gained by an algorithm that is designed such that it is capable of excluding even when detection is not available after exclusion. However, such an algorithm must still meet the missed alert (including wrong exclusion) requirement on a per failure basis. In other words, there must be a means of demonstrating that, when exclusion is attempted without subsequent detection, the equipment excludes the correct satellite with a probability of at least 0.999 (a 0.001 probability of missed alert).*

1.8 Assumptions and Approach to Selected Issues

1.8.1 General

1.8.1.1 GPS Constellation and WAAS Ground/Space Segments

It is assumed that the GPS constellation provides the accuracy and availability specified in the 1999 Federal Radionavigation Plan. It is also assumed that the GPS signals being transmitted are in conformance with the GPS SPS Performance Standard, October 2001, and ICD-GPS-200C, “Navstar GPS Space Segment/Navigation User Interfaces”, April 2000. Where it is assumed that Selective Availability (SA) is active, its effect on position accuracy remains bounded by the Federal Radionavigation Plan.

It is assumed that the WAAS-specific ground and space segments operate in accordance with the WAAS Specification FAA E-2892B, Change 2 dated August 13, 2001. It is also assumed that the signal-in-space format is in accordance with Appendix A of this document.

Note: *In the absence of SA, the availability of GPS/WAAS integrity, particularly FDE, can be dramatically increased. The GPS Signal Specification has been replaced by GPS SPS Performance Standard, October 2001, and ICD-GPS-200C, “Navstar GPS Space Segment / Navigation User Interfaces”, April 2000. SA was turned off on 1 May 2000. FDE requirements with SA in accordance with the FRP are included in Section 2.*

1.8.1.2 GPS/WAAS Performance

Initially, it is envisioned that aircraft using the GPS/WAAS signal will maintain conformance to current airway or other airspace separation requirements and to available/applicable approach and terminal instrument procedures. Over time, it is anticipated that these requirements and procedures will be revised and/or extended to take advantage of GPS/WAAS capabilities.

Note: *RTCA Special Committee 181 defined Required Navigation Performance (RNP) standards in RTCA/DO-236A,* Minimum Aviation System Performance Standards (MASPS): Required Navigation Performance (RNP) for Area Navigation (RNAV). *The requirements of this document satisfy many of the requirements specified in RTCA/DO-236A.*

1.8.1.3 Applicability

The contents of this MOPS are applicable to GPS/WAAS equipment installed in aircraft operating both within and outside of the coverage area served by the WAAS. Integrity outside of the WAAS coverage area, may be assured by use of autonomous Fault Detection and Exclusion (FDE) or through the use of Message Type 28.

1.8.1.4 Interoperability

This document specifies a standard which will provide interoperability between WAAS signals-in-space provided by the FAA and other potential international service providers and receiving equipment developed by different manufacturers. Interoperability will simplify certification procedures and permit users to obtain maximum benefit from GPS/WAAS equipage. This degree of standardization is intended to accelerate the advent of a generally available WAAS capability. In order to promote aircraft interface standardization, Appendix H provides a recommended GPS/WAAS data output standard.

1.8.1.5 Integrity Monitoring

The integrity of the GPS and WAAS geostationary satellite signals is monitored by the WAAS ground system in accordance with the WAAS Specification FAA-E-2892B, change 2, dated August 13, 2001. The airborne GPS/WAAS receiver then determines which particular sets of satellites to use in the navigation solution. The integration of FDE techniques with WAAS-provided integrity information is discussed in Section 2.1.2.2 of this document. This document assumes that the FDE requirements for GPS/WAAS sensors are driven by the need to provide a planned primary means of navigation in the event that an operation is to begin during a period of time that the WAAS is not available. Such a planned primary means of navigation will have lower availability than that supplied by the WAAS. In addition, FDE provides the necessary integrity and continuity for supplemental operations outside of WAAS coverage.

1.8.1.6 Navigational Waypoints

It is assumed that appropriate waypoints are provided to the aircraft's navigation system with sufficient accuracy and integrity for the WAAS-supported phases of operation. This document uses the term “waypoints” as a generic term to refer to navigation fixes regardless of whether they are coincident with existing navigation aids or are used as part of a published procedure. Additionally, it is assumed that when GPS/WAAS-based non-precision and precision approaches are approved for the same runway end and utilize the same Initial Approach Waypoint (IAWP), they will also have the same Intermediate Waypoint (IWP), Final Approach Waypoint (FAWP), Landing Threshold Point/ Fictitious Threshold Point (LTP/FTP), and Missed Approach Waypoint (MAWP). The use of these terms in this document is intended to provide a concise definition of these points for the manufacturers of GPS/WAAS equipment: there is no intent to replace the standard terminology already in use in the cockpit, (IAF, IF, FAF, MAP, MAHP). Further, it is assumed that the FAWP is less than 30 nautical miles from the destination airfield. The relationship between these waypoints and the navigation service provided is discussed within the mode switching requirements in Section 2.2 of this document.

> ***Note:*** *RTCA/DO-200A addresses the processing of aeronautical data. RTCA Special Committee 181 is developing a revision of RTCA/DO-201A which will address waypoint generation and distribution for all phases of operation.*

1.8.1.7 RF Interference

It is assumed that this document's specification of the RF interference environment specified in Appendix C in which GPS/WAAS sensors must operate successfully will be consistent with the real environment.

1.8.1.8 Time of Applicability of Information in the WAAS Signal-in-Space

It is assumed that the time of applicability of the differential information in the WAAS signal-in-space is the start of transmission from the WAAS GEO of the 1-second message block containing that information. It is anticipated that this start of transmission will be synchronized to the beginning of the corresponding WAAS Network Time (WNT) second (WNT is planned to be negligibly different in this regard from GPS time).

1.8.1.9 Change of Broadcast Ephemeris

It is assumed that after the broadcast ephemeris has changed, the WAAS ground segment will generate satellite corrections based on the old ephemeris for a period of time in order to ensure that all user receivers have decoded the new ephemeris.

1.8.1.10 WAAS Regional Message Type (Message Type 27 and 28)

Message Types (MT) 27 and 28 allow characterization of residual errors specific to a region. MT 27 allows an arbitrary region and associated degradation of performance to be defined. MT 28 models the residual ephemeris error, which is the only system error that has a regional impact that is not otherwise modeled. A service provider may broadcast a Type 28 message, or a Type 27 message, or neither, but not both. GPS/WAAS airborne equipment must be able to decode and use the data in both Type 27 and Type 28 messages.

1.8.2 Precision Approach Applications

1.8.2.1 WAAS Performance for Precision Approach Operations

WAAS precision approach includes the use of horizontal and vertical instrument guidance and failure monitoring. Three levels of service are defined for Class Gamma equipment:

a. GNSS Landing System (GLS) with alert limits consistent with facility Category I Instrument Landing System (ILS) at 200 ft above the threshold.

b. Approach operations with Vertical guidance (APV-II) with less stringent vertical alert limits, and

c. Lateral navigation/vertical navigation (LNAV/VNAV) approach operations with a vertical alert limit consistent with barometric VNAV.

The terminology GLS, APV-II and LNAV/VNAV has been introduced to describe the three levels of SBAS precision approach service and is consistent with the ICAO GNSS ANNEX 10 SARPs for CAT-I PA, APV-II, and APV-I, respectively. This terminology is used throughout the remainder of this document. The terms “GLS” and “LNAV/VNAV” are consistent with the FAA plans for approach publication. A naming convention for APV-II has not been proposed.

This MOPS requires that the annunciated naming convention can be stored in the navigation database since the chart naming convention for these levels of service has not been internationally standardized.

Class Beta-2 equipment provides the LNAV/VNAV capability, Class Beta-3 equipment provides all three capabilities, and Delta-4 equipment provides a GNSS Landing System (GLS) capability.

1.8.2.2 Precision Approach Path-in-Space

Precision approach path-in-space accuracy and integrity requirements for GPS/WAAS precision approaches are discussed in Section 2.2.4 for LNAV/VNAV and Section 2.2.5 for GLS and APV-II. These requirements presume that path-in-space creation is accomplished using a process, which assures high accuracy and integrity of source information for the GPS/WAAS equipment. Integrity of data distribution is accomplished through the use of the standard CRC algorithm described in Section 2.2.4 for LNAV/VNAV and Section 2.2.5 for GLS and APV-II (the format of data defining the path-in-space for the Final Approach Segment of a GPS/WAAS precision approach is presented in Appendix D).

1.8.2.3 LNAV/VNAV and Precision Approach Position Integrity

Horizontal and vertical protection level estimates developed using the WAAS signal-in-space (HPL_{WAAS} and VPL_{WAAS}) and autonomous fault detection (HPL_{FD} and VPL_{FD}), as described in Appendix J, are used to assure GPS/WAAS integrity during precision approach operations. The use of autonomous fault detection as described in Appendix E assures GPS/WAAS integrity with acceptable GPS/WAAS continuity, particularly in the presence of geographically-localized (e.g., atmospheric) phenomena which cannot be fully modeled by the WAAS ground segment.

The approach capability will be calculated by the GPS/WAAS airborne equipment prior to the aircraft reaching the FAWP. As long as this capability is adequate, the approach may be initiated. The avionics will then iteratively compute (1) aircraft position and a corresponding Vertical Alert Limit (VAL); (2) VPL_{WAAS}; and (3) VPL_{FD}. The approach can be continued unless either VPL_{WAAS} becomes greater than VAL or a fault is detected by the fault detection algorithm. A similar process will be followed in the horizontal dimension.

1.8.2.4 Vector-to-Final (VTF) Precision Approach

This document introduces the concept of a VTF approach for Class Gamma equipment. Although GPS/WAAS equipment can provide precision guidance relative to a complete approach procedure, it is sometimes advantageous to intercept the final approach segment of the procedure. This capability is inherent in ILS, where the path in space is fixed and the aircraft simply captures that path.

GPS/WAAS equipment provides equivalent functionality with the VTF approach. If the aircraft is vectored to the final approach segment, the pilot selects a VTF approach, which causes the equipment to discontinue using the published procedure and provide guidance relative to the (extended) final approach segment. It is anticipated that the aircraft will be vectored to intercept that approach in the same fashion aircraft are currently vectored to intercept ILS.

In addition to this capability to intercept the final approach segment, GPS/WAAS equipment can circumvent any portion of a procedure as necessary through the use of the Direct-To function.

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2 EQUIPMENT PERFORMANCE AND TEST PROCEDURES

2.1 General Requirements

The requirements of this section apply to Class Beta, Class Gamma, and Class Delta equipment (see Table 1-1). Section 2.1.1 applies to all equipment and all navigation modes, while Sections 2.1.2 through 2.1.5 define the additional requirements for the en route/terminal mode, nonprecision approach mode, and precision approach (including LNAV/VNAV, GLS and APV-II) mode. GPS/WAAS equipment must meet all of the requirements for the applicable navigation modes, depending on the Operational Class**.**

2.1.1 Requirements Applicable to Beta, Gamma, and Delta Equipment

2.1.1.1 General Requirements for All Navigation Modes

2.1.1.1.1 Airworthiness

Design and manufacture of the airborne equipment shall support installation so as not to impair the airworthiness of the aircraft.

2.1.1.1.2 General Performance

The equipment shall perform its intended function, as defined by this MOPS and the manufacturer.

2.1.1.1.3 Fire Resistance

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

2.1.1.1.4 Equipment Interfaces

The interfaces with other aircraft equipment shall be designed such that, properly installed with adequately designed other equipment, normal or abnormal GPS/WAAS equipment operation shall not adversely affect the operation of other equipment nor shall normal or abnormal operation of other equipment adversely affect the GPS/WAAS equipment except as specifically allowed.

2.1.1.1.5 Effects of Test

The design of the equipment shall be such that the application of the specified test procedures shall not produce a condition detrimental to the performance of the equipment, except as specifically allowed in this MOPS.

2.1.1.2 GPS Signal Processing Requirements

GPS/WAAS equipment shall be designed to process the GPS signals and necessary data described in the latest GPS SPS Performance Standard, October 2001, and ICD-GPS-200C, “Navstar GPS Space Segment / Navigation User Interfaces”, April 2000, under interference conditions described in Appendix C and under the minimum signal conditions defined in Section 2.1.1.10. If the ionospheric corrections provided by the WAAS are not applied to a pseudorange, then the equipment shall decode the ionospheric coefficients in the GPS navigation message and apply the ionospheric corrections described in the ICD-GPS-200C, “Navstar GPS Space Segment / Navigation User Interfaces”, April 2000. If the ionospheric corrections provided by WAAS are applied to a satellite pseudorange, the GPS ionospheric model shall not be used for that satellite. A tropospheric correction shall be applied (an acceptable algorithm is described in Appendix A, Section A.4.2.4).

GPS satellite navigation data shall be continuously decoded. Except for "not healthy" information (as defined in Section 2.1.1.5.5), new clock and ephemeris data (subframes 1, 2 and 3 of the GPS navigation message) shall not be used until the data is verified by reception of a second message containing the same data. Ionospheric data (subframe 4) shall not be used until the data is verified by reception of a second message, potentially from a different satellite, containing the same data. The WAAS equipment shall apply the satellite clock correction (including relativistic corrections) derived from the clock parameters in subframe 1 of the GPS navigation message after smoothing the pseudorange measurement (if applicable).

In addition, the equipment shall not mistake one GPS satellite for another due to cross-correlation during acquisition or reacquisition. An acceptable means of preventing cross-correlation effects during acquisition is to reject GPS satellite ranging data if there is a 3000 km separation between satellite positions derived from the almanac and broadcast ephemerides. An acceptable means of preventing cross-correlation effects during reacquisition is to accomplish the screen test described in Appendix I.

Note: *Equipment should be able to track satellites under conditions of ionospheric scintillation that could occur during solar maximum at auroral and equatorial latitudes. There is insufficient information to characterize scintillation and define appropriate requirements and tests for inclusion in this MOPS. However, equipment should be able to track satellites through phase jitter and amplitude fading that can result from scintillation. New requirements may be defined when ionospheric effects can be adequately characterized.*

2.1.1.3 WAAS Signal Processing Requirements

2.1.1.3.1 Acquisition and Track

The GPS/WAAS equipment shall be designed to acquire and track the SBAS PRN codes as described in Appendix A, paragraph A.3.3, at power levels as described in A.2.6.5, and under interference conditions described in Appendix C and under the minimum signal conditions defined in Section 2.1.1.10. Paragraph A.3.4 describes two methods for accomplishing this function.

If the ionospheric corrections provided by the WAAS are not applied to a pseudorange, then the equipment shall decode the ionospheric coefficients in the GPS navigation message and apply the ionospheric corrections described in the ICD-GPS-200C, “Navstar GPS Space Segment / Navigation User Interfaces”, April 2000. If the ionospheric corrections provided by WAAS are applied to a satellite pseudorange, the GPS ionospheric model shall not be used for that satellite. A tropospheric correction shall be applied (an acceptable algorithm is described in Appendix A, Section A.4.2.4).

In addition, when using a WAAS satellite for ranging, the equipment shall not mistake one WAAS satellite for another due to cross-correlation during acquisition or reacquisition. An acceptable means of preventing cross-correlation effects during acquisition is to reject WAAS satellite ranging data if there is a 200 km separation between the satellite positions derived from most recent almanac (received within 15 minutes) and the broadcast ephemerides. An acceptable means of preventing cross-correlation effects during reacquisition is to accomplish the screen test described in Appendix I.

Note: *The equipment shall not use SBAS PRN codes other than those specified in Table A-1 of Appendix A.*

2.1.1.3.2 Demodulation and Forward Error Correction (FEC) Decoding

The GPS/WAAS equipment shall be designed to demodulate the signals described in the WAAS Signal Specification, paragraph A.2.3. The embedded forward error correction shall be applied in order to minimize data errors in the decoded messages.

The equipment shall not utilize any message for which the Cyclic Redundancy Check described in Appendix A, paragraph A.4.3.3, does not check.

The WAAS message loss rate shall be less than 1 message in 10^3 for the interference conditions described in Appendix C and under the minimum signal conditions defined in Section 2.1.1.10.

Note: *Testing of this requirement will require an output of whether or not the CRC for a message has failed, in order to determine the message loss rate.*

2.1.1.3.3 WAAS Satellite Pseudorange Determination

The GPS/WAAS equipment shall determine the pseudorange to each WAAS satellite that is currently being used in the position computation. These pseudoranges shall be referenced to the same time base as that of the GPS satellites. The equipment shall account for earth rotation in determining the pseudorange. If the ionospheric corrections provided by the WAAS are not applied to the WAAS satellite pseudoranges, then the equipment shall decode the ionospheric coefficients in the GPS navigation message and apply the ionospheric corrections described in ICD-GPS-200C, “Navstar GPS Space Segment / Navigation User Interfaces”, April 2000. A tropospheric correction shall be applied (an acceptable algorithm is described in Appendix A, Section A.4.2.4).

2.1.1.4 WAAS Message Processing

Message Types 0, 1, 2, 3, 4, 5, 6, 7, 9, 17, 24, 25, 27, and 28 shall be utilized in all navigation modes. Additional message requirements for precision approach mode (including LNAV/VNAV, GLS and APV-II) are defined in 2.1.4.9, and 2.1.5.9. Any such messages may optionally be used in modes for which they are not specifically required, but shall then conform to the relevant requirements. If an optional message is used, the loss of those messages shall not cause loss of function. For example, if WAAS ionospheric corrections are used during a nonprecision approach, timeout of those corrections should result in reversion to the GPS ionospheric model as described in Section 2.1.1.2. Message Types the equipment is not specifically designed to decode shall be ignored.

Note: *It is recommended that equipment apply WAAS ionospheric corrections whenever available and monitored.*

2.1.1.4.1 Message Type 0 — Don't Use for Safety Applications

The receipt of a Message Type 0 shall result in the cessation of the use and discarding of any ranging data and all message types 1-7, 9-10, 18, 24-28 obtained from that WAAS signal (PRN code). Other message types may be retained, such as message type 17, for potential performance enhancements. In addition, that WAAS signal (PRN code) shall be deselected for at least one minute. (See Appendix A, Section A.4.4.1.)

Notes: ***1.*** *Message Type 0's will be used during testing of a new WAAS satellite, and could be used if the WAAS ground system determined that there was a problem in the signals or data already transmitted. In the end-state WAAS there will be at least one other WAAS satellite in view for the GPS/WAAS equipment to use. This message applies to a particular PRN signal; it does not apply to the satellite itself as there could be more than one signal broadcast by a satellite.*

2. *If a Message Type 0 is being broadcast, no particular level of integrity is guaranteed. When WAAS is testing, Type 2 messages will not be broadcast; instead, the contents of a Type 2 message will be provided in the Type 0 message. Other service providers may broadcast both Type 0 and Type 2 messages during testing. The non-safety-of-life user can use the data at the user's own risk.*

2.1.1.4.2 Message Type 1 — PRN Mask Assignments

The GPS/WAAS equipment shall be able to store and use two PRN masks per GEO PRN signal. It shall be able, during the transition period between masks, to use corrections with different IODPs simultaneously. This prevents any interruption of service during the PRN mask switching. (See Appendix A, Section A.4.4.2.)

2.1.1.4.3 Message Types 2-5 and 24 — Fast Clock Corrections

All classes of equipment shall decode Message Types 2, 3, 4, 5 and 24. Neither integrity nor correction data shall be utilized for any satellite unless the IODP matches the IODP obtained from a Type 1 message. (See Appendix A, Sections A.4.4.3 and A.4.4.8.)

The equipment shall determine and apply the fast clock corrections for all WAAS HEALTHY satellites being used in the position solution.

2.1.1.4.4 Message Type 6 — Integrity Information

All classes of equipment shall decode Message Type 6. The GPS/WAAS equipment shall decode the UDREI for use in determining the integrity of the corrected position. Four $IODF_j$'s are broadcast, one for each fast corrections message type (2-5). If an $IODF_j$ is equal to 3 in an integrity (type 6) message, the equipment shall utilize the UDREs regardless of the $IODF_j$ in the associated type 2-5, 24 message. If the $IODF_j$ is less than 3 in an integrity message, the equipment shall use the σ_{UDRE}s only if the $IODF_j$ matches the IODF in the associated fast corrections message (type 2-5 or 24). (See Appendix A, Section A.4.4.4.) When interpreting a type 6 message, the user equipment shall use the most recently received PRN mask for which corrections have been received.

2.1.1.4.5 Message Type 7 — Fast Correction Degradation

The GPS/WAAS equipment shall decode Message Type 7 and determine the timeout interval for fast corrections. (See Appendix A, Section A.4.4.5.)

2.1.1.4.6 Message Type 9 — WAAS Satellite Navigation Message

The GPS/WAAS equipment shall utilize the navigation information contained in Message Type 9, which contains WAAS satellite orbit information, to determine the location of each WAAS satellite being tracked. The equipment shall always use the most recent Message Type 9. (See Appendix A, Section A.4.4.11.)

2.1.1.4.7 Message Type 17 — WAAS Satellite Almanac

The most recent almanac data for at least two WAAS satellites above the minimum mask angle, if available, shall be stored in order to support rapid acquisition of a new WAAS satellite. (See Appendix A, Section A.4.4.12.)

2.1.1.4.8 Message Type 27 — WAAS Service Message

The GPS/WAAS equipment shall examine the information contained in all Type 27 messages, if broadcast, to determine the δUDRE factor applicable to the user location. The GPS/WAAS equipment shall use the applicable δUDRE factor to inflate the fast and long-term correction residual variances (σ^2_{flt}) as described in Appendix J (J.2.2). (Reference: A.4.4.13, A.4.5.1, and J.2.2.)

The data in a Type 27 message shall be retained for the time-out interval in Table 2-1, even after power-off. If a Type 27 message with a new IODS indicates a higher δUDRE for the user location, the higher δUDRE shall be applied immediately. A lower δUDRE in a new Type 27 message shall not be used until the complete set of messages with the new IODS has been received. Once the complete set of Type 27 messages with a given IODS has been received, all previously received Type 27 messages with different IODS shall be discarded.

Notes: **1.** *WAAS and MSAS will not broadcast the Type 27 message. EGNOS plans to broadcast the Type 27 message.*

2. *Type 27 messages are optional on the part of SBAS service providers and may not be broadcast.*

2.1.1.4.9 Message Timeout Periods

WAAS equipment shall only use data until it has timed out. The beginning of the timeout interval is the end of the reception of a message. The timeout intervals are a function of the navigation mode. Timeout intervals are given in Table 2-1. The timeout interval for fast corrections is a function of the fast corrections degradation factor broadcast in a Type 7 message and the navigation mode of the equipment, as shown in Table 2-2. The most recently decoded a_{ij} shall apply. The WAAS ground system will adjust the maximum fast correction broadcast interval to ensure that fast corrections do not time-out prematurely. Those data items which do not timeout shall continue to be used until replaced. For PRN and ionospheric masks, the equipment must retain the new and old versions of the masks to accomplish a smooth mask transition (see Section A.4.4.2 and A.4.4.9).

<u>TABLE 2-1</u> TIMEOUT INTERVALS

Data	Associated Message Types	En route, Terminal, NPA Timeout (seconds)	Precision Approach Timeout (seconds)
Don't Use for Safety Applications	0	N/A*	N/A*
PRN Mask	1	600	600
UDREI	2-6, 24	18	12
Fast Corrections	2-5, 24	Variable**	Variable**
Long Term Corrections	24, 25	360	240
GEO Navigation Data	9	360	240
Fast Correction Degradation	7	360	240
Degradation Parameters	10	360	240
Ionospheric Mask	18	1200	1200
Ionospheric Corrections, GIVEI	26	600	600
Service Level	27	86,400	86,400
Clock-Ephemeris Covariance Matrix	28	360	240
Timing Data	12	86,400	86,400
Almanac Data	17	None	None

* Reception of a Type 0 message results in cessation of the use and discarding of any ranging data and all message types 1-7, 9-10, 18, 24-28 obtained from that WAAS signal (PRN code).

** The timeout interval for fast corrections is a variable, depending upon the fast corrections degradation factor (Type 7 message). The maximum fast correction broadcast interval must be adjusted per <u>Table 2-2</u>, to ensure that fast corrections do not time-out prematurely causing a loss of continuity.

<u>TABLE 2-2</u> FAST CORRECTION USER TIME-OUT INTERVAL EVALUATION

Fast Corrections Degradation Factor Indicator (ai_j)	**En Route through NPA User Time-Out Interval for corrections - seconds**	**PA User Time-Out Interval for corrections - seconds**	**Maximum Fast Correction Update Interval (seconds)**
0	180	120	60
1	180	120	60
2	153	102	51
3	135	90	45
4	135	90	45
5	117	78	39
6	99	66	33
7	81	54	27
8	63	42	21
9	45	30	15
10	45	30	15
11	27	18	9
12	27	18	9
13	27	18	9
14	18	12	6
15	18	12	6

2.1.1.4.10 Combining Data from Separate Broadcasts

In precision approach mode, corrections and integrity data for all satellites shall be obtained from the same WAAS signal (PRN code). Otherwise, corrections for satellites may be obtained from different WAAS signals (PRN codes) (including signals from different SBAS service providers, e.g., EGNOS or MSAS). If data from multiple WAAS satellites are used, then the equipment shall account for differences in the time reference used to generate corrections (e.g., WAAS network time as achieved by each satellite). For each individual GPS or WAAS satellite, the fast correction, σ^2_{UDRE}, long-term corrections, ionospheric correction, σ^2_{GIVE}, fast correction degradation factor δUDRE, and any Type 10 message degradation factors used shall be derived from a single WAAS signal (PRN code).

Ranging measurements from multiple WAAS satellites may be used in the position solution.

Note: *The difference in WNT may be solved for or the uncertainties in the ranges may be inflated to account for the WNT differences. An acceptable method for accounting for the WNT differences is to increase the uncertainty on one of the satellite's data by the equivalent of 100 nanoseconds - +50 nanoseconds for the first WAAS signal (PRN code) and –50 nanoseconds for the second WAAS signal (PRN code).*

2.1.1.4.11 Message Type 24 and 25 Long-Term Corrections and Message Type 9 GEO Navigation Data

The GPS/WAAS equipment shall decode Message Types 24 and 25 and determine and apply the long-term clock corrections for all satellites being used in the position solution or FDE algorithm, except for the SBAS satellites operated by the same service provider as the satellite providing corrections. When using SBAS satellites operated by the same service provider as the satellite providing corrections, the GPS/WAAS equipment shall decode Message Type 9 and determine and apply the GEO navigation data, in lieu of long-term corrections, to the SBAS geostationary satellite. When using other SBAS satellites operated by a different service provider, the equipment shall decode the Message Type 9 from that satellite and a Message Type 24 or 25 long term correction from the satellite providing corrections and apply both. Long term correction data shall not be utilized for any satellite unless the IODP matches the IODP obtained from a Type 1 Message. For GPS satellites, the equipment shall compare the Issue of Data (WAAS IOD) in the WAAS Type 24 or 25 Messages for each GPS satellite with the IODE of that GPS satellite being utilized by the equipment. There are three possible outcomes:

a. The WAAS IOD and GPS IODE match (the normal condition), in which case the WAAS correction shall be applied using the current GPS IODE to compute satellite position;

b. The WAAS IOD and GPS IODE do not match, but the WAAS IOD matches the previous GPS IODE (a condition which will happen for a few minutes each hour), in which case the WAAS corrections shall be applied using the previous GPS IODE to compute satellite position;

c. They do not match, nor does the WAAS IOD match the previous GPS IODE (a rare condition), then the equipment shall not apply the fast or long-term correction.

The equipment shall retain old ephemeris information for at least 5 minutes, or until a match between WAAS IOD and GPS IODE is obtained. Long term corrections shall not be applied without active fast corrections.

Note 1: *The requirement to retain old ephemeris information for 5 minutes requires that at least three sets of broadcast ephemeris may be stored, as GPS satellite data can be updated twice within a five minute interval.*

The airborne equipment shall use the active long term correction with latest time of applicability which is less (earlier) than the current time whenever possible. If long term corrections are received with a time of applicability in the future, those corrections should not be used until: (1) the current time equals the time of applicability; or (2) the previous long term corrections time out.

Note 2: *The WAAS will generate each satellite correction based on the old ephemeris for approximately two minutes after the GPS broadcast ephemeris has changed, in order to ensure that the user equipment has decoded the new ephemeris. During this period, the GPS/WAAS equipment needs to retain the old ephemeris in order to ensure that the pseudorange measurement and the long-term correction for that satellite are based on the same ephemeredes.*

2.1.1.4.12 Application of Differential Corrections

If the equipment filters code or Doppler measurements in developing a pseudorange estimate, the differential corrections shall be applied after filtering, and immediately before computing a position. Long term, fast and range rate corrections shall be applied when available. When any of these corrections are not available (during data initialization), the model variance of the residual error shall be as defined in Section J.2.2.

Since there are no Range-Rate Corrections (RRCs) broadcast directly by the WAAS, each equipment shall compute these from the WAAS Message Type 2-5 and 24 data. The RRC is computed by differencing fast corrections as described in Section A.4.4.3.

The equipment shall correct the pseudorange as:

$$PR_{i,corrected}(t) = PR_{i,measured}(t) + PRC_i(t_{i,of}) + RRC_i(t_{i,of}) \times (t - t_{i,of})$$

The clock offset error correction and clock drift error correction shall be computed from the information in Message Types 24 and 25 in accordance with Appendix A, Section 4.4.7, and added to the t_{SV} term obtained from the satellite navigation data message.

2.1.1.4.13 Message Type 28 — Clock-Ephemeris Covariance Matrix Message

The GPS/WAAS equipment shall examine the information contained in Type 28 messages to determine the δUDRE factor applicable to the user location. The GPS/WAAS equipment shall use the applicable δUDRE factor to calculate the fast and long-term residual variances (σ^2_{flt}) as described in Appendix J (J.2.2). (Reference: A.4.4.16, A.4.5.1, and J.2.2.) If a Type 28 message has been received for any satellite, and is still active, then UDREIs for satellites without an active Type 28 message shall not be used (therefore the variance of the residual error is as defined in Appendix J.2.2) unless the UDREIs indicate “Don’t Use” or “Not Monitored”. If there is no active Type 28 message, all the δUDRE terms are defined to be 1 (unless a Type 27 message has been received).

The Type 28 message data shall not be utilized for any satellite unless the IODP matches the IODP obtained from a Type 1 message. (See Appendix A, Section A.4.4.3.)

2.1.1.5 Satellite Integrity Status

The GPS/WAAS equipment shall designate each GPS and WAAS satellite as WAAS UNHEALTHY, WAAS UNMONITORED, or WAAS HEALTHY as defined in Sections 2.1.1.5.2 through 2.1.1.5.4. The order of precedence is as listed. The GPS/WAAS equipment shall also designate each satellite as GPS HEALTHY or GPS UNHEALTHY, as defined in Sections 2.1.1.5.5 and 2.1.1.5.6. The latency of this designation must be consistent with the requirements of Sections 2.1.1.13 and 2.1.4.12.

2.1.1.5.1 Step Detector

The GPS/WAAS equipment shall detect a pseudorange step greater than 700 meters on any satellite used in the position solution, including steps which cause loss of lock for less than 10 seconds. A pseudorange step can be caused by:

a. A change in navigation data; or

b. A sudden change in the code phase.

The equipment shall falsely declare a pseudorange step less frequently than 10^{-5}/flight hour. If the equipment is capable of recovering a satellite after a step error has been declared, the declaration of a pseudorange step shall only be cleared if it is verified through autonomous fault detection.

An example step detector algorithm is defined in Appendix I.

Note: *The manufacturer is free to choose any method to detect step errors. However, any method used should properly take into account satellite movement and aircraft dynamics.*

2.1.1.5.2 WAAS UNHEALTHY Designation

The GPS/WAAS equipment shall designate any GPS or WAAS satellite as WAAS UNHEALTHY upon the occurrence of any of the following conditions:

- The equipment has successfully decoded a UDREI of 15, indicating that the WAAS has assessed the satellite’s signal as unusable;
- The step detection function has declared a step error;

- For WAAS satellites, user range accuracy index of 8 or more; or
- For WAAS satellites, failure of parity on 4 successive messages.

The WAAS UNHEALTHY status for that satellite shall be changed only after the condition has cleared (including time-out of UDREI data) and none of the above conditions exist. When a WAAS satellite is designated as UNHEALTHY due to any one of the above conditions, the integrity and correction data can continue to be applied (subject to the timeout requirements in Section 2.1.1.4.9).

Note: *Although not considered WAAS UNHEALTHY, satellites with UDREI≥12 cannot be used for GLS, APV-II, or LNAV/VNAV (see sections 2.1.4.9.1 and 2.1.5.9).*

2.1.1.5.3 WAAS UNMONITORED Designation

The GPS/WAAS equipment shall designate any GPS or WAAS satellite as WAAS UNMONITORED upon the occurrence of any of the following conditions (if not designated as WAAS UNHEALTHY):

- WAAS UDREI=14 ("Not Monitored");
- WAAS data is not provided (satellite not in mask);
- WAAS signals are not being received (affects all satellites);
- WAAS data has timed out; or
- If using long-term corrections, WAAS IOD and GPS IODE cannot be reconciled, as described in 2.1.1.4.11.

The WAAS UNMONITORED status for that satellite shall be changed only after the condition has cleared and none of the above conditions exist.

2.1.1.5.4 WAAS HEALTHY Designation

A GPS or WAAS satellite shall be designated as WAAS HEALTHY if the following conditions are both met and if not designated as WAAS UNHEALTHY or WAAS UNMONITORED:

- The step detection function has not declared a step error; or
- The equipment has not received a UDREI of 14 or 15 for the satellite;

Note: *The WAAS may declare a satellite as usable under some conditions even when the GPS navigation message indicates the satellite is unhealthy. For example, the GPS satellite may be declared unhealthy for P(Y)-code reasons while the C/A-code is operating normally. In such a case the user may utilize the satellite in any mode of navigation.*

2.1.1.5.5 GPS UNHEALTHY Designation

The GPS/WAAS equipment shall designate any GPS satellite as GPS UNHEALTHY if the GPS satellite navigation message meets any of the following conditions:

- 6 bit health word in subframe 1: all cases where MSB="1" except when other bits are "11101", indicating that the satellite will be out of service but is not at this time (ref. 20.3.3.3.1.4 and 20.3.3.5.1.3 of ICD-GPS-200C, “Navstar GPS Space Segment / Navigation User Interfaces”, April 2000.;
- Failure of parity on 5 successive words (3 seconds);
- Broadcast IODE does not match 8 least-significant bits of broadcast IODC;
- User range accuracy index of 8 or more;

- Bit 18 of the HOW set to 1(Ref. 20.3.3.2 of ICD-GPS-200C, “Navstar GPS Space Segment / Navigation User Interfaces”, April 2000.);
- All bits in subframe 1, 2, or 3 are 0's;
- Default navigation data is being transmitted in subframes 1, 2, or 3 (ref. 20.3.3.2 of ICD-GPS-200C, “Navstar GPS Space Segment / Navigation User Interfaces”, April 2000.); or
- The preamble does not equal 8B (hexadecimal) or 139 (decimal).

The GPS UNHEALTHY status for a satellite shall be changed only after the condition has cleared.

Note: *The condition of failure of parity on 5 successive words is intended to avoid processing an interfering signal by mistake.*

2.1.1.5.6 GPS HEALTHY

The GPS/WAAS equipment shall designate any GPS satellite as GPS HEALTHY if it does not satisfy any of the criteria listed under Section 2.1.1.5.5 (if not designated as GPS UNHEALTHY).

2.1.1.6 Satellite Selection

The equipment shall monitor the data broadcast of at least one WAAS signal (PRN code) that is providing valid integrity information, if one is available. The equipment should select the best WAAS signal (PRN code), taking into account the correction and integrity information that is being provided.

Note: *Selecting the WAAS satellite with the highest elevation angle is normally sufficient. However, a satellite with the highest elevation angle may not be broadcasting corrections on a large number of or even any satellites or any ionospheric grid points visible to a user, while a satellite with a lower elevation angle may be providing the required data.*

To ensure continued performance in the event of loss of the WAAS signal (PRN code), it is recommended that a second WAAS signal (PRN code) from the same SBAS service provider be monitored, if available. Two PRN codes may be broadcast from the same GEO.

GPS/WAAS equipment shall automatically select satellites for use in the navigational computation, and, if the FDE algorithm is being applied, for use in the FDE algorithm itself.

The equipment shall not utilize any satellite designated WAAS UNHEALTHY. A WAAS HEALTHY designation shall override a GPS UNHEALTHY designation, except that a GPS satellite designated as GPS UNHEALTHY due to failure of parity on five successive words or due to default navigation data shall not be used.

The GPS/WAAS equipment shall select: (1) a set of satellites that can satisfy the performance requirements of the navigation mode; or (2) a set of satellites that provide the smallest HPL or VPL; or (3) select satellites as shown in Figure 2-1.

When a change to the selected set of satellites is necessary, the GPS/WAAS equipment shall accomplish this change within the time-to-alert (6 seconds for precision approach mode, or as specified in section 2.1.2.2.2.2.1 or 2.1.3.2.2.2.1 for other operations).

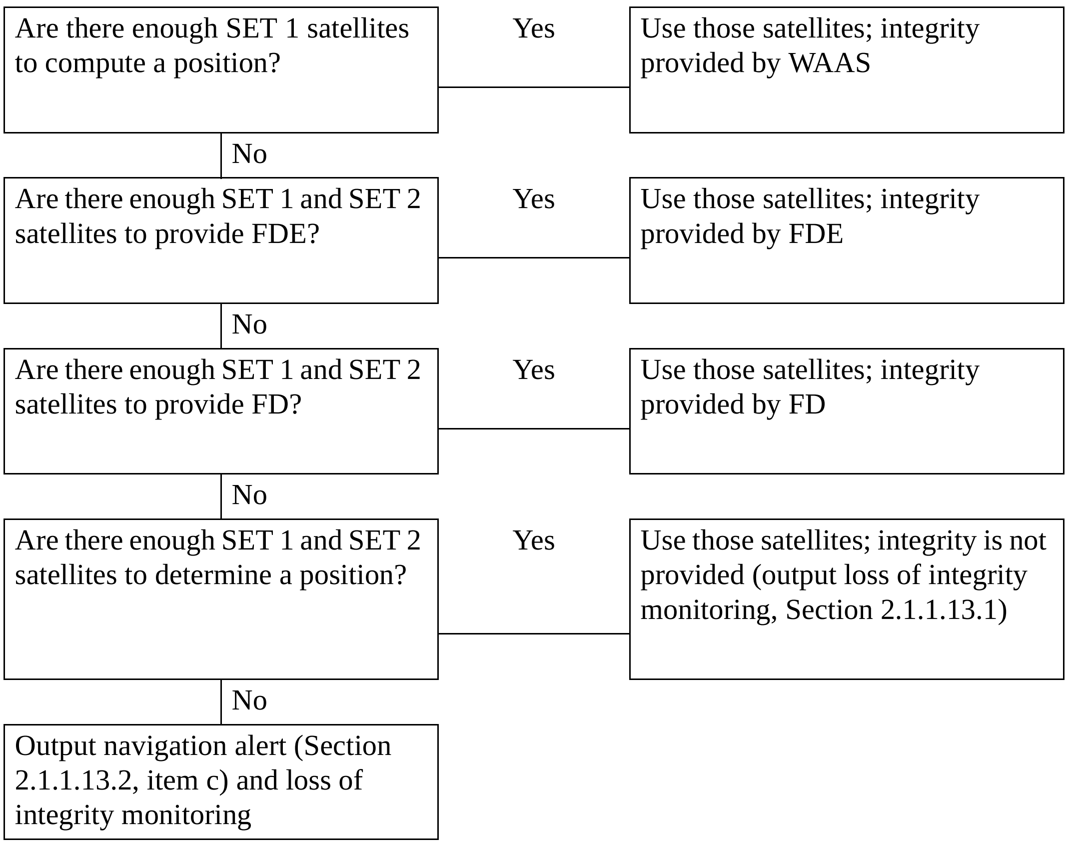
The equipment may allow selection/deselection of SBAS service providers as described in Section 1.3.3.

It is recommended that the equipment does not provide manual deselection of satellites in order to avoid situations where the pilot incorrectly deselects satellites or fails to reselect them. In a GPS/WAAS environment, it is highly unlikely that the pilot is aware of a satellite failure that the GPS/WAAS system has not flagged. If manual deselection is implemented, the manufacturer shall address these issues. Consideration should be given to annunciations to remind the pilot that satellites have been deselected, the capability to readily reselect satellites, and the appropriate training to ensure proper equipment operation. The equipment shall clear all previous manual deselections at power-up.

Manual selection of satellites which have been designated WAAS UNHEALTHY or GPS UNHEALTHY shall be prohibited.

SET 1 is satellites designated as WAAS HEALTHY, excluding satellites designated as GPS UNHEALTHY due to failure of parity or due to default navigation data

SET 2 is GPS satellites designated as both WAAS UNMONITORED and GPS HEALTHY and WAAS satellites designated as WAAS UNMONITORED



<u>FIGURE 2-1</u> AN ACCEPTABLE SATELLITE SELECTION HIERARCHY

2.1.1.7 Initial Acquisition Time

The equipment shall be capable of acquiring satellites and determining a position without any initialization information, including time, position, and GPS and WAAS almanac data.

In addition, with latitude and longitude initialized within 60 nautical miles, with time and date within 1 minute, with valid almanac data and unobstructed satellite visibility, and under interference conditions of Appendix C and under the minimum signal conditions defined in Section 2.1.1.10, the time from application of power to the first valid position fix shall be less than 5 minutes. In this context, valid means all of the following conditions are met:

a. If available, signals from at least one WAAS satellite are received and processed within the 5-minute period;

b. The determined position meets the accuracy requirements of Section 2.1.2.1, and continues to meet the requirement after the first valid position fix;

c. Integrity monitoring is provided as defined in Section 2.1.2.2.2.

2.1.1.8 Satellite Acquisition Time

2.1.1.8.1 GPS Satellite Acquisition Time

After steady state accuracy has been established, i.e., at least one minute of accurate navigation, the equipment shall be capable of incorporating a new GPS satellite signal into the position within 80 seconds. This requirement applies to a satellite with the minimum signal power in the presence of interfering signals described in Appendix C, and assumes valid almanac data is available.

Note: *66 seconds is required to ensure that a new ephemeris message is received twice, plus 14 seconds for Doppler and range bin search. The 80 seconds begins when a satellite becomes available.*

2.1.1.8.2 WAAS Satellite Acquisition Time

After steady state accuracy has been established, i.e., at least one minute of accurate navigation, the equipment shall be capable of acquiring a new WAAS satellite signal, applying the WAAS integrity information, and incorporating that satellite signal into the position solution within 134 seconds. This requirement applies to a satellite with the minimum signal power in the presence of interfering signals described in Appendix C, and assumes valid almanac data is available.

Note: *120 seconds is required to ensure that the GPS/WAAS equipment has time to demodulate a Message Type 9 navigation message and applicable fast corrections, plus an additional 14 seconds. The 134 seconds begins when a satellite becomes available.*

2.1.1.9 Satellite Reacquisition Time

For satellite signal outages of 30 seconds or less when the remaining satellites provide a GDOP of 6 or less, the equipment shall reincorporate the satellite into the position solution within 10 seconds from the time the signal is reintroduced. This requirement applies to a satellite with the minimum signal power in the presence of interfering signals as described in Appendix C.

Note: *For WAAS satellites, the momentary loss of signal does not obviate any of the time out intervals defined for WAAS data in Section 2.1.1.4.9. The equipment can continue to use data until it times out.*

2.1.1.10 Sensitivity and Dynamic Range

This standard allows for two different equipment architectures with respect to the antenna and preamplifier. These architectures are shown in Figure 2-2. They are also discussed in RTCA/DO-228, Minimum Operational Performance Standards for Global Positioning System Antenna.

If the manufacturer chooses to be interoperable with a standard GPS antenna without preamplifier, as specified in RTCA/DO-228, the GPS/WAAS equipment shall be capable of tracking GPS satellites with a minimum input signal power of -136 dBm at the receiver port (see Figure 2-2) in the presence of background thermal noise density of -176.6 dBm/Hz. The equipment shall be capable of tracking WAAS satellites with a minimum input signal power of -137 dBm at the receiver port in the presence of background thermal noise density of -176.6 dBm/Hz. The equipment shall have the capability of tracking GPS and WAAS satellites with a maximum power of at least -116 dBm at the receiver port.

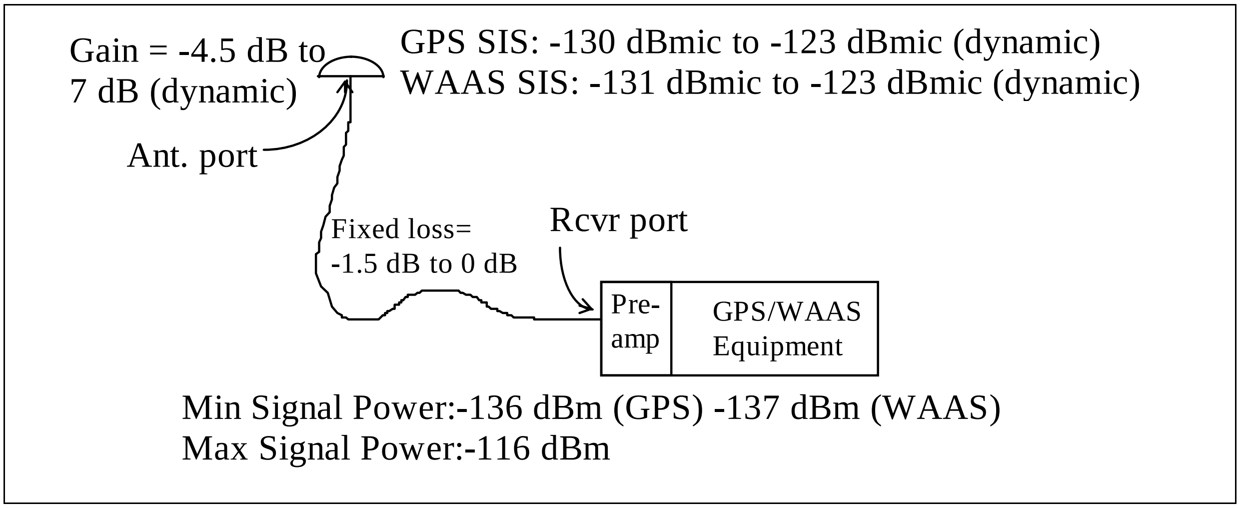
Note 1: *Installations of equipment interoperable with a RTCA/DO-228 antenna without preamplifier require less than 1.5 dB of loss between the antenna and the receiver, including loss due to coupling. This equipment should indicate in the installation instructions that this equipment is intended for installation with a RTCA/DO-228 antenna without preamplifier.*

If the manufacturer does not choose to be interoperable with a RTCA/DO-228 antenna without preamplifier as a component in his equipment, the GPS/WAAS equipment sensitivity and dynamic range depends on the RF amplifier design. The antenna shall satisfy the performance requirements of RTCA/DO-228. In addition, consideration must be given to the performance of the preamplifier and the potential effects of installation losses. The preamplifier shall accommodate GPS signals with a minimum input signal power of -134.5 dBm, and WAAS signals with a minimum input signal power of -135.5 dBm, in the presence of background thermal noise density of -178.6 dBm/Hz. The equipment shall have the capability of tracking GPS and WAAS satellites with a maximum power of at least -116 dBm at the input of the preamplifier. In addition, the maximum tolerable loss (L_{max} in Figure 2-2) between the preamplifier and the receiver port shall be determined in order to support testing of the minimum signal power at the receiver port. Finally, the minimum loss (L_{min}) shall be determined in order to support testing of the maximum signal power at the receiver port. See Figures 2-21 and 2-22.

Note 2: *Installations of equipment that is not interoperable with the standard antenna require that the manufacturer specify the minimum and maximum tolerable loss for installation. These limitations should be included in the installation instructions for this equipment. In addition, if the antenna component of the non-standard setup does not comply with the specification for the standard antenna, then the sensitivity and dynamic range must be modified based upon the antenna gain.*

Note 3: *If antenna is also non-standard, or if lower mask angle (< 5 degrees) is to be used, then gain values must be adjusted, sensitivity and dynamic range specified.*

(a) Antenna without Preamplifier



(b) Antenna with Preamplifier

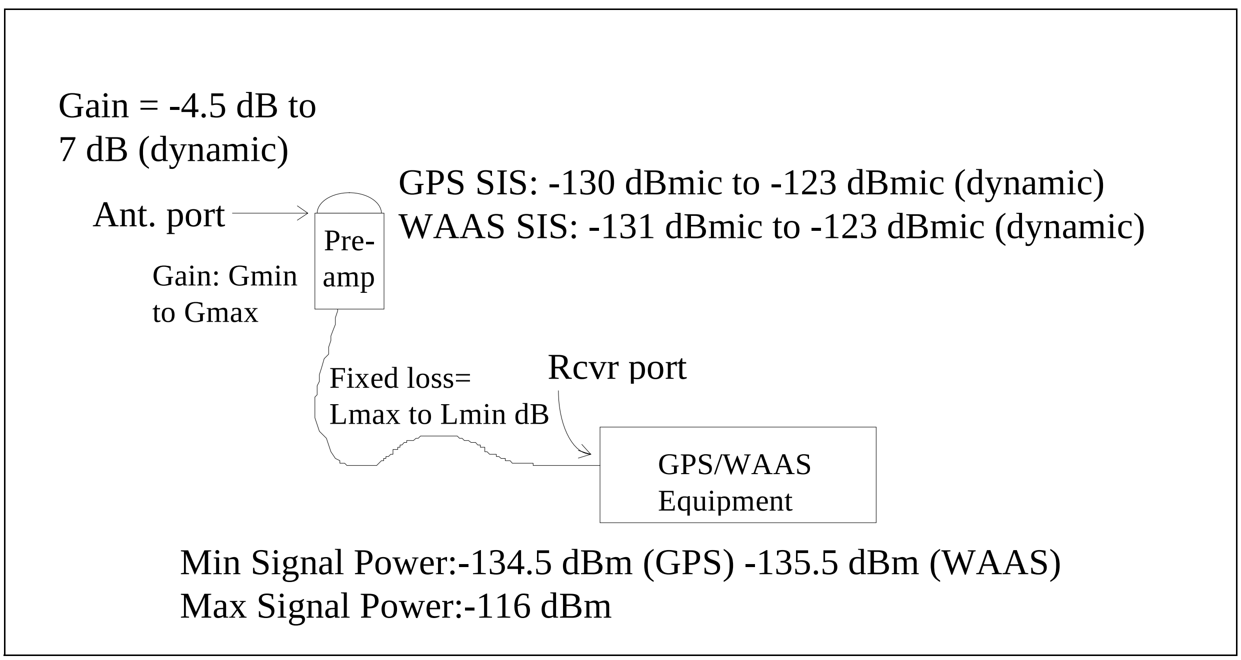


FIGURE 2-2 SENSITIVITY AND DYNAMIC RANGE CONFIGURATIONS

2.1.1.11 Equipment Burnout Protection

GPS/WAAS equipment shall withstand, without damage, an in-band CW signal of +20 dBm input to the preamplifier (at the receiver port or antenna port, as applicable).

2.1.1.12 Integrity in the Presence of Interference

The GPS/WAAS equipment shall satisfy the applicable integrity requirement within the time-to-alert (See section 2.1.2.2.2.2.1, 2.1.3.2.2.2.1, and 6 seconds for precision approach operations) for the output of misleading information in the presence of interfering signals higher in power than the values specified in Appendix C. Under these extreme conditions, it is acceptable to output a navigation alert, but not to output misleading information. The equipment shall autonomously return to steady state accuracy (according to the conditions in Section 2.1.1.7) within 5 minutes after the interference conditions return to those specified in Appendix C for initial acquisition.

Notes: ***1.*** *This requirement is comprehensive in nature in that it is intended to prevent the output of misleading information under any unintentional interference scenario that could arise. It is not intended to address the potential effects of intentional interference. While it is recognized that this requirement is impossible to completely verify through testing, an acceptable means of compliance can be found in Section 2.5.7.*

2. *In order to support problem investigation and maintenance, it is recommended that the equipment output the signal-to-noise ratio for each satellite. This data can be useful when determining if a particular outage is caused by the environment or by receiver anomalies.*

2.1.1.13 Alerts/Outputs

GPS/WAAS equipment provides, either as data outputs or as display alerts, information when significant conditions occur that affect flight decisions, in particular loss of integrity monitoring or navigation. Such conditions are described below for Class Beta equipment. The requirements for Class Gamma and Class Delta equipment can be found in 2.2.1.6 and 2.3.6, respectively.

2.1.1.13.1 Protection Level

Class Beta equipment shall output the Horizontal Protection Level (HPL_{WAAS} or HPL_{FD} as described in Sections 2.1.2.2.2, 2.1.3.2.2, 2.1.4.2.2, and 2.1.5.2.2). Class Gamma and Delta equipment intended to support an external ADS-B function shall output HPL. The latency of the WAAS-based protection levels shall not exceed 4.8 seconds, from the arrival at the antenna port of the last bit of a message which affects the horizontal protection level. The GPS/WAAS equipment shall indicate if the HPL cannot be calculated (insufficient number of WAAS HEALTHY satellites and fault detection is not available).

Notes: ***1.*** *In addition to the HPL, the equipment may output the HUL.*

2. *When no HPL can be calculated, integrity monitoring is not provided.*

3. *Class Gamma and Delta equipment requirements can be found in Sections 2.2.1.6 and 2.3.6. Class Gamma and Delta equipment are required to compute the HPL, but are not required to output them to an external device unless it is intended to support an external ADS-B function.*

2.1.1.13.2 Navigation Alert

Class Beta equipment shall provide an indication or output of the loss of navigation capability within one second of the onset of any of the following conditions:

a. The absence of power (loss of function is an acceptable indicator);

b. Probable equipment malfunction or failure (must consider all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5} per flight hour);

c. The presence of a condition lasting five seconds or more where there are an inadequate number of usable satellites to compute a position solution (i.e., no computed data);

d. The presence of a condition where fault detection detects a position failure which cannot be excluded within the time-to-alert.

The alert shall be returned to its normal state immediately upon termination of the responsible condition.

Note: *These requirements do not preclude the implementation of a dead reckoning mode, which would allow continued display of navigation information even under condition c, together with a clear indication that the equipment is using the dead reckoning mode.*

2.1.2 Requirements for En Route and Terminal Mode

2.1.2.1 Accuracy

The horizontal radial position fixing error for en route (domestic and oceanic) and terminal area navigation shall not exceed 100 m, 95th percentile, when HDOP is normalized to 1.5. This requirement shall be met under the minimum signal conditions defined in Section 2.1.1.10 and interference conditions defined in Appendix C.

Notes:

1. *The assumptions are as follows: signal-in-space pseudorange error of 33 m, 1 sigma (due primarily to SA) and avionics pseudorange error of no more than 5 m (due to receiver noise, multipath, etc.), 1 sigma, for a total (root-sum-square) pseudorange error of 33.3 m, 1 sigma. Flight technical error (FTE), waypoint error, and RNAV path computation error are not included in this error.*

2. *Section 2.5.8 describes the test for this requirement. In order to reduce the duration of testing required to demonstrate accuracy in the presence of the interference conditions, Section 2.5.8 excludes the effects of SA and uses a sensor pseudorange accuracy threshold of 5 meters.*

If a time output is provided, it shall be within 1 second of coordinated universal time (UTC).

2.1.2.2 Integrity Requirements

2.1.2.2.1 Development Assurance

The hardware and software shall be designed such that the output of misleading information, considered to be a major failure condition, shall be improbable. To demonstrate compliance it will be necessary to conduct a safety assessment to evaluate the system's implementation against known failure conditions.

Notes:

1. *The design requirements applicable to this hazard classification depend upon the aircraft type. The following two paragraphs define acceptable means of compliance for the most stringent application of this hazard classification.*

2. *In addition to showing compliance with the above requirement, for equipment that supports approach, arrival and departure phases of flight, the European JAA requires that for electronic display systems, displaying hazardously misleading navigational or position information simultaneously on both pilots' displays must be "Extremely Remote" (reference- JAA AMJ 25.11 and AMJ 25.1309).*

2.1.2.2.1.1 Hardware Compliance

An acceptable means of compliance for GPS/WAAS equipment (oceanic/en route/terminal modes) is to show that failures of the equipment that result in misleading information are not more probable than 10^{-5}/flight hour. For complex firmware implementations such as application-specific integrated circuits (ASIC's), processes similar to those described in RTCA/DO-178B or RTCA/DO-254 provide an acceptable means of compliance with applicable airworthiness requirements.

2.1.2.2.1.2 Software Compliance

AC 20-115B, which references RTCA/DO-178B, provides an acceptable means for showing that software complies with applicable airworthiness requirements. One acceptable approach to software development is to develop all software that affects navigation and integrity functions to at least the Level C criteria, as defined in RTCA/DO-178B. Another acceptable approach is to substantiate software levels in the safety assessment.

2.1.2.2.2 Integrity Monitoring

The equipment shall be capable of computing HPL_{WAAS} and HPL_{FD}. At a minimum, the equipment shall compute HPL_{WAAS} when it is available; otherwise it shall compute HPL_{FD}. If the equipment uses integrated GPS/inertial and does not use the WAAS integrity and correction data, it shall meet the requirements and accomplish the test procedures in Appendix R.

2.1.2.2.2.1 WAAS-Provided Integrity Monitoring

The equipment shall compute a horizontal protection level HPL_{WAAS} as defined in Appendix J.

Notes: ***1.*** *The probability that the horizontal error exceeds the HPL_{WAAS} will be less than or equal to 10^{-7} per hour.*

2. *For non-weighted solutions, a smaller HPL_{WAAS} may in some cases be achievable by excluding satellites from the position solution (e.g., those with large σ_{flt}, if the σ_{flt} is used in computing HPL_{WAAS}).*

2.1.2.2.2.2 FDE-Provided Integrity Monitoring

GPS/WAAS equipment shall have a fault detection and exclusion (FDE) capability that utilizes redundant GPS and WAAS ranging measurements to provide independent integrity monitoring.

This algorithm shall be used to monitor the navigation solution whenever WAAS integrity is not available. The detection function refers to the capability to detect a positioning failure which affects navigation, while the exclusion function refers to the capability to exclude one or more satellites from the solution and prevent a positioning failure from affecting navigation.

The FDE algorithm shall use the URA broadcast to modify the modes for alerting. At a minimum, the FDE algorithm shall set: (1) an SA mode, if any satellite URA's are greater than 16 meters; (2) an SA off mode, if the URA for every satellite being used is less than or equal to 16 meters.

Note 1: *The nominal URA index in ICD-GPS-200C, "Navstar GPS Space Segment / Navigation User Interfaces", April 2000, paragraph 20.3.3.3.1.3 can be used to determine range-domain uncertainty by assuming the URA maps into the near-Gaussian distribution.*

Note 2: *The URA does not include the tropospheric or ionospheric uncertainties. These uncertainties are included in Appendix J.*

Note 3: *Use of a weighted least squares solution is an acceptable means of satisfying this requirement.*

Equipment which utilizes barometric altitude to improve the performance of this algorithm shall meet the requirements specified in Appendix G. Equipment which utilizes inertial information to improve the performance of this algorithm shall meet the requirements specified in Appendix R. Equipment which utilizes other measurements (besides

GPS, WAAS, barometric altitude or inertial) must demonstrate that equivalent safety and performance is obtained. FDE algorithms which use other navigation signals external to the aircraft such as LORAN or VOR/DME must be shown to satisfy the availability requirement without the use of the other navigation signals. The manufacturer must provide the means to test and analyze alternate FDE algorithms to demonstrate compliance.

Note 4: *This FDE capability is required in order to provide a transition to primary means-navigation utilizing the WAAS. It enables operation outside of the WAAS coverage area and provides a secondary means of providing integrity should a catastrophic WAAS failure occur.*

The equipment shall compute a horizontal protection level HPL_{FD}. The FDE algorithm shall meet the following requirements under the standard assumptions of GPS performance specified in Appendix B. If FDE is applied to pseudoranges which have been fully or partially corrected by WAAS, the assumed error distribution can be modified based upon the post-correction accuracy. If the equipment uses a mixture of corrected and uncorrected satellites, the FDE algorithm shall account for the difference between WNT and GPS time.

Note 5: *The difference between WNT and GPS time may be solved for or the uncertainties in the ranges may be inflated to account for the difference. An acceptable method for accounting for the difference is to increase the uncertainty on one of the sets (corrected or uncorrected satellites) by the equivalent of 50 nanoseconds.*

2.1.2.2.2.2.1 Time-to-Alert

The time-to-alert for Class Beta equipment is 8 seconds for FDE-provided integrity monitoring.

Note: *The loss of navigation display timing requirements for Class Gamma and Class Delta equipment is discussed in 2.2.2.6.3, 2.2.3.6.3, 2.2.4.6.3, 2.2.5.6.3 and 2.3.6.*

2.1.2.2.2.2.2 Missed Alert Probability

The probability of missed alert shall be less than or equal to 0.001 for every geometry and every navigation mode, regardless of which satellite is causing the positioning failure. If this requirement is not met for a given geometry, then the detection function is defined to be unavailable for that geometry (See Section 1.7.3).

Notes:

1. *This requirement is on the missed alert rate generated by the GPS/WAAS equipment. The missed alert probability is a function of missed detection and wrong exclusion.*
2. *The testing paragraph defines specific constellations to be used to evaluate this requirement.*

2.1.2.2.2.2.3 False Alert Probability

The probability of false alert shall be less than or equal to 10^{-5}/flight hour. The product of the average duration of a false alert and the probability of a false alert shall be less than 3.33×10^{-7}. If this requirement is not met for a given geometry, regardless of whether S/A is on or off, then the detection function is defined to be unavailable for that geometry (See Section 1.7.3).

Notes:

1. *The testing paragraph defines specific constellations to be used to evaluate this requirement.*

2. *With S/A on, the average duration of a false alert is assumed to be 2 minutes, so that the product of 10^{-5}/hour and 2 minutes is 3.33×10^{-7}.*

2.1.2.2.2.2.4 Failed Exclusion Probability

The probability of failed exclusion shall be less than or equal to 10^{-3} for every geometry and every navigation mode, regardless of which satellite is causing the positioning failure. If this requirement is not met for a given geometry, then the exclusion function is defined to be unavailable for that geometry (See Section 1.7.3).

Note: *This requirement is on the alert rate generated by the GPS/WAAS equipment due to failed exclusion. It is equivalent to the probability that a positioning failure is annunciated when a GPS satellite failure occurs and is detected internally. For some algorithms, this probability may be 0 in that exclusion is conducted whenever a failure is detected, if at least 6 measurements are available. However, such an algorithm could only be used if it also meets the missed alert requirement.*

2.1.2.2.2.2.5 Availability

The availability of the FDE algorithm to meet the above requirements with an HAL of 1 nm, when evaluated over the constellations and grids specified in the test procedures for Case 1 of Section 2.5.9 (i.e., S/A on), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to the following:

Availability of detection:	99.80%
Availability of exclusion:	94.55%

The availability of the FDE algorithm to meet the above requirements with an HAL of 1 nm, when evaluated over the constellations and grids specified in the test procedures for Case 2 (Section 2.5.9), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to the following:

Availability of detection:	99.9%
Availability of exclusion:	98.0%

Note: *This requirement is intended to provide a means to assess the adequacy of FDE algorithms. These numbers are based upon simulation and analysis of the practical availability and are intended to ensure a consistent minimum capability, which can be used by airspace system designers. This availability has not been determined to meet all operational requirements.*

2.1.2.3 Equipment Reliability

The equipment should be designed for reliable operation.

2.1.2.4 Satellite Tracking Capability

The GPS/WAAS equipment shall be capable of simultaneously tracking a minimum of 8 GPS satellites and no WAAS satellites. It shall also be capable of simultaneously tracking at least 6 GPS satellites and two WAAS satellites, including demodulating and storing WAAS data from both satellites.

2.1.2.5 Dynamic Tracking

When the aircraft has dynamics within normal maneuvers defined by the maximum ground speeds and accelerations shown below, the equipment shall meet the accuracy requirements of 2.1.2.1 and the satellite acquisition time requirements of 2.1.1.8 and the satellite reacquisition requirements of 2.1.1.9. Note that g = acceleration of gravity = 9.8 m/s^2.

Ground **Speed**	Horiz. **Accel.**	Vertical **Accel.**	Total **Jerk**
800 kt	0.58 g	0.5 g	0.25 g/s

Abnormal maneuvers are defined to be maneuvers whose accelerations/jerks exceed these values, up to the maximum ground speeds and accelerations shown below.

Ground **Speed**	Horiz. **Accel.**	Vertical **Accel.**	Total **Jerk**
800 kt	2 g	1.5 g	0.74 g/s

During abnormal maneuvers, the equipment shall not output misleading information. When the aircraft returns to normal maneuvers from abnormal maneuvers, the equipment shall meet the steady-state reacquisition requirements of Section 2.1.1.9. During the abnormal maneuver period, loss-of-navigation capability and loss-of-integrity monitoring alerts and outputs shall function as specified.

2.1.2.6 Position Output

The GPS/WAAS equipment shall determine a position for navigation. This position shall represent the WGS-84 position of the aircraft antenna (or center of navigation) at the time of applicability.

The equipment shall provide an electronic data interface capable of transmitting digital data containing position, velocity, integrity and other pertinent data.

Note: *Appendix H provides guidance concerning this requirement.*

2.1.2.6.1 Position Output Update Rate

The minimum update rate of position outputs used for navigation shall be once per second.

2.1.2.6.2 Position Output Latency

The latency of the position output, defined as the interval between the time of the measurement and the time of applicability of the position, shall be less than or equal to 500 milliseconds.

The data defining the position shall be output prior to 200 milliseconds after the time of applicability.

2.1.3 Requirements for Nonprecision Approach Mode

2.1.3.1 Accuracy

The horizontal radial position fixing error for nonprecision approach navigation shall not exceed 100 m, 95th percentile, when HDOP is normalized to 1.5. This requirement shall be met under the minimum signal conditions defined in Section 2.1.1.10 and interference conditions defined in Appendix C.

Notes: ***1.*** *The assumptions are as follows: signal-in-space pseudorange error of 33 m, 1 sigma (due primarily to SA) and avionics pseudorange error of no more than 5 m (due to receiver noise, multipath, etc.), 1 sigma, for a total (root-sum-square) pseudorange error of 33.3 m, 1 sigma. Flight technical error (FTE), waypoint error, and RNAV path computation error are not included in this error.*

2. *Section 2.5.8 describes the test for this requirement. In order to reduce the duration of testing required to demonstrate accuracy in the presence of the interference conditions, Section 2.5.8 excludes the effects of SA and uses a sensor pseudorange accuracy threshold of 5 meters.*

2.1.3.2 Integrity Requirements

2.1.3.2.1 Development Assurance

See Section 2.1.2.2.1.

2.1.3.2.2 Integrity Monitoring

See Section 2.1.2.2.2.

2.1.3.2.2.1 WAAS-Provided Integrity Monitoring

See Section 2.1.2.2.2.1.

2.1.3.2.2.2 FDE-Provided Integrity Monitoring

See Section 2.1.2.2.2.2.

2.1.3.2.2.2.1 Time-to-Alert

See Section 2.1.2.2.2.2.1.

2.1.3.2.2.2.2 Missed Alert Probability

See Section 2.1.2.2.2.2.2.

2.1.3.2.2.2.3 False Alert Probability

See Section 2.1.2.2.2.2.3.

2.1.3.2.2.2.4 Failed Exclusion Probability

See Section 2.1.2.2.2.2.4.

2.1.3.2.2.2.5 Availability

The availability of the FDE algorithm to meet the above requirements with an horizontal alert limit (HAL) of 0.3 nm, when evaluated over the constellations and grids specified in the test procedures for Case 1 (Section 2.5.9), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to the following:

Availability of detection: 97.06%

Availability of exclusion: 57.30%

The availability of the FDE algorithm to meet the above requirements with an HAL of 0.3 nm, when evaluated over the constellations and grids specified in the test procedures for Case 2 (Section 2.5.9), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to the following:

Availability of detection: 99.7%

Availability of exclusion: 92.0%

Note: *This requirement is intended to provide a means to assess the adequacy of FDE algorithms. These numbers are based upon simulation and analysis of the practical availability and are intended to ensure a consistent minimum capability which can be used by airspace system designers. This availability has not been determined to meet all operational requirements.*

2.1.3.3 Equipment Reliability

See Section 2.1.2.3.

2.1.3.4 Satellite Tracking Capability

See Section 2.1.2.4.

2.1.3.5 Dynamic Tracking

When the aircraft has dynamics within normal maneuvers defined by the maximum ground speeds and accelerations shown below, the equipment shall meet the accuracy requirements of 2.1.3.1 and the satellite acquisition time requirements of 2.1.1.8 and the satellite reacquisition requirements of 2.1.1.9. Note that g = acceleration of gravity = 9.8 m/s^2.

Ground Speed	Horiz. Accel.	Vertical Accel.	Total Jerk
250 kt	0.58 g	0.5 g	0.25 g/s

Abnormal maneuvers are defined to be maneuvers whose accelerations/jerks exceed these values, up to the maximum ground speeds and accelerations shown below.

Ground Speed	Horiz. Accel.	Vertical Accel.	Total Jerk
250 kt	2 g	1.5 g	0.74 g/s

During abnormal maneuvers, the equipment shall not output misleading information. When the aircraft returns to normal maneuvers from abnormal maneuvers, the equipment shall meet the steady-state reacquisition requirements of Section 2.1.1.9. During the abnormal maneuver period, loss-of-navigation capability and loss-of-integrity monitoring alerts and outputs shall function as specified.

2.1.3.6 Position Output

See Section 2.1.2.6.

2.1.3.6.1 Position Output Update Rate

See Section 2.1.2.6.1.

2.1.3.6.2 Position Output Latency

See Section 2.1.2.6.2.

2.1.3.7 WAAS Message Processing

See Section 2.1.1.4.

2.1.3.8 Application of Differential Correction Terms

The equipment shall meet the requirements specified in Section 2.1.1.4.12.

2.1.3.9 Satellite Selection

In addition to the general requirements of Section 2.1.1.6, the equipment shall select at least two WAAS satellites, if they are available. When two WAAS satellites are available, the equipment shall be capable of switching between WAAS data streams to maximize continuity of function.

2.1.4 Requirements for LNAV/VNAV Operations

LNAV/VNAV functional requirements apply to the extended Final Approach Segment (FAS). The FAS is the straight line which prescribes the three-dimensional straight-line path in space that an aircraft is supposed to fly on final approach. Although LNAV/VNAV is a level of WAAS precision approach service as described in Section 1.8.2.1, it has some different requirements than GLS and APV-II; therefore, LNAV/VNAV will be covered in this section. GLS and APV-II will be covered in Section 2.1.5.

2.1.4.1 Accuracy

2.1.4.1.1 Smoothing

The equipment shall perform carrier smoothing. In the presence of a code-carrier divergence rate of up to 0.018 m/s, the smoothing filter output shall achieve an error less than 0.25 m within 200 seconds after initialization, relative to the steady-state response of the following filter:

$$Pproj = P_{n-1} + \frac{\lambda}{2\pi}\left(\phi_n - \phi_{n-1}\right)$$

$$P_n = \alpha\rho_n + (1-\alpha)P_{proj}$$

where

P_n is the carrier-smoothed pseudorange in meters,

P_{n-1} is the previous carrier-smoothed pseudorange in meters,

P_{proj} is the projected pseudorange in meters,

ρ_n is the raw pseudorange measurement in meters (code loop carrier driven, 1st order or higher and with a one sided noise bandwidth greater than or equal to 0.125 Hz),

λ is the wavelength in meters,

ϕ_n is the accumulated carrier phase measurement in radians,

ϕ_{n-1} is the previous accumulated carrier phase measurement in radians, and

α is the filter weighting function (a unit less parameter), equal to the sample interval in seconds divided by the time constant of 100 seconds.

Notes:

1. *The difference between the steady-state response of the smoothing filter implemented in the equipment and the steady-state response of the filter defined above is included in the accuracy requirements of section 2.1.4.1.3.*
2. *One acceptable implementation of the airborne smoothing filter is the filter specified above. This filter is standardized to allow differences between this nominal filter and the dual-frequency ground system filters induced by ionospheric divergence to be included in the broadcast error bounds (σ_{GIVE} and σ_{UDRE} as appropriate). Smoothing can be done in parallel with other acquisition processes, making the smoothed pseudoranges available as quickly as possible.*

2.1.4.1.2 Measurement Quality Monitoring

The satellite signal tracking quality shall be monitored such that the allocated integrity risk due to undetected cycle slip or other undetected measurement faults is within the manufacturer's allocation.

Notes:

1. *The risk is allocated as part of the integrity budget and the continuity impact of these monitors is allocated within the continuity budget.*

2. *During an approach, satellite power levels may vary (e.g., due to elevation angles and fading effects that may result in cycle slips). If the satellite is used for positioning and guidance, the loss of the satellite may result in loss of function. The specified interference will further lower the signal-to-noise ratio. Excessive CW interference could cause large pseudorange errors – see Notes 3) and 4) below.*

3. *An example of a monitoring method to maintain integrity at low power and in the presence of normal interference is signal-to-noise ratio monitoring and navigation message parity checking.*

4. *A raw pseudorange measurement that deviates excessively from the projected smoothed pseudorange should be excluded from being used by the smoothing filter. If successive measurements are consistently discarded, which would be the case if a carrier or pseudorange step has occurred, the carrier-smoothed pseudorange should not be used. One possible implementation:*

   If $|(\rho_n - P_{proj})| < 10$ m

   then $P_n = P_{proj} + \alpha(\rho_n - P_{proj})$

   Otherwise $P_n = P_{proj}$

2.1.4.1.3 Accuracy

The accuracy requirements specified in Sections 2.1.4.1 and 2.1.4.1.5 represent the performance in steady state, including errors such as processing errors, thermal noise, interference, and any residual ionospheric errors caused by a difference between the implemented smoothing filter and the smoothing filter defined in Section 2.1.4.1.1 in the presence of code carrier divergence rate. The code-carrier divergence rate can be assumed to be represented by a Normal distribution with zero mean and a standard deviation of 0.012 m/s. Steady-state operation is defined to be following 360 seconds of continuous operation of the smoothing filter.

Notes:

1. *Other than the steady-state ionospheric divergence error, the specified accuracy requirements do not include residual signal propagation errors (e.g., multipath or residual tropospheric errors).*

2. *Receiver accuracy performance is classified in terms of the Airborne Accuracy Designations.*

3. *The code-carrier divergence rate assumption does not affect equipment that implements the filter defined in Section 2.1.4.1.1, since the steady-state error from that filter is defined to be zero regardless of the magnitude of the code-carrier divergence (it is the reference filter).*

2.1.4.1.4 GPS Satellites

The RMS of the total steady-state equipment contribution to the error in the corrected pseudorange for a GPS satellite ($RMS_{pr\_air,GPS}$) at the minimum and maximum signal levels (Section 2.1.1.10) shall be as follows:

Minimum signal level:

a. $RMS_{pr\_air,GPS} \leq 0.36$ meters for Airborne Accuracy Designator-A, and

b. $RMS_{pr\_air,GPS} \leq 0.15$ meters for Airborne Accuracy Designator-B

Maximum signal level:

a. $RMS_{pr\_air,GPS} \leq 0.15$ meters for Airborne Accuracy Designator-A, and

b. $RMS_{pr\_air,GPS} \leq 0.11$ meters for Airborne Accuracy Designator-B.

Notes: ***1.*** *The Airborne Accuracy Designator characterizes the airborne equipment's contribution to error in the differentially corrected pseudoranges. The Airborne Accuracy Designator consists of a single letter associated with the accuracy of the equipment. Two designators are defined in this document.*

2. *Two levels of receiver accuracy are defined to retain consistency with the LAAS MOPS. However, it is anticipated that WAAS-only avionics will be developed to the AAD-A requirements since significant differences in WAAS availability have not been identified. Manufacturers who choose the AAD-B standard to enable growth towards CAT III LAAS can document that compliance for both WAAS and LAAS.*

2.1.4.1.5 WAAS Satellites

The RMS of the total steady-state equipment contribution to the error in the corrected pseudorange for a WAAS satellite ($RMS_{pr\_air,GEO}$) at the minimum and maximum signal levels (Section 2.1.1.10) shall be as follows:

Minimum signal level: $RMS_{pr\_air,GEO} \leq 1.8$

Maximum signal level: $RMS_{pr\_air,GEO} \leq 1.0$

2.1.4.1.6 Position Solution

The equipment shall compute three-dimensional position using a linearized, weighted least-squares solution as defined in Appendix J.

2.1.4.2 Integrity Requirements

2.1.4.2.1 Development Assurance

See Section 2.1.2.2.1.

2.1.4.2.2 Integrity Monitoring

When in LNAV/VNAV, the equipment shall compute WAAS-based protection levels (HPL_{WAAS} and VPL_{WAAS}). The equipment shall also perform fault detection, if more than four satellites are available. The presence of integrity monitoring is determined solely on the WAAS-based protection levels, while the detection of a failure is based on both methods of integrity.

Notes: ***1.*** *The LNAV/VNAV integrity method is discussed in detail in Section 2.2.4.6 and Appendix E. It has been designed to maximize the detection probability of an error with minimal impact on availability.*

2. *If only 4 satellites are available and WAAS-based protection levels are within the alert limits, LNAV/VNAV may be performed.*

2.1.4.2.2.1 WAAS-Provided Integrity Monitoring

The equipment shall compute Horizontal and Vertical Protection Levels HPL_{WAAS} and VPL_{WAAS} as described in Appendix J.

2.1.4.2.2.2 Fault Detection-Provided Integrity Monitoring

GPS/WAAS equipment shall have a fault detection integrity monitoring capability that utilizes redundant WAAS-corrected GPS and WAAS ranging measurements to provide independent integrity monitoring.

Notes: ***1.*** *If only 4 ranging sources are available, LNAV/VNAV can be performed using WAAS integrity only.*

2. *The equipment is required to provide a fault-detection capability in order to detect local anomalies that may not be detectable by WAAS. Since the underlying probability of these anomalies is not quantified, it is not practical to assign a missed alert probability to the fault detection algorithm. Instead the equipment is required to use the information redundancy that is available to the maximum extent possible.*

2.1.4.2.2.2.1 Frequency of Fault Detection

For LNAV/VNAV, the fault detection algorithm shall be performed at a rate of at least once per minute or within 6 seconds of a change in the set of satellites that are being used in the navigation solution.

Note: *This requirement is consistent with the time to alert requirement of 6 seconds, since it is only intended to detect slowly-changing conditions.*

2.1.4.2.2.2.2 Missed Alert

There is no missed alert probability requirement for LNAV/VNAV.

Note: *For the purpose of testing, the vertical protection level ($VPLT_{FD}$) is evaluated on the basis of a missed alert probability of 0.1.*

2.1.4.2.2.2.3 False Alert

The probability of false alert shall be less than or equal to 2 x 10^{-5} per approach. This requirement shall be met for every geometry.

2.1.4.2.2.2.4 Availability

The availability of the fault detection function algorithm for LNAV/VNAV to meet the above requirements assuming a missed alert rate of 0.1 and a vertical alert limit of 15 m, when evaluated over the constellations and grids specified in the test procedures (Section 2.5.10), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to 95 percent.

Note: *This requirement is only intended to provide a means to assess the adequacy of fault detection algorithms.*

2.1.4.3 Equipment Reliability

The equipment should be designed for reliable operation.

2.1.4.4 Satellite Tracking Capability

Note: *See Section 2.1.2.4.*

2.1.4.5 Tracking Constraints

Due to the nature of possible satellite failures, and the necessity to protect against their effects, it is necessary to constrain the technical implementation of the GPS receiver. These constraints are described in terms of Delay Lock Loop (DLL) discriminator correlator spacing, receiver bandwidth and receiver differential group delay. Allowable combinations are defined below. The satellite failure effects considered in developing these constraints are:

1. Distorted satellite signal causing multiple correlation peaks.
2. Correlator peak asymmetry in transmitted signal due to code coherent spurious signals (such as reflected signals or code transition induced waveforms in the satellite).
3. Code coherent spurious signals distorted by RF filter differences.
4. Flat correlation peaks causing excessive noise or drift.

Depending on the pre-correlation bandwidth of the equipment, the correlator spacing, d, and the differential group delay shall be within the range as defined in Table 2-3A-C.

2.1.4.5.1 GPS Tracking Constraints

For early-minus-late (E-L) DLL discriminator tracking GPS satellites, the pre-correlation bandwidth of the equipment, correlator spacing, d, and the differential group delay shall be within the ranges as defined in Table 2-3A.

TABLE 2-3A GPS TRACKING CONSTRAINTS FOR E-L DLL DISCRIMINATORS

Region (Figure 2-3A)	**3 dB Pre-correlation bandwidth, BW**	**Average Correlator Spacing (d) [C/A chips]**	**Instantaneous Correlator Spacing (d) [C/A chips]**	**Equipment Differential Group Delay**
1	2<BW≤7 MHz	0.045-1.1	0.04-1.2	≤600 nsec – N
2	7<BW≤16 MHz	0.045-0.21	0.04-0.235	≤150 nsec – N
3	16<BW≤20 MHz	0.045-0.12	0.04-0.15	≤150 nsec – N

Note: *N is the antenna allocation as defined in RTCA/DO-228(latest version). If the GPS antenna is part of the WAAS equipment, then the combination of the GPS antenna and receiver differential group delay must meet the requirement in the table with N = 0.*

The instantaneous correlator spacing is defined as the spacing between a particular set of early and late samples of the correlation function. The average correlator spacing is defined as a one-second average of the instantaneous correlator spacing. The average applies over any one-second time frame.

The discriminator (Δ) shall be based upon an average of correlator spacings within the specified range. Either a coherent or a non-coherent discriminator may be used.

For the Double Delta (DD) DLL discriminators of the type $\Delta = 2\Delta_{d1} - \Delta_{2d1}$ tracking GPS satellites, the pre-correlation bandwidth of the equipment, correlator spacings (d_1 and $2d_1$) and the differential group delay shall be within the range as defined in Table 2-3B. Either a coherent or a non-coherent discriminator may be used.

TABLE 2-3B GPS TRACKING CONSTRAINTS FOR DD DLL DISCRIMINATORS

Region (Figure 2-3B)	**3 dB Pre-correlation bandwidth, BW**	**Average Correlator Spacing (d_1 and $2d_1$) [C/A chips]**	**Instantaneous Correlator Spacing (d_1 and $2d_1$)**	**Equipment Differential Group Delay**
1	2<BW≤7 MHz	0.045-0.6	0.04-0.65	≤600 nsec – N
2	7<BW≤14 MHz	0.045-0.24	0.04-0.26	≤150 nsec – N
3	14<BW≤16 MHz	0.07-0.24	0.06-0.26	≤150 nsec – N

Note: *N is the antenna allocation as defined in RTCA/DO-228(latest version). If the GPS antenna is part of the WAAS equipment, then the combination of the GPS antenna and receiver differential group delay must meet the requirement in the table with N = 0.*

The differential group delay is defined as:

$$\left| \left.\frac{d\phi}{d\omega}\right|_{\omega=2\pi f_c} - \left.\frac{d\phi}{d\omega}\right|_{\omega=2\pi f_0} \right|$$

where:

f_c is the pre-correlation band pass filter center frequency

f_0 is any frequency within the 3 dB bandwidth of the pre-correlation filter

ϕ is the combined phase response of the equipment (either receiver or receiver and antenna)

ω is the frequency in radians/sec; $\omega = 2\pi f$

For the DD DLL Discriminators, the pre-correlation filter shall roll-off by at least 30 dB per octave in the transition band.

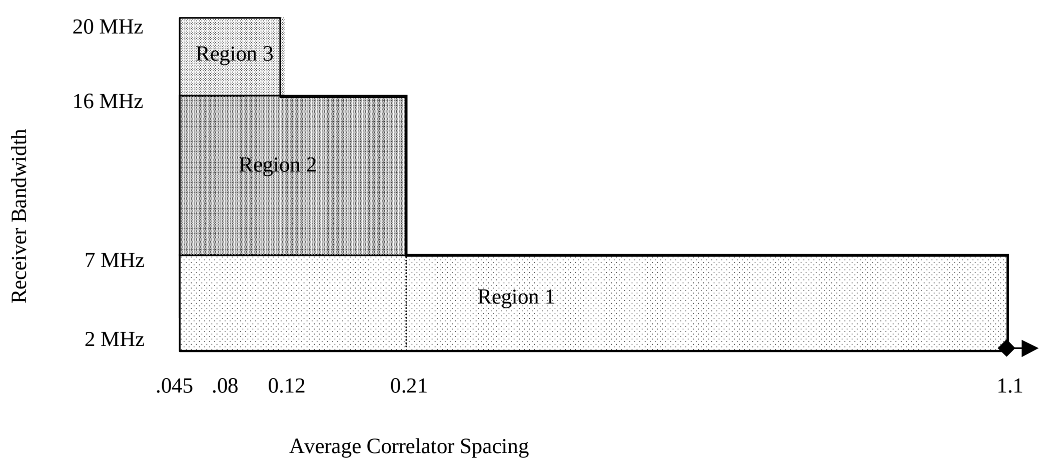


FIGURE 2-3A RECEIVER BANDWIDTH AND AVERAGE CORRELATOR SPACING FOR E-L DISCRIMINATOR TRACKING OF GPS SATELLITES

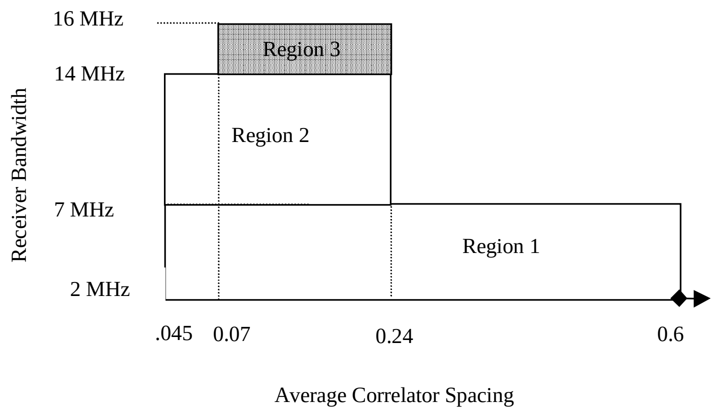


FIGURE 2-3B RECEIVER BANDWIDTH AND AVERAGE CORRELATOR SPACING FOR DD DISCRIMINATOR TRACKING OF GPS SATELLITES

2.1.4.5.2 SBAS Tracking Constraints

For the E-L and DD DLL discriminator tracking SBAS satellites, the pre-correlation bandwidth of the equipment, correlator spacing, (d, d_1 and $2d_1$) and the differential group delay shall be within the range as defined in Table 2-3C.

TABLE 2-3C SBAS RANGING FUNCTION TRACKING CONSTRAINTS

Region	3 dB Pre-correlation bandwidth, BW	Average Correlator Spacing (d, d_1 and $2d_1$) [C/A chips]	Instantaneous Correlator Spacing (d, d_1 and $2d_1$) [C/A chips]	Equipment Differential Group Delay
1	2<BW≤7 MHz	0.045-1.1	0.04-1.2	≤ 600 nsec – N
2	7<BW≤20 MHz	0.045-1.1	0.04-1.2	≤ 150 nsec – N

Note: *N is the antenna allocation as defined in RTCA/DO-228 (latest version). If the GPS antenna is part of the WAAS equipment, then the combination of the GPS antenna and receiver differential group delay must meet the requirement in the table with N = 0.*

For the DD DLL Discriminators, the pre-correlation filter shall roll-off by at least 30 dB per octave in the transition band.

2.1.4.6 Correlation Peak Validation

The equipment shall acquire the main C/A code correlation peak for each GPS and WAAS ranging source used for the navigation solution.

For Double Delta DLL discriminators, the equipment shall operate at the correct tracking point corresponding to the strongest peak within the main C/A code correlation peak.

Note: *The requirement to track the strongest peak is based on the effect of potential satellite signal failures on DD DLL discriminators (See B.6). It does not apply to E-L DLL discriminators. DD DLL discriminators may demonstrate compliance with this requirement by verifying that the strongest peak is tracked during acquisition and reacquisition. It is not necessary to continually monitor for this condition.*

2.1.4.7 Dynamic Tracking

When the aircraft has dynamics within normal maneuvers defined by the maximum ground speeds and accelerations shown below, the equipment shall output positions meeting the accuracy requirements of Section 2.1.4.1 and the satellite acquisition time requirements of 2.1.1.8 and the satellite reacquisition requirements of 2.1.1.9. Note that g = acceleration of gravity = 9.8 m/s^2.

Ground Speed	Horiz. Accel.	Vertical Accel.	Total Jerk
250 kt	0.58 g	0.5 g	0.25 g/s

Abnormal maneuvers are defined to be maneuvers having accelerations/jerks that exceed these values, up to the maximum ground speeds and accelerations shown below. Note that g = acceleration of gravity = 9.8 m/s^2.

Ground Speed	Horiz. Accel.	Vertical Accel.	Total Jerk
250 kt	2 g	1.5 g	0.74 g/s

During abnormal maneuvers, the equipment shall not output misleading information. When the aircraft returns to normal maneuvers from abnormal maneuvers, the equipment shall meet the steady-state reacquisition requirements of Section 2.1.1.9. During the abnormal maneuver period, loss-of-navigation and loss-of-integrity monitoring alerts and outputs shall function as specified.

2.1.4.8 Position Output

See Section 2.1.2.6.

2.1.4.8.1 Position Output Update Rate

See Section 2.1.2.6.1.

Note: *The displayed data for LNAV/VNAV must be updated at a 5 Hz rate (see 2.2.4.4.7).*

2.1.4.8.2 Position Output Latency

See Section 2.1.2.6.2.

2.1.4.9 WAAS Message Processing

The minimum message set to be decoded consists of Message Types 0, 1, 2, 3, 4, 5, 6, 7, 9, 10, 17, 18, 24, 25, 26, 27, and 28.

2.1.4.9.1 Message Type 2-5, 6 and 24 Fast Clock Corrections

Message Types 2-5 and 24 shall be processed in accordance with Section 2.1.1.4.3 and Message Type 6 shall be processed in accordance with Section 2.1.1.4.4. In addition, a satellite shall not be used for LNAV/VNAV if the $UDREI_i$ associated with that satellite is 12 or greater. (See Appendix A, Sections A.4.4.3 and A.4.4.8.)

Note: *The exclusion of a satellite for LNAV/VNAV if the $UDREI_i$ is greater than or equal to 12 allows the service provider to designate satellites not to be used for precision approach under certain failure conditions.*

2.1.4.9.2 Message Types 24 and 25 Long-Term Corrections and Message Type 9 GEO Navigation Data

The equipment shall meet the requirements specified in Section 2.1.1.4.11.

2.1.4.9.3 Message Type 18 — Ionospheric Grid Point Masks

Section A.4.4.9 of Appendix A defines a mask of ones and zeros which indicate which grid points have an associated ionospheric delay, developed by the WAAS and given in Message Type 26. The GPS/WAAS equipment shall decode the information in Message Type 18 to accurately and unambiguously identify the grid point latitude and longitude for each correction in the associated Message Type 26. The GPS/WAAS equipment shall be able to store and use two IGP masks per GEO PRN signal. It shall be able, during the transition period between masks, to use corrections with different IODIs simultaneously. This prevents any interruption of service during the IGP mask switching. (See Appendix A, Section A.4.4.9.)

2.1.4.9.4 Message Type 26 — Ionospheric Grid Point Delays

The GPS/WAAS equipment shall decode the Message Type 26 and store the vertical delay and Grid Ionospheric Vertical Error Indicator (GIVEI) at each grid point needed to compute ionospheric corrections for which information is provided by the WAAS.

If the Issue Of Data Ionospheric (IODI) in Message Type 26 does not match that of the applicable previous Message Type 18, the equipment shall continue to use previous estimates until a match is achieved. (See Appendix A, Section A.4.4.10.)

2.1.4.9.5 Message Types 7 and 10 — Degradation Parameters

The equipment shall decode Message Types 7 and 10 as described in Appendix A, Section A.4.4.5 and A.4.4.6. These degradation parameters are used in computing HPL_{WAAS} and VPL_{WAAS} as described in Appendices A and J.

2.1.4.10 Application of Differential Correction Terms

The equipment shall meet the requirements specified in 2.1.1.4.12, except as modified below:

The equipment shall correct the pseudorange as:

$$PR_{i,corrected}(t) = PR_{i,measured}(t) + PRC_i\left(t_{i,of}\right) + RRC\left(t_{i,of}\right) \times \left(t - t_{i,of}\right) + TC_i + IC_i$$

where:

TC_i is the tropospheric model described in Section 2.1.4.10.3

IC_i is the ionospheric model described in Section 2.1.4.10.2.

2.1.4.10.1 Application of Clock and Ephemeris Corrections

Clock and ephemeris corrections are applied as described in Section 2.1.1.4.12.

2.1.4.10.2 Application of Ionospheric Corrections

Section A.4.4.10 of Appendix A defines the vertical ionospheric delays and associated model variances for each grid point identified in Message Type 18. The GPS/WAAS equipment shall first compute an ionospheric pierce point and obliquity angle for each satellite used in the position computation.

The equipment shall compute the ionospheric slant range delay as defined in Appendix A, Section A.4.4.10.4. Satellites for which this correction cannot be computed shall not be used in the position computation for LNAV/VNAV.

2.1.4.10.3 Application of Tropospheric Corrections

Equipment shall apply the tropospheric delay correction specified in Section A.4.2.4.

2.1.4.11 Satellite Selection

In addition to the general requirements of Section 2.1.1.6, the equipment shall select at least two WAAS satellites that are broadcasting correction data (including ionosphere) for the user's location, if they are available. When two WAAS satellites are available, the equipment shall be capable of switching between WAAS data streams to maximize continuity of function.

For procedures defined by a FAS data block, (see Appendix D), the equipment shall only use data from satellites for which the service provider ID in the Type 17 message matches the service provider ID in the FAS data block unless any service provider may be used (ID=15).

The position determination shall not include satellites (GPS or WAAS) with elevation angles below 5 degrees.

For LNAV/VNAV, only satellites designated WAAS HEALTHY shall be used for the position solution.

Notes: ***1.*** *Tracking two WAAS satellites is required in order to enhance continuity of correction information. For best results, it is advisable that the satellite selection algorithm choose satellites for ranging to optimize the performance of the LNAV/VNAV fault detection algorithm, in order to enhance the availability of high integrity. This may mean that no WAAS satellites are used in the position solution, depending upon constraints of the number of satellites incorporated in the position and the satellite geometry.*

2. *If only one WAAS satellite is available, the procedure should be designed such that the WAAS has sufficient continuity so that a missed approach is unlikely (including the effects of failures and WAAS satellite signal blockage).*

3. *For standalone LNAV/VNAV approaches (see Section 2.2.4.3.1), the equipment may use data from any WAAS satellite.*

2.1.4.12 Alerts/Outputs/Inputs

LNAV/VNAV GPS/WAAS equipment will provide, either as data outputs or as display alerts, information when significant conditions occur that affect flight decisions, in particular loss of integrity monitoring or navigation. Such conditions are described in the subparagraphs of 2.1.4.12 for Class Beta-2 equipment. The requirements for Class Gamma-2, Class Gamma-3 and Class Delta-4 equipment can be found in 2.2.4.6, 2.2.5.6 and 2.3.6, respectively.

2.1.4.12.1 Protection Level

Class Beta-2 equipment shall output WAAS-based protection levels (HPL_{WAAS} and VPL_{WAAS}) once per second. The latency of the output of the WAAS-based protection levels shall not exceed 0.7 seconds, from the arrival at the antenna port of the last bit of a message, which affects the horizontal or vertical protection levels to output of the last bit of a message containing the protection levels. The GPS/WAAS equipment shall indicate if the HPL_{WAAS} and VPL_{WAAS} cannot be calculated (insufficient number of WAAS HEALTHY satellites). Note that when the HPL_{WAAS} and VPL_{WAAS} cannot be calculated, LNAV/VNAV is not available.

Note: *The equipment that determines deviation data from the Beta-2 position has been allocated a latency of 0.1 seconds. Class Gamma and Delta equipment requirements can be found in Sections 2.2.4.6, 2.2.5.6 and 2.3.6. Class Gamma and Delta equipment are required to compute the HPL_{WAAS} and VPL_{WAAS}, but are* *not required to output them to an external device, unless the equipment supports ADS-B.*

2.1.4.12.2 Navigation Alert

Class Beta-2 equipment shall provide an indication or output of the loss of navigation capability within one second of the onset of any of the following conditions:

a. The absence of power (loss of function is an acceptable indicator);

b. Probable equipment malfunction or failure (must consider all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5});

c. The presence of a condition where fault detection detects a position failure; or

d. when no valid WAAS message has been received for 4 seconds or more (this indicates a probable communications link problem or WAAS signal blockage).

Class Beta-2 equipment shall also provide an indication or output of the loss of navigation capability within 0.6 seconds of the onset of any of the following conditions:

e. there are fewer than 4 WAAS HEALTHY satellites (e.g., onset of condition is: (1) when satellite is blocked; (2) when the last bit of a WAAS message indicating "Don't Use" arrives at the antenna port).

The alert shall be returned to its normal state immediately upon termination of the responsible condition.

Note: *A navigation alert does not require removal of navigation information from the navigation display. Consideration should be given to continued display of navigation information concurrent with the failure/status annunciation when conditions warrant.*

2.1.5 Requirements for APV-II and GLS Precision Approach Operations

APV-II and GLS approach functional requirements apply to the extended Final Approach Segment (FAS). The FAS is the straight line which prescribes the three-dimensional straight-line path in space that an aircraft is supposed to fly on final approach.

2.1.5.1 Accuracy

See Section 2.1.4.1 and all subsections.

2.1.5.2 Integrity Requirements

2.1.5.2.1 Development Assurance

The hardware and software shall be designed such that the output of misleading information, considered to be a severe-major/hazardous failure condition, shall be extremely remote during a 150-second approach. To demonstrate compliance it will be necessary to conduct a safety assessment to evaluate the system's implementation against known failure conditions.

Note: *The design requirements applicable to this hazard classification depend upon the aircraft type. The following two paragraphs define acceptable means of compliance for the most stringent application of this hazard classification.*

2.1.5.2.1.1 Hardware Compliance

An acceptable means of compliance for GPS/WAAS equipment (precision approach mode) is to show that failures of the equipment that result in misleading information are not more probable than 6×10^{-8}/150 seconds. For complex firmware implementations such as application-specific integrated circuits (ASIC's), processes similar to those described in

RTCA/DO-178B or RTCA/DO-254 provide an acceptable means of compliance with applicable airworthiness requirements.

2.1.5.2.1.2 Software Compliance

AC 20-115B, which references RTCA/DO-178B, provides an acceptable means for showing that software complies with applicable airworthiness requirements. One acceptable approach to software development is to develop all software that affects navigation and integrity functions for precision approach to at least the Level B criteria, as defined in RTCA/DO-178B. Another acceptable approach is to substantiate software levels in the safety assessment.

2.1.5.2.2 Integrity Monitoring

When in GLS or APV-II, the equipment shall compute WAAS-based protection levels (HPL_{WAAS} and VPL_{WAAS}). The equipment shall also perform fault detection, if more than four satellites are available. The presence of integrity monitoring is determined solely on the WAAS-based protection levels, while the detection of a failure is based on both methods of integrity.

Notes: ***1.*** *The GLS or APV-II integrity method is discussed in detail in Section 2.2.5.6 and Appendix E. It has been designed to maximize the detection probability of an error with minimal impact on availability.*

2. *If only 4 satellites are available and WAAS-based protection levels are within the alert limits, GLS or APV-II may be performed.*

2.1.5.2.2.1 WAAS-Provided Integrity Monitoring

See Section 2.1.4.2.2.1.

2.1.5.2.2.2 Fault Detection-Provided Integrity Monitoring

GPS/WAAS equipment shall have a fault detection integrity monitoring capability that utilizes redundant WAAS-corrected GPS and WAAS ranging measurements to provide independent integrity monitoring.

Notes: ***1.*** *If only 4 ranging sources are available, GLS or APV-II can be performed using WAAS integrity only.*

2. *The equipment is required to provide a fault-detection capability in order to detect local anomalies that may not be detectable by WAAS. Since the underlying probability of these anomalies is not quantified, it is not practical to assign a missed alert probability to the fault detection algorithm. Instead the equipment is required to use the information redundancy that is available to the maximum extent possible*

2.1.5.2.2.2.1 Frequency of Fault Detection

For GLS or APV-II, the fault detection algorithm shall be performed at a rate of at least once per minute or within 6 seconds of a change in the set of satellites that are being used in the navigation solution.

Note: *This requirement is consistent with the time to alert requirement of 6 seconds, since it is only intended to detect slowly-changing conditions.*

2.1.5.2.2.2.2 Missed Alert

There is no missed alert probability requirement for GLS or APV-II.

Note: *For the purpose of testing, the vertical protection level ($VPLT_{FD}$) is evaluated on the basis of a missed alert probability of 0.1.*

2.1.5.2.2.2.3 False Alert

See Section 2.1.4.2.2.2.3.

2.1.5.2.2.2.4 Availability

The availability of the fault detection function algorithm for GLS or APV-II to meet the above requirements assuming a missed alert rate of 0.1 and a vertical alert limit of 15 m, when evaluated over the constellations and grids specified in the test procedures (Section 2.5.10), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to 95 percent.

Note: *This requirement is only intended to provide a means to assess the adequacy of fault detection algorithms.*

2.1.5.3 Equipment Reliability

See Section 2.1.4.3.

2.1.5.3.1 GPS Satellites

See Section 2.1.4.3.1.

2.1.5.3.2 GEO Satellites

See Section 2.1.4.3.2.

2.1.5.4 Satellite Tracking Capability

Note: *See Section 2.1.2.4.*

2.1.5.5 Tracking Constraints

See Section 2.1.4.5.

2.1.5.5.1 GPS Tracking Constraints

See Section 2.1.4.5.1.

2.1.5.5.2 SBAS Tracking Constraints

See Section 2.1.4.5.2.

2.1.5.6 Correlation Peak Validation

See Section 2.1.4.6.

2.1.5.7 Dynamic Tracking

See Section 2.1.4.7.

2.1.5.8 Position Output

The GPS/WAAS equipment shall determine a position for navigation. This position shall represent the WGS-84 position of the aircraft antenna (or center of navigation) at the time of applicability. Class Beta-3 shall output this position (latitude, longitude, and height above WGS-84 ellipsoid).

2.1.5.8.1 Position Output Update Rate

The GPS/WAAS Class Beta-3 equipment shall compute and output a position at a 5 Hz rate to support an unaided GLS and APV-II navigator. The equipment shall compute and output at a 1 Hz rate to support a GLS and APV-II navigator that is aided by a separate sensor providing at least 5 Hz data (e.g., inertial). Each computed position shall be dynamically independent of the previous position.

Notes: ***1.*** *To be dynamically independent, a computed position must account for acceleration occurring in the interval since the last position. Extrapolation of position through velocity vectors is not adequate to meet this requirement.*

2. *For any installation, further measures may be required to preserve the dynamic response of the integrated system and insure that the position output data is compatible with other equipment using the position data as an input. This may include filtering and smoothing and an increase in the position output rate.*

2.1.5.8.2 Position Output Latency

For Class Beta-3 equipment that supports an unaided GLS and APV-II navigator, the overall latency, defined as the interval between the time of measurement and time of applicability of the measurement, shall not exceed 300 milliseconds. The output of the data defining the position shall also be completed prior to 300 milliseconds after the time of the measurement. Class Beta-3 equipment that supports a GLS and APV-II navigator that is aided by a separate sensor shall have overall latency that does not exceed 400 milliseconds, and the output of data defining the position shall also be completed prior to 400 milliseconds after the time of the measurement.

Note: *The specified output latency may not be sufficient for all aircraft installations.*

2.1.5.9 WAAS Message Processing

See Section 2.1.4.9.

2.1.5.9.1 Message Type 2-5, 6 and 24 Fast Clock Corrections

Message Types 2-5 and 24 shall be processed in accordance with Section 2.1.1.4.3 and Message Type 6 shall be processed in accordance with Section 2.1.1.4.4. In addition, a satellite shall not be used for GLS or APV-II if the $UDREI_i$ associated with that satellite is 12 or greater. (See Appendix A, Sections A.4.4.3 and A.4.4.8.)

Note: *The exclusion of a satellite for GLS or APV-II if the $UDREI_i$ is greater than or equal to 12 allows the service provider to designate satellites not to be used for precision approach under certain failure conditions*

2.1.5.9.2 Message Types 24 and 25 Long-Term Corrections and Message Type 9 GEO Navigation Data

The equipment shall meet the requirements specified in Section 2.1.1.4.11.

2.1.5.9.3 Message Type 18 — Ionospheric Grid Point Masks

See Section 2.1.4.9.3.

2.1.5.9.4 Message Type 26 — Ionospheric Grid Point Delays

See Section 2.1.4.9.4.

2.1.5.9.5 Message Types 7 and 10 — Degradation Parameters

See Section 2.1.4.9.5.

2.1.5.10 Application of Differential Correction Terms

See Section 2.1.4.10.

2.1.5.10.1 Application of Clock and Ephemeris Corrections

Clock and ephemeris corrections are applied as described in Section 2.1.1.4.12.

2.1.5.10.2 Application of Ionospheric Corrections

Section A.4.4.10 of Appendix A defines the vertical ionospheric delays and associated model variances for each grid point identified in Message Type 18. The GPS/WAAS equipment shall first compute an ionospheric pierce point and obliquity angle for each satellite used in the position computation.

The equipment shall compute the ionospheric slant range delay as defined in Appendix A, Section A.4.4.10.4. Satellites for which this correction cannot be computed shall not be used in the position computation for GLS or APV-II.

2.1.5.10.3 Application of Tropospheric Corrections

See Section 2.1.4.10.3.

2.1.5.11 Satellite Selection

In addition to the general requirements of Section 2.1.1.6, the equipment shall select at least two WAAS satellites that are broadcasting correction data (including ionosphere) for the user's location, if they are available. When two WAAS satellites are available, the equipment shall be capable of switching between WAAS data streams to maximize continuity of function.

For procedures defined by a FAS data block, (see Appendix D), the equipment shall only use data from satellites for which the service provider ID in the Type 17 message matches the service provider ID in the FAS data block unless any service provider may be used (ID=15).

The position determination shall not include satellites (GPS or WAAS) with elevation angles below 5 degrees.

For GLS or APV-II, only satellites designated WAAS HEALTHY shall be used for the position solution.

Notes:

1. *Tracking two WAAS satellites is required in order to enhance continuity of correction information. For best results, it is advisable that the satellite selection algorithm choose satellites for ranging to optimize the performance of the GLS or APV-II fault detection algorithm, in order to enhance the availability of high integrity. This may mean that no WAAS satellites are used in the position solution, depending upon constraints of the number of satellites incorporated in the position and the satellite geometry.*

2. *If only one WAAS satellite is available, the procedure should be designed such that the WAAS has sufficient continuity so that a missed approach is unlikely (including the effects of failures and WAAS satellite signal blockage).*

2.1.5.12 Alerts/Outputs/Inputs

GLS or APV-II GPS/WAAS equipment will provide, either as data outputs or as display alerts, information when significant conditions occur that affect flight decisions, in particular loss of integrity monitoring or navigation. The requirements for Class Gamma-2, Class Gamma-3 and Class Delta-4 equipment can be found in 2.2.4.6, 2.2.5.6 and 2.3.6, respectively.

2.1.5.12.1 Protection Level

Class Beta-3 equipment shall output WAAS-based protection levels (HPL_{WAAS} and VPL_{WAAS}) once per second. The latency of the output of the WAAS-based protection levels shall not exceed 0.7 seconds, from the arrival at the antenna port of the last bit of a message, which affects the horizontal or vertical protection levels to output of the last bit of a message containing the protection levels. The GPS/WAAS equipment shall indicate if the HPL_{WAAS} and VPL_{WAAS} cannot be calculated (insufficient number of WAAS HEALTHY satellites). Note that when the HPL_{WAAS} and VPL_{WAAS} cannot be calculated, GLS or APV-II are not available.

Note: *The equipment that determines deviation data from the Beta-3 position has been allocated a latency of 0.1 seconds. Class Gamma and Delta equipment requirements can be found in Sections 2.2.4.6, 2.2.5.6 and 2.3.6. Class Gamma and Delta equipment are required to compute the HPL_{WAAS} and VPL_{WAAS}, but are not required to output them to an external device.*

2.1.5.12.2 Navigation Alert

Class Beta-3 equipment shall provide an indication or output of the loss of navigation capability within one second of the onset of any of the following conditions:

a. The absence of power (loss of function is an acceptable indicator);

b. Probable equipment malfunction or failure (must consider all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5});

c. The presence of a condition where fault detection detects a position failure; or

d. when no valid WAAS message has been received for 4 seconds or more (this indicates a probable communications link problem or WAAS signal blockage).

Class Beta-3 equipment shall also provide an indication or output of the loss of navigation capability within 0.6 seconds of the onset of any of the following conditions:

e. there are fewer than 4 WAAS HEALTHY satellites (e.g., onset of condition is: (1) when satellite is blocked; (2) when the last bit of a WAAS message indicating "Don't Use" arrives at the antenna port).

The alert shall be returned to its normal state immediately upon termination of the responsible condition.

Note: *A navigation alert does not require removal of navigation information from the navigation display. Consideration should be given to continued display of navigation information concurrent with the failure/status annunciation when conditions warrant.*

2.2 Class Gamma Requirements

The requirements of Section 2.2 apply to Class Gamma equipment. Section 2.2.1 applies to all operational classes and all navigation modes, while Sections 2.2.2 through 2.2.5 define the additional requirements for the en route/terminal mode, nonprecision approach mode, LNAV/VNAV, and precision approach mode. GPS/WAAS equipment must meet all of the requirements for the applicable navigation modes, depending on the Operational Class.

2.2.1 Class Gamma General Requirements

2.2.1.1 General Human Factors Requirements and Applicable Documents

Note: *The requirements in this section are intended to provide a consistent application and interpretation of the human factors issues associated with developing equip-*

ment to be used as a primary means of navigation. These requirements are intended to provide design guidance, and it is not implied that every "shall" must be specifically tested. The test procedures described in Section 2.5.10 further define these requirements by describing a method of determining compliance, and it is recommended that the test procedures be reviewed in conjunction with these requirements.

Controls and displays should be consistent with the referenced human factors guidelines below. Controls and displays should be designed to maximize operational suitability, minimize pilot workload, and minimize the possibility of human error associated with equipment operations. Maintaining situational awareness is a key factor in catching errors.

Guidelines for the design of the human factors aspects of controls displays and operating procedures are available in the following documents:

- FAA-AC 25-11 Transport Category Airplane Electronic Display Systems (AC 25-11), July, 1987
- SAE Aerospace Recommended Practice 4102-4 Flight deck alerting systems (ARP 4102-4), July, 1988
- SAE Aerospace Recommended Practice 4102-7 Electronic Displays (ARP-4102-7), July, 1988
- Military Standard 1472D, Human engineering design criteria for military systems, equipment, and facilities, 1989
- SAE <u>Aerospace Standard on Nomenclature and Abbreviations for Use on the Flight Deck</u> SAE AS 425C), December, 1985
- Title 14, Code of Federal Regulations, part 25.1322 (14 CFR part 25.1322)
- Guidelines for the Design of GPS and LORAN Receiver Controls and Displays, Huntley, M.S.,1995, DOT/FA/RD-95/1, DOT-VNTSC-FAA-95-7 (Huntley, 1995)

Relevant portions of the first three documents and others are reviewed and abstracted in (Huntley, 1995). This document also includes background information and additional relevant detail required for display and control design issues identified below.

Where multiple actions are necessary to accomplish a function, the equipment shall provide contextual information of the active subfunction or mode (e.g., NAV, FPL).

2.2.1.1.1 Controls

The design and operation of controls should be consistent with the principles and specifics presented in the above documents.

2.2.1.1.1.1 Operation

Controls that are normally adjusted in flight shall be accessible without interfering with the visibility of critical displays. Controls shall provide clear tactile or visual feedback when operated. The controls shall be movable without excessive effort and detents shall be well defined. Control spacing, physical size, and control logic shall be sufficient to avoid inadvertent activation. Controls shall be operable with the use of only one hand.

2.2.1.1.1.2 Control Labels

Labels shall be readable from viewing distances of 30 inches, under anticipated lighting conditions (Section 2.5.11.2.2). Labels should be unobstructed by controls when viewed within the angle of regard, and located next to or on the controls that they reference. Label placement should follow a consistent logic. Terminology for labeling should describe the function of the control in meaningful terms. Terms should be consistent with those on the display of the function or mode selected and spelled out whenever possible.

2.2.1.1.2 Equipment Operating Procedures

Equipment operating procedures should be designed to maximize operational suitability, minimize pilot workload, and minimize reliance on pilot memory. Detectability of operating errors should be maximized. The actions required to recover from errors should be intuitive, quick, and with minimum impact on subsequent operations. Where possible, maximum use of prompting should be used to minimize reliance on pilot memory.

Operating rules and use of controls required to implement equipment functions should be consistent from mode to mode.

Use of prompting cues shall be consistent. For example, if used as such a cue, illumination of controls would always indicate that the illuminated control should be used next.

2.2.1.1.3 Minimum Workload Functions

Operations that occur with a high frequency or are conducted under potentially stressful operating conditions (e.g., missed approaches) must be possible with a small number of control operations. The number of operations may be minimized through the use of dedicated controls, anticipation of pilot requirements and the use of quick-access menus designed to facilitate rapid selection of required navigation functions, such as direct flight to a waypoint and returning to the final approach course after a missed approach.

The tasks shown in Table 2-4 shall be capable of being accomplished within the indicated time (as a bench test without distraction). The number of actions is included as a guideline. Both the time and number of actions are worst-case, regardless of where the function is initiated (i.e., the pilot may be in the middle of doing something else before initiating the function). An action is defined as a discrete action: e.g., a single button push or a continuous turn of a knob, even if the knob must be turned multiple times. It is acceptable to exceed the maximum number of actions, provided the particular actions required are easy to accomplish and result in a comparable pilot workload (e.g., repeated button pushes of the same button).

In order to reduce negative transfer between equipment, the recommended pilot procedure to accomplish these functions is included in Table 2-4.

TABLE 2-4 SAFETY-CRITICAL FUNCTIONS

Function	Recommended Maximum Number of Actions	Maximum Time to Accomplish	Recommended Pilot Procedure
En route/terminal-related functions:			
Access primary navigation information (see Section 2.2.1.1.4.7)	1	2 seconds	Select primary navigation display.
Suspend automatic sequencing or Hold at the active waypoint (ref. Section 2.2.1.3.11)	2 5	2 seconds 10 seconds	Select SUSP Select [holding] function, select course
Direct to any named waypoint in a published departure, arrival, or approach procedure already in active flight plan (including selecting the waypoint)	5	10 seconds	Select waypoint, then select Direct-To.
Direct to any waypoint in the database, but not in the active flight plan (including selecting a five character waypoint)[1]	14	20 seconds	Select waypoint, then select Direct-To or Select Direct-To function, then select waypoint.
Select a course to or from an active waypoint	4	10 seconds	Select desired course on [OBS] or Select "course to/from" function, then select course.
Select one of the 9 nearest airports and go Direct.	4	10 seconds	Select NRST function, select airport, select Direct-To
Approach-Related Functions:			
Select and activate an approach at the departure airport, which may be pre-programmed as alternate flight plan.	5	10 seconds	Select airport, select approach. or Select and activate the pre-programmed flight plan.
Select and activate an approach at an airport, given that the airport is the active waypoint	11	13 seconds	Select approach, activate

Function	Recommended Maximum Number of Actions	Maximum Time to Accomplish	Recommended Pilot Procedure
Initiation of the missed approach procedure (ref. Section 2.2.3.2.2) upon sequencing the MAWP, if manually initiated.	2	2 seconds	Pilot procedure may vary with published missed approach procedure.
Anytime after the IAWP, repeat the approach with the same IAWP (including providing guidance to the IAWP)	5	10 seconds	Select IAWP, select Direct-To.
Initiate a different approach, or the same approach with a different IAWP, at the same airport as a previously selected or activated approach, either before, during, or after conducting the original approach (including providing guidance to the IAWP)	8	10 seconds	Select approach, select IAWP, initiate guidance to IAWP
Selecting a Vector-to-Final (VTF) to the approach in the active flight plan when in either terminal or approach mode	6	8 seconds	Select VTF.

Notes: **1.** *The "Recommended Pilot Procedure" column describes one or more means, but not the only means, for a receiver to be considered readily intuitive for a pilot with minimum experience and some training in using WAAS receivers. Receivers not using these standards should demonstrate an equivalent level of simplicity.*

2. *The "Recommended Maximum Number of Actions" column presumes that the selected waypoint is not a duplicate, as selecting a waypoint from a list of duplicates may involve additional actions.*

2.2.1.1.4 Displays

Note: *Additional information on electronic displays can be found in AC-25-11.*

2.2.1.1.4.1 Discriminability

Alerts and symbols shall be distinctive and discriminable from one another. If a control is used to perform multiple functions, the functionality shall be clearly distinguished. There should be a clear indication when any control is in an altered state and not the default (e.g., if a knob is pulled out and functions differently). Fields that are editable, selectable, or require operator entry should be clearly denoted.

The equipment should provide an indication when additional information (e.g., pages) is available.

2.2.1.1.4.2 Brightness, Contrast and Color

Displays shall be readable and colors shall be discriminable under anticipated lighting conditions (Section 2.5.11.2.2). Aviation conventions should be observed when using colors for coding. Color coding of safety-critical information should be accompanied with another distinguishing characteristic such as shape or location. No more than five colors should be used on the display. When color is used to distinguish between functions and indications, red shall not be used other than for warning indications (hazards which may require immediate corrective action). Amber (yellow) shall be reserved for caution indicators. Blue should be avoided because it is difficult for the human eye to bring blue symbols into focus and to distinguish the color from yellow when the symbols are small. (Ref. AC 25-11 for generally accepted aviation practices.)

2.2.1.1.4.3 Angle of Regard

All displays shall be fully readable up to a horizontal viewing angle of 35 degrees from normal to the face of the display screen. They shall be fully readable up to a vertical viewing angle of 20 degrees from normal to the face of the display screen. This angle of regard does not ensure that the equipment may be installed in any aircraft; it is recommended that the angle of regard be maximized to increase the flexibility of the equipment for installation.

2.2.1.1.4.4 Symbology

Displays should use characteristics and symbols similar to those shown on published charts and sectionals or with commonly accepted aviation practices. The potential for misinterpreting symbols should be minimized. Symbols used for one purpose on published charts should not be used for another purpose on the equipment display. Guidelines for electronic display symbology are provided in SAE ARP 4102-7.

2.2.1.1.4.5 Alphanumerics

Display of letters and numbers depicting primary data shall be readable from viewing distances of 30 inches under anticipated lighting conditions (Section 2.5.11.2.2). The required size may depend upon the display technology used. Initial guidelines for symbol sizes for the indicated categories of information are:

0.18” for primary data

0.12” for secondary data

0.09” for legends

Note: *Installation restrictions may be used to compensate for limitations of display designs.*

Information critical to determining the location and closure rate of the aircraft on the active waypoint and desired track and the name of that waypoint should be presented in a manner that facilitates rapid cross-checking by the pilot. This information should be differentiated from other information, and it should be located in a consistent manner (including order and position). Except on map displays, the initial approach, final approach, missed approach and missed approach holding waypoints shall be labeled clearly when used as part of an approach procedure. If space limitations require the use of abbreviations, see Section 2.2.1.1.7.

2.2.1.1.4.6 Moving Map

Map displays contribute significantly to pilot positional awareness, facilitate the location of crew programming errors, and provide important checks on the location of waypoints that define instrument approach procedures. However, because they are so compelling and believable, it is essential that they be designed and implemented with care. If a moving map is provided, the following requirements apply.

It should be easy to cross-check map formats with paper renditions of the same information, such as instrument approach procedure charts and sectionals. Map scale shall be appropriate and clear. Map update rates shall be appropriate for approach, terminal and en route operations. Map orientation, such as north-up or track-up, shall be capable of being displayed on the map page and shall be pilot selectable, if multiple orientations are available. Location and track of the aircraft shall be shown on the plan view and on the profile view if available. The display of obstructions shall reflect database precision. If the map is used as a primary means of steering guidance, the accuracy determination should take into account any error contribution of the cartography.

Note: *RTCA SC-181 has developed RTCA/DO-257*, Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps. *Manufacturers should comply with these standards.*

2.2.1.1.4.7 Primary Navigation Display

As discussed in Sections 2.2.1.4, 2.2.3.4, and 2.2.4.4 below, it is permitted to use a selectable display, in lieu of continuous display, for certain primary navigation display parameters. If a selectable display is used for this purpose, reconfiguring the display to access the primary navigation information shall require a maximum of two operator actions.

The display design should accommodate the installation requirements of Section 3.3.1.1.1.

2.2.1.1.4.8 Bearing Labels

All bearing data fields shall be labeled as "°" to the right of the bearing value. All true bearing data fields shall be labeled as "°T" to the right of the bearing value. The "°T" label could be indicated with a single or two characters. (This applies to all courses, tracks, and bearings).

2.2.1.1.5 Annunciations

Visual annunciations shall be consistent with the criticality of the annunciation and shall be readable under all cockpit illumination conditions (See Section 2.5.11.2.2). Visual annunciations shall not be so bright or startling as to reduce pilot dark adaptation. The use of colors to code annunciations should follow color conventions described in AC 25-11, SAE ARP 4102-4, and 14 CFR, part 25.1322.

Auditory alerts have the advantage of being useful regardless of the pilots head and eye orientation, but their use with GPS/WAAS equipment should be considered with care to avoid compromising other auditory alerts that may be available in the cockpit. Application of such alerts should be consistent with ARP 4102-4 and adaptable to the annunciator philosophy of the aircraft. Auditory alerts should not be used as the sole source of information, but to draw the pilots attention to information on a visual display, and they should be detectable by the pilot when wearing a headset.

Warnings, annunciations, and messages not critical to the safety of instrument approaches or missed approaches should be suppressed during those phases of terminal operations.

2.2.1.1.5.1 Annunciators

A simple font should be used for all alphanumerics. Characters used on alert and status indications should be of the size and brightness necessary to be readable without error or strain under anticipated lighting conditions (Section 2.5.11.2.2). Brightness shall be controllable, which does not preclude automatic adjustment. The equipment shall provide the capability to test all external annunciators.

2.2.1.1.5.2 Messages

Messages should be grouped by urgency level and listed chronologically within each group. All current messages shall be retrievable. An indication shall be provided to identify new messages. The equipment should also indicate when there are current messages.

2.2.1.1.6 Set of Standard Function Labels

Table 2-5 lists potential functions and indications, and provides the associated label or message associated. Not all of these functions are required. If a function is implemented as a discrete action, the equipment shall use the labels or messages in the Table. If several of the following functions are accomplished as a discrete action, one of the applicable labels in Table 2-5 shall be used (e.g., suspend automatic sequencing and accessing the ability to select a course to or from a waypoint would be labeled “DCRS”). Except for waypoint identifiers, these abbreviations shall not be used to represent a different term.

TABLE 2-5 LABELS AND MESSAGES

Function	**Label/Message**
Enter, confirm or acknowledge	Enter (ENT)
Suspend / unsuspend automatic waypoint sequencing	Suspend (SUSP)
Access to selecting a course to or from a waypoint	OBS, CRS[1]
Clear previous entry, no, or delete	Clear (CLR)
Activates and deactivates the cursor	Cursor (CRSR)
Access to a message	Message (MSG)
Access Direct-To function	Direct To (D→)
Access to nearest airports or other fixes	Nearest (NRST)
Access to flight planning functions	Flight Plan (FPL)
Select Vectors-to-Final (Section 2.2.3.2.1)	Vectors-to-Final (VTF)
Access to primary navigation display (Section 2.2.1.4.1)	NAV
Annunciations	
Indication that there is a message	Message (MSG, M)
Indication of loss of integrity monitoring	LOI “Loss of Integrity - Cross Check Nav.”
Indication of impending turn	WPT (flashing)[2], or “Turn to [next heading] in [distance] nm”
Indication of start of turn	WPT (continuously lit, not flashing)[2], or “Turn to [next heading] now”

[1] If this function is accomplished using a button, it shall be labeled “OBS” to avoid confusion with “CRSR”. For display of the selected course, including the ability to select that course, it may be labeled “OBS” or “CRS”.

[2] This can be used to indicate other conditions (e.g., waypoint alerting).

2.2.1.1.7 Set of Standard Abbreviations and Acronyms

When using abbreviations and acronyms, the following abbreviations and acronyms should be used for the terms below, including use in checklists, messages, identification and labels for control functions. These abbreviations should not be used to represent a different term, and they shall be used consistently in the design of the pilot handbook supplements, quick reference checklists and the controls and displays of the equipment.

Note: *These requirements are intended to increase the compatibility and consistency between different GPS/WAAS equipment. This will become more important as GPS/WAAS equipment begins to replace VOR and DME equipment as the basic navigation capability. It is not the intent of this list to require upper case abbreviations, as many of these abbreviations may be clearly represented in a combination of upper and lower case type. In all cases the meaning should be easily construed and remain consistent in a given piece of equipment.*

Acknowledge (ACK)
Active, Activate (ACT, ACTV)
Airport, aerodrome (APT)
Air Traffic Control (ATC)
Alert/Alerting (ALRT)
Altitude (ALT)
Along-Track Distance (ATD)
Along-Track Error (ATE)
Along-track (ATK)
Approach, Approach control (APPR, APR)
Approach with Vertical Guidance (APV-II, APV)
Area navigation (RNAV)
Arm, Armed (ARM)
Barometric setting (BARO)
Bearing (BRG)
Cancel (CNCL)
Center runway (C)
Centigrade (C)
Clear (CLR)
Coordinated universal time (UTC)
Course (CRS)
Course Deviation Indicator (CDI)
Course to Fix (CF)
Cross-track (XT, XTK)
Cross-track error (XTE)
Cursor (CRSR)
Database (DB)
Dead reckoning (DR)
Decision Altitude (DA)
Delete (DEL)
Departure, Departure control (DEP)
Desired Track (DK, DTK)
Destination (DEST)
Dilution of Precision (DOP)
Direct, Direction (DIR)
Direct-To (direct symbol, D with arrow)
Direct-To Fix (DF)
Distance (DIS, DIST)
Drift Angle (DA)
East (E)
Emergency Safe Altitude (ESA)
En Route (ENR)

En Route Safe Altitude (ESA)
Enter (ENT)
Estimated Time of Arrival (ETA)
Estimated Time of Departure (ETD)
Estimated Time En route (ETE)
Fahrenheit (F)
Feet, foot (‘, FT)
Feet per Minute (FPM)
Final Approach Waypoint, for waypoint identifiers (f, FA, FAWP)
Flight Level (FL)
Flight Plan (FPL)
From (FR)
Full-scale Deflection (FSD)
Global Navigation Satellite System (GNSS) Landing System (GLS)
Global Positioning System (GPS)
Greenwich Mean Time (GMT)
Ground speed (GS)
Heading (HDG)
Height Above Threshold (HAT)
Hold, holding, holding pattern (HLD)
Horizontal Alert Limit (HAL)
Horizontal Protection Level (HPL)
Horizontal Situation Indicator (HSI)
Horizontal Uncertainty Level (HUL)
Instrument Flight Rules (IFR)
Initial approach waypoint, for waypoint identifiers (i, IA, IAWP)
Intermediate Waypoint (IWP)
Intersection (INT)
Lateral Navigation (LNAV)
Lateral Navigation/Vertical Navigation (LNAV/VNAV, L/V)
Latitude (LAT)
Left (L, LFT)
Left runway (L)
Localizer (LOC)
Localizer-type Directional Aid (LDA)
Longitude (LON)
Magnetic (M, MAG)
Mean Sea Level (MSL)
Message (MSG)
Meters (M)
Military Operating Area (MOA)
Millibars (mB)
Minimum Descent Altitude (MDA)
Minimum En route Altitude (MEA)
Minimum Safe Altitude (MSA)
Missed-approach holding waypoint (h, MH, MAHWP)
Missed-approach waypoint, for waypoint identifiers (m, MA, MAWP)
Nautical Mile (nm, NM)
Nautical miles per hour, Knots (KT)
Nearest (NRST)
Non-Directional Beacon (NDB)
Non-precision approach (NPA)

North (N)
Offset (OFST)
Off route obstacle clearance altitude (OROCA)
Omni-bearing selector (OBS)
Outer marker (OM)
Parallel track (PTK)
Precision approach (PA)
Present position (PPOS, PP)
Procedure (PROC)
Procedure turn (PT)
Radial (R, RAD)
Radial/Distance (R/D)
Radius to fix (RF)
Range (RNG)
Receiver Autonomous Integrity Monitoring (RAIM)
Relative bearing (RB)
Required Navigation Performance (RNP)
Reverse, revision, revise (REV)
Right (R, RT)
Right runway (R)
Route (RTE)
Runway (RWY)
Selective Availability (SA)
Sequence, sequencing (SEQ)
Setup (SET)
South (S)
Special Use Airspace (SUA)
Standard Terminal Arrival Route (STAR)
Suspend (SUSP)
Temperature (TEMP)
Terminal (TERM, TER)
Test (TST)
Threshold Crossing Height (TCH)
Time to alert (TTA)
To (TO)
To/From (T/F)
Tower (TWR)
Track (TK, TRK)
Track to fix (TF)
Track Angle Error (TKE)
Transition Altitude (TA)
Transition Level (TL)
True (T)
True airspeed (TAS)
True heading (TH)
Variation (VAR)
Vector (VECT)
Vector to Final (VTF)
Vertical Alert Limit (VAL)
Vertical Navigation (VNAV, VNV)
Vertical Protection Level (VPL)
Vertical speed (VS)

Vertical track (VTK)
Vertical Track Error (VTE)
Vertical Uncertainty Level (VUL)
VHF Omni-directional Range (VOR)
Visual Flight Rules (VFR)
Warning (WARN, WRN)
Waypoint (WPT)
West (W)
Wide Area Augmentation System (WAAS)
World Geodetic System (WGS)

2.2.1.2 Path Selection

Note: *The inherent nature of RNAV procedures requires that a series of waypoints can be connected to define a procedure. In this document, the term "flight plan" is used to refer to this basic concept, and can refer to any sequence of waypoints which are interconnected (such as an approach procedure). The equipment should allow the pilot to select and activate an approach procedure without specifically accessing the flight plan functions defined in Section 2.2.1.2.*

2.2.1.2.1 Flight Plan Selection

The equipment shall be capable of accommodating an active flight plan of at least twenty discrete waypoints. The equipment shall also be capable of maintaining at least one alternate flight plan. If named automatically, the equipment should label the flight plans with the departure and arrival airports when any flight plan is presented for review, edit, activation, or deletion. If no departure or arrival airport is identified, the flight plan should be labeled with the first and last waypoints as appropriate.

The equipment shall be capable of creating these flight plans, consisting of at least the following items, strung together in any order:

a. The ability to select a procedure by name, and automatically include the series of waypoints and paths that define the procedure (refer to database requirements in Sections 2.2.3.5, 2.2.4.5 and 2.2.5.5, for a discussion of the appropriate procedures);

b. The ability to individually select waypoints by name as part of the flight plan. Waypoint names shall be consistent with published names. The equipment shall provide a minimum 5-character field for input and display of database fix identifiers. Airport identifiers shall be accessible using standard ICAO nomenclature when available (e.g., KJFK);

c. The ability to manually select user-defined waypoints as part of the flight plan. (The equipment must provide the capability to manually enter user-defined waypoints as required in Section 2.2.1.2.6.)

The equipment shall provide a means for the operator to differentiate between duplicate waypoint identifiers in the database, including waypoints in the navigation database and user defined waypoints.

2.2.1.2.2 Flight Plan Review

The equipment shall provide a means to readily display each waypoint of any flight plan for review. The active leg or waypoint shall be identified as such. The equipment should provide a means for the pilot to be able to verify the waypoints in the flight plan (e.g., leg distance, desired leg track, or total flight plan distance).

The equipment shall provide the ability to edit the flight plan, including the ability to insert or delete any waypoint in the flight plan other than those waypoints which are part of a published procedure (departure, arrival, approach). For those waypoints which are part of a published procedure, the equipment shall provide the capability to bypass waypoints or proceed to a waypoint not part of the published procedure. Modifying the final approach segment (i.e., inserting a waypoint between the FAWP and MAWP or bypassing the FAWP or MAWP) shall disable the approach mode.

The equipment shall allow the operator to replace a procedure (i.e., departure, arrival or approach) with a different procedure without first deleting the procedure. The equipment shall prompt the operator before replacing a procedure.

When a flight plan is being reviewed or edited, any change shall not be incorporated into the flight plan until that change has been accepted.

The time lag between accepting changes to an active flight plan and outputting navigation guidance derived from the modified flight plan shall not exceed five seconds.

2.2.1.2.3 Flight Plan Activation

Means shall be provided for the pilot to select and activate a flight plan. Prior to activating the flight plan, the equipment shall ensure that the data in the flight plan or obtained from the database is valid. For example, the equipment may verify the entire database upon initial power-up, provided the corruption of the data after verification is improbable. If the database is not available or fails a verification check, the equipment shall continue to function, preventing access to the invalid data (but still providing access to valid data, including user-defined waypoint functions).

Note: *The location of a waypoint can change without a change to the name of the waypoint, so it is not adequate to only check the name. When a flight plan includes a procedure (e.g., an approach procedure), the entire procedure should be confirmed as the published procedure may have changed by adding/deleting a waypoint, moving a waypoint, etc.*

2.2.1.2.4 Waypoint Sequencing

For To-To navigation, the equipment shall automatically sequence waypoints in the active flight plan. If automatic sequencing is suspended for any reason, the equipment shall retain the active flight plan for later selection.

If the equipment provides the capability to suspend and unsuspend automatic sequencing as a discrete action (SUSP), the equipment shall continuously annunciate when waypoint sequencing has been suspended. When the pilot deselects SUSP mode, automatic sequencing of waypoints shall resume upon reaching the current waypoint if the current waypoint is in the flight plan. If the current waypoint is not in the flight plan, the equipment should facilitate rejoining the flight plan.

Note: *Waypoint sequencing may be suspended for a number of reasons, including: manually accomplishing procedure turns and holding patterns; initial leg of a missed approach procedure; and defining a course to/from a fix. It is possible to accomplish these functions without a unique manual ability to suspend automatic sequencing.*

2.2.1.2.5 Manually-Selected Active Waypoint

2.2.1.2.5.1 Direct To

The equipment shall provide the capability to fly from the present position Direct To any designated waypoint.

2.2.1.2.5.2 TO/FROM Course Selection

The equipment shall provide a means of selecting and displaying an active waypoint and a desired course TO or FROM that waypoint. The minimum entry and display resolution of such a selected course shall be 1 degree. The equipment shall provide the capability to intercept any course to a designated waypoint (CF path). The equipment shall provide an indication, capable of installation in the normal field of view, of whether the equipment is in TO or FROM operation.

2.2.1.2.5.3 Manually-Selected Waypoint and Waypoint Sequencing

If the desired "TO" waypoint is selected from the active flight plan, automatic sequencing of the remaining waypoints in the active flight plan shall continue following the "TO" waypoint.

If the desired "TO" waypoint is **not** selected from the active flight plan, the waypoints in that flight plan shall be retained. When the manually selected waypoint is crossed, the equipment shall automatically enter FROM operation, maintaining the prior track. The equipment shall remain in FROM operation until the pilot manually selects another TO waypoint, either on the active flight plan or not.

Note: *When the desired waypoint is selected from the flight plan, it is recommended that the equipment facilitate the pilot intercepting the course or track defined by the flight plan leg leading to the desired waypoint.*

2.2.1.2.6 User-Defined Waypoints

The equipment shall provide the capability to manually enter and display (prior to its utilization in the flight plan) the coordinates of a waypoint in terms of latitude and longitude with a resolution of 0.1 minute or better. The equipment shall also provide the capability to create a waypoint at the present position.

The equipment shall provide the ability to enter a waypoint as a range and bearing from another waypoint, with range resolution of 0.1 nm and bearing resolution of 1 degree or better.

Note: *If space permits, the equipment should automatically name user-defined waypoints. Standardized names are recommended for waypoint/radial/distance waypoints (e.g., LAX240/20). For waypoints entered as a lat/lon, a standardized name is not practical.*

2.2.1.2.7 Emergency Procedures

The equipment shall provide the capability to determine at least the nearest (NRST) 9 airports, and shall provide the capability to fly directly to any of them. If the NRST function provides access to other types of waypoints, airports should be the default to support rapid identification of a nearby airport in case of an emergency.

Note: *The equipment should provide additional information about the runways and approaches available at the nearest airports (e.g., display of the runway length and communication frequencies).*

2.2.1.3 Path Definition

The GPS/WAAS equipment shall define a desired flight path based upon the active flight plan. The current position of the aircraft shall be determined relative to that desired path in order to determine cross-track deviation. Except as specifically noted, the equipment shall auto-sequence from one waypoint to the next, in accordance with the flight plan, along the flight path. The desired path shall be defined according to the leg type:

TF leg: straight segment between two waypoints

CF leg: straight segment following a course to a waypoint

FROM leg: straight line following a course from a waypoint

In defining any leg that is predicated on course guidance, the local declination (if available from the database) shall be used; otherwise the mag-var model shall be used. Other leg types are optional. If the equipment is designed to perform DME arcs or RF legs (constant radius turn segment), it shall meet the requirements in Section 2.2.1.3.3.

The equipment shall not permit the flight crew to select a procedure or route that is not supported by the equipment, either manually or automatically (e.g., a procedure is not supported if it incorporates an RF leg if the equipment does not provide RF leg capability).

Note: *Procedures (approaches, arrivals, departures) are expected to be defined by a series of waypoints and leg types. RNAV procedures (including GPS approaches) will be defined such that they can be coded using only the leg types defined above. In addition, all overlay procedures can be coded using manual procedures and the leg types above.*

2.2.1.3.1 Initial Fix (IF)

An initial fix is defined by a fixed waypoint. An initial fix is used only to define the beginning of a route.

Note: *An initial fix does not define a desired track in of itself, but is used in conjunction with leg type (e.g., TF) in order to define the desired path.*

2.2.1.3.2 Fixed Waypoint to a Fixed Waypoint (TF)

A TF leg shall be defined by a WGS-84 geodesic path between two fixed waypoints (Figure 2-4). The first waypoint is either the previous leg termination in the flight plan or an IF.

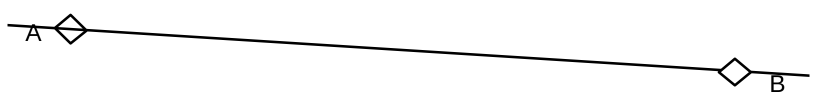


FIGURE 2-4 TF LEG

2.2.1.3.3 DME Arcs (AF) and Constant Radius to a Fix (RF)

If the ability to perform DME arcs is provided, the equipment shall permit the pilot to readily accomplish such procedures in accordance with published non-precision approach procedures utilizing piloting techniques similar to those applicable to use of the reference DME facility. This capability may be coded as an arc-to-a-fix (AF) leg type in accordance with ARINC 424.

Note: *The equipment should ensure that the non-numerical cross-track information is portrayed relative to the published arc or is flagged.*

If the equipment is designed to perform RF legs, an RF leg shall be defined by a constant radius circular arc path about a defined turn center that terminates at a fixed waypoint. The termination fixed waypoint, the turn direction of the leg and the turn center are provided by the navigation database. The radius shall be computed as the distance from the turn center to the termination waypoint by the navigation computer. The beginning of the leg shall be defined by the termination waypoint of the previous leg, which must also lie on the arc. The preceding and following legs are tangent to the arc. See Figure 2-5.

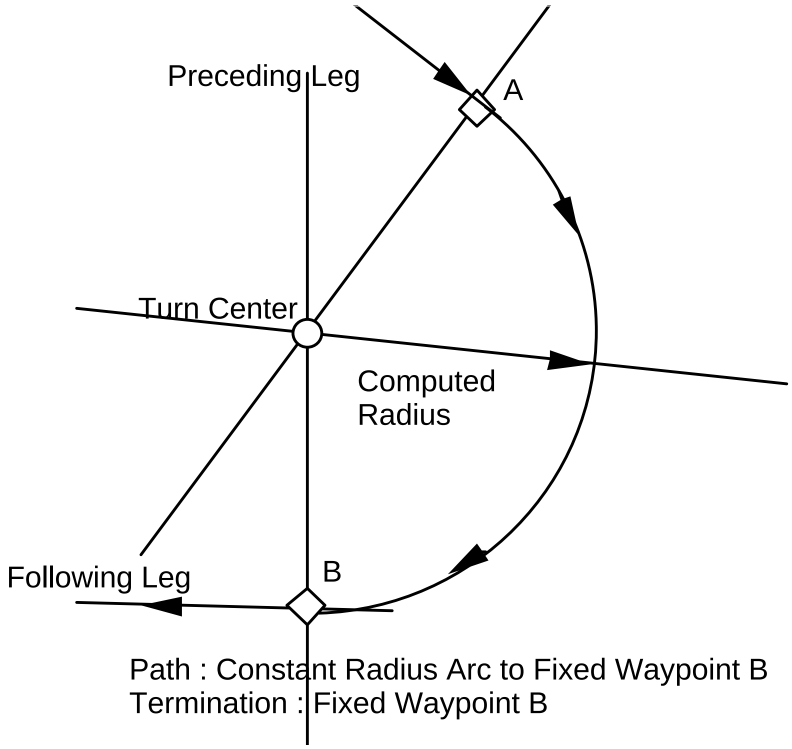


FIGURE 2-5 RF LEG

2.2.1.3.4 Direct-To (DF)

The navigation system shall have a Direct-To function that has the following characteristics:

a. The Direct-To function shall be able to be activated at any time by the flight crew, when required. The Direct-To function shall be available to any fix.

b. The system shall be capable of generating a geodesic path to the designated "To" fix. The aircraft shall capture this path without "S-turning" and without undue delay.

The required transition is shown in Figure 2-6. Procedural techniques may be an acceptable means of meeting this requirement (e.g., selecting Direct-To several times if the equipment does not account for the change in aircraft heading).

Note: *Reinitialization of the Direct-To function following completion of most of the required track change may be an acceptable means of compliance for equipment which does not account for the change in aircraft heading.*

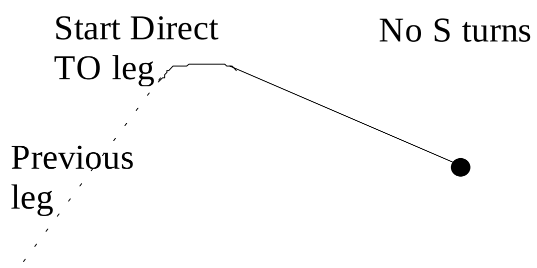


FIGURE 2-6 DIRECT-TO PATH DEFINITION

2.2.1.3.5 Course to a Fix Waypoint (CF)

A CF leg shall be defined by a WGS-84 geodesic path that terminates at a fixed waypoint with a defined course. The course may be defined as magnetic or true. See Figure 2-7.

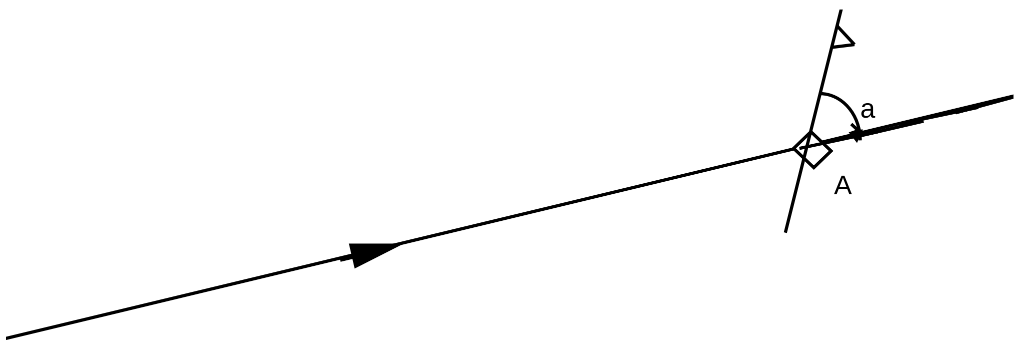


FIGURE 2-7 CF LEG

2.2.1.3.6 FROM Leg

The equipment shall provide the capability to define a desired course from a waypoint. That course shall define a WGS-84 geodesic path that passes through the FROM waypoint with the desired course.

2.2.1.3.7 Fly-By Turns

The equipment shall provide fly-by turn capability. The equipment should provide deviations through the turn.

Unless otherwise designated by a procedure, all turns with heading changes of less than or equal to120 degrees shall be accomplished as fly-by turns.

Note: *The fly-by performance of the equipment will be evaluated when installed in an aircraft. Consideration should be given to coupled operation, bank angles, altitude and different airspeeds. Systems that rely on procedural means (i.e., do not provide guidance through turns) to accomplish the turn may not be able to be coupled to left-right deviation autopilots.*

2.2.1.3.7.1 Fly-By Turn Indications

The equipment shall provide an indication at the start of a defined turn, to indicate to the pilot that the turn has begun. (See Figure 2-10.)

The equipment shall provide an indication prior to the start of a defined turn, to indicate to the pilot that a turn is anticipated. It is recommended that this indication be provided 10 seconds prior to the turn initiation distance for turns up to 120 degrees, and 30 seconds prior to turn initiation for turns of 120 degrees or more. (See Figure 2-10.) The equipment shall provide an indication of the desired course of the next active leg no later than the onset of the turn anticipation indication.

Note: *These requirements may be satisfied through the use of a moving map display if it is the primary navigation display and it provides adequate representation of the turn to ensure that the turn is initiated at the correct point.*

2.2.1.3.7.2 Fly-By Theoretical Transition Area

The defined path shall ensure that the turn is accomplished within the theoretical transition area defined below.

There are no turn requirements for turns greater than 120 degrees.

The theoretical transition area is defined by the region circumscribed by the two legs and an arc with radius R that intercepts the first leg at a distance of Y from the transition way-point. The values of R and Y are defined for various operations:

Region	Track Change (α)	Max. Radius (R)	Max. Turn Initiation Distance (Y)
High Altitude (above 19,500 ft)	< 24.1°	93.7 nm	$R\tan\left(\frac{\alpha}{2}\right)$
	≥ 24.1°	$\frac{Y}{\tan\left(\frac{\alpha}{2}\right)}$	20 nm
Low Altitude (below 19,500 ft)	≤ 46.0°	$\frac{Y}{\tan\left(\frac{\alpha}{2}\right)}$	3.65 nm
	> 46.0°	8.59 nm	$R\tan\left(\frac{\alpha}{2}\right)$
Feeder, Missed Approach and Departure	≤ 46.0°	$\frac{Y}{\tan\left(\frac{\alpha}{2}\right)}$	1.78 nm
	> 46.0°	4.18 nm	$R\tan\left(\frac{\alpha}{2}\right)$
Initial Approach	≤ 46.0°	$\frac{Y}{\tan\left(\frac{\alpha}{2}\right)}$	1.45 nm
	> 46.0°	3.41 nm	$R\tan\left(\frac{\alpha}{2}\right)$
Intermediate Approach	≤ 46.0°	$\frac{Y}{\tan\left(\frac{\alpha}{2}\right)}$	1.00 nm
	> 46.0°	2.38 nm	$R\tan\left(\frac{\alpha}{2}\right)$

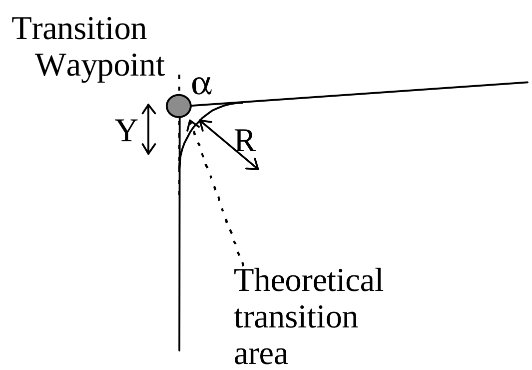


FIGURE 2-8 FLY-BY THEORETICAL TRANSITION AREA

2.2.1.3.7.3 Acceptable Means of Defining Fly-By Turns

An acceptable means of complying with 2.2.1.3.7.2 is as follows:

The equipment determines the turn initiation distance according to the following equations:

$$\text{radius of turn (NM)} = \text{R} = 1.458 \times 10^{-5} \frac{(groundspeed)^2}{\tan(\phi)}$$

$$\text{turn initiation distance (NM)} = \text{Y} = R \tan\left(\frac{\alpha}{2}\right)$$

where:

ϕ = bank angle (nominal of 15°)

α = track change (degrees)

groundspeed in knots

Note: *It is acceptable to provide deviations relative to the arc with radius R.*

2.2.1.3.8 Fly Over Turns

The equipment shall define a path to accomplish fly-over turns that passes through the transition waypoint. There are no requirements which apply to the transition area, as the equipment provides guidance relative to the two straight segments to and from the transition waypoint. See Figure 2-9.

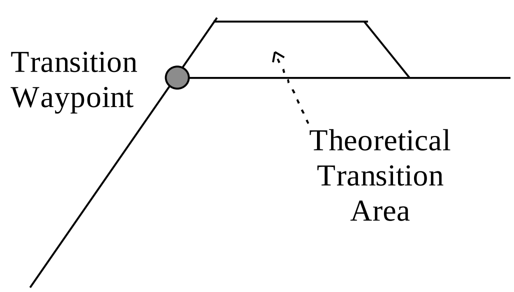


FIGURE 2-9 FLY-OVER THEORETICAL TRANSITION AREA

2.2.1.3.9 Fixed Radius Turns

It is recommended that the equipment be capable of defining a path to accomplish fixed radius turns. The turn radius is defined among a small set of predetermined values: 22.5 nm above FL195 (High altitude) and 15.0 nm at or below FL195 as defined in ICAO RGCSP "Guidance material for RNP" document.

The parameters necessary to define a fixed radius turn are the definition of the transition waypoint and the fixed path transition requirement associated with the route or transition.

Note: *This type of turn may be used to space two parallel routes close together. When this is used, the turn will be published and denoted as a high altitude or low altitude turn. Thus the turn radius is a function of the route, and not the aircraft altitude.*

2.2.1.3.10 Waypoint Sequencing

The equipment shall provide an indication when a waypoint is sequenced (crossed).

If cross-track deviations are provided relative to a curved path through the turn at a waypoint and the estimated position is within the theoretical transition area, the waypoint shall be sequenced when the estimated position crosses the bisector of the angle defined by the leg on either side of the waypoint. (See Figure 2-10.)

If cross-track deviations are not provided relative to a curved path through the turn at a waypoint, the waypoint shall be sequenced at the turn initiation point and deviations provided relative to the extension of the next leg.

Note 1: *For VNAV guidance, vertical deviations are based upon sequencing to the next leg at the bisector. Therefore, sequencing at the turn initiation point is not acceptable for VNAV.*

After sequencing past a waypoint, the equipment shall be capable of recalling it if necessary. An example application of this feature is an ATC request to "hold at previous waypoint".

When the final waypoint in the flight plan is the active waypoint, the equipment shall automatically switch to FROM operation at the active waypoint.

Note 2: *An acceptable means of compliance would be to provide a flashing indication prior to the turn, provide a solid indication at the start of the turn, and remove the indication when deviations are provided relative to the next leg.*

Note 3: *These requirements replace the waypoint alert requirements of RTCA/DO-208.*

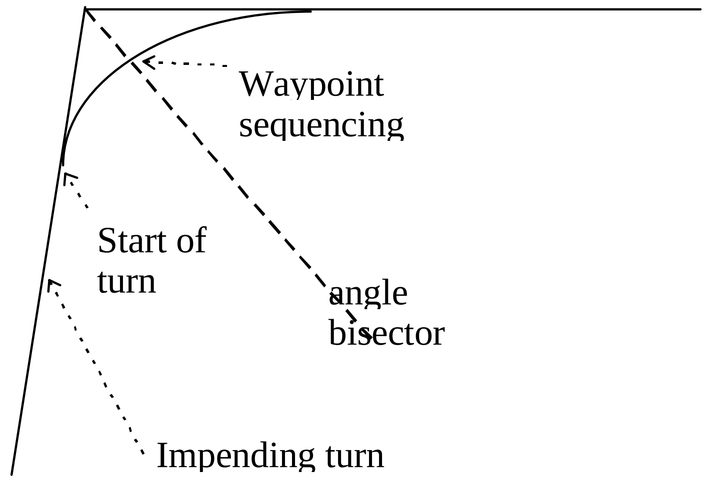


FIGURE 2-10 WAYPOINT SEQUENCING

2.2.1.3.11 Holding Patterns/Procedure Turns

The equipment shall provide the capability for accomplishment of holding patterns at any waypoint. The equipment shall provide the capability to accomplish procedure turns in accordance with published procedures.

If holding patterns are accomplished manually, then they will be accomplished by suspending automatic waypoint sequencing prior to the hold waypoint. The equipment should allow the pilot to suspend automatic waypoint sequencing with a single pilot action. If holding patterns are accomplished automatically, then the characteristics of a particular installation should be considered.

If automatic sequencing of the flight plan has been suspended, the equipment shall indicate the condition. Automatic sequencing of flight plan waypoints shall resume upon completion or cancellation of the suspended mode.

Notes:

1. *Conventional holding pattern entry procedures are based on overflying the station or fix upon which the holding pattern is based. A consequence is the need for additional protection for entry procedures, particularly on the non-holding side of the holding pattern. With the advent of more capable RNAV systems, it may not be necessary to overfly the station or holding waypoint and more airspace-efficient holding patterns can be developed. RTCA/SC-181 is including criteria for advanced holding patterns in the RNP MASPS. This information should be considered by the manufacturer.*

2. *As the NAS transitions to satellite-based navigation, the publication of procedures which include procedure turns is expected to cease. As such, no specific capability to accomplish procedure turns is required in the GPS/WAAS equipment other than the capability to enter FROM operation and accomplish the procedure turn manually. Consideration should be given to coding procedure turns so they can be accomplished without the pilot manually suspending automatic sequencing on the outbound leg and then manually activating it on the inbound leg.*

2.2.1.3.12 Magnetic Course

The source of the magnetic variation used for paths which are defined using magnetic course shall be in accordance with the following:

a. If the leg is part of a database terminal area procedure and the magnetic variation is specified by the State for that procedure, the magnetic variation to be used is the value specified.

b. If the leg is not part of a procedure and the active fix is a VOR, the magnetic variation to be used is the published station declination for the VOR.

c. If the leg is not part of a procedure and the terminating fix is not a VOR, the magnetic variation to be used shall be defined by the system using an internal model.

The navigation system shall have the capability of assigning a magnetic variation at any location within the region that flight operations may be conducted using Magnetic North reference. The assigned magnetic variation shall be within two degrees of the value determined at the same location and time by an internationally recognized magnetic model that is valid for the time of computation (e.g., USGS, IGRF).

2.2.1.3.13 Dead Reckoning

The equipment shall provide a Dead Reckoning capability. The Dead Reckoning capability shall be active whenever no position can be obtained from GPS/WAAS. Dead Reckoning shall be clearly indicated to the pilot. This caution may be implemented by flagging the primary navigation display.

If automatic input of TAS or heading is not available, the equipment shall project the last known GPS/WAAS position forward using last known position, groundspeed and desired track. The equipment shall continue to navigate relative to the active flight plan. The equipment shall change its assumed track in accordance with the flight plan (i.e., if the flight plan requires a track change, the equipment assumes that the pilot performs the track change as displayed by the equipment). The equipment shall provide the capability to determine bearing to an airport, based upon the dead reckoning position (e.g., accessible via the nearest airport function described in Section 2.2.1.2.7).

Note: *The performance of the dead reckoning capability can be significantly improved by the input of more recent information, such as a position updating capability (e.g., place/bearing/distance as reported by ATC) and groundspeed updating. The performance can be significantly improved by integration with the Traffic Information Service (TIS) to automatically update the position estimate as reported by TIS.*

It is recommended that the equipment accept input of TAS and heading. If this capability is provided and this information is available, the equipment shall project the last known GPS/WAAS position forward using TAS and heading, corrected for last known wind. The equipment shall continue to navigate using this position and the active flight plan.

2.2.1.3.14 Fuel Management and Alerting

Note: *Class Gamma GPS/WAAS equipment has access to a significant amount of information that could be used to assist the pilot in managing fuel resources, as such consideration should be given to providing a fuel monitoring function to alert the pilot if the estimated fuel reserves fall below an acceptable level. Equipment that provides this capability should have access to reliable fuel consumption rates, ideally from a fuel flow sensor. It may be possible to provide a capability similar to the automatic fuel-flow sensor by defining algorithms that model the amount of fuel burned based upon aircraft trajectory (e.g., climb,* *cruise, descent). This capability should be provided in a manner that minimizes pilot workload and reliance on memory.*

2.2.1.3.15 Geodesic Path Computation Accuracy

The cross-track path deviation error between the computed path used to determine cross-track deviations and the true geodesic shall be less than 10% of the horizontal alert limit of the navigation mode applicable to the leg containing the path.

Note: *This requirement may be satisfied by using an algorithm which satisfies this accuracy requirement for paths of any length (e.g., Appendix L), or by using an algorithm which approximates the geodesic with the required accuracy for paths of a limited length (e.g., great circle approximations). In the latter case, the equipment must limit the maximum length of individual path segments either procedurally or by insertion of additional waypoints which shall be available for filing as part of the flight plan.*

2.2.1.3.16 Parallel Offsets

The parallel offset is defined as a route parallel to, but offset from, the original active route. The basis of the offset path is the original flight plan leg(s) and one or more offset reference points as computed by the navigation system. The computed offset reference point is located so that it lies on the intersection of lines drawn parallel to the host route at the desired offset distance and the line that bisects the track change angle. An exception to this occurs if there is a route discontinuity (or end of route). In this case, the offset reference point is located abeam of the original flight plan waypoint at the offset distance.

The offset path and associated waypoint must be created to the same standards as the host route. The earth model must be WGS-84 and the offset reference point must have the same or better resolution than the host route waypoint.

The parallel offset function shall be available for enroute TF and the geodesic portion of DF leg types at a minimum.

Note: *The parallel offset function enables an aircraft to be flown on a flight path offset from the center line of a route while maintaining all characteristics of that flightpath, as if it were being flown centrally on the route. Examples for the use of offsets are weather avoidance, air traffic conflict avoidance, etc.*

The system shall have the capability to fly parallel tracks at a selected offset distance. When executing a parallel offset, the navigation mode and all performance requirements of the original route in the active flight plan shall be applicable to the offset route. The system shall provide for entry of offset distance in increments of 1 nm, left or right of course. The system shall be capable of offsets of at least 20 nm. The fact that the system is operating in offset mode shall be clearly indicated to the flight crew. When in offset mode, the system shall provide reference parameters (e.g., cross-track deviation, distance-to-go, time-to-go) relative to the offset path and offset reference points.

An offset shall not be propagated through route discontinuities, unreasonable path geometries, or beyond the initial approach fix. Annunciation shall be given to the flight crew prior to the end of the offset path, with sufficient time to return to the original path. Once a parallel offset is activated, the offset shall remain active for all flight plan route segments until removed automatically, until the flight crew enters a Direct-To routing, or until flight crew (manual) cancellation.

Note: *RTCA/DO-236A provides additional information on parallel offsets.*

2.2.1.4 Navigation Displays

2.2.1.4.1 Primary Navigation Display

At a minimum, the non-numeric cross-track deviation shall be continuously displayed in all navigation modes (either on an internal or on an external display).

At a minimum, the following navigation parameters shall be displayed, either continuously or on the selectable display, in all navigation modes (either on an internal or an external display):

a. Active waypoint distance or estimated time en route to the active waypoint

b. Active waypoint name

c. Active waypoint bearing

d. (Desired track and actual track) or track angle error

e. Indication of navigation TO or FROM the active waypoint

Distance, bearing, desired track, actual track, and track angle error shall be distinguishable.

2.2.1.4.2 Non-Numeric Display/Output Characteristics

2.2.1.4.2.1 Electrical Output

If the equipment does not include a non-numeric cross-track (and vertical deviation for LNAV/VNAV or precision approach) display, or intends to drive other displays, it shall provide an electrical output capable of driving a display. The electrical output shall have the following characteristics shown in Table 2-6.

TABLE 2-6 NON-NUMERIC ELECTRICAL OUTPUT REQUIREMENTS

	Requirement (% of Full-Scale)
Resolution of Electrical Output	1%
Accuracy of Centered Display	3%
Linearity of Display or Electrical Output	5%

Note: *These characteristics can be demonstrated by driving any display.*

2.2.1.4.2.2 Display

If the equipment provides a non-numeric display of cross-track deviation (or vertical deviation for LNAV/VNAV or precision approach) that is intended to substitute for an external display, the GPS/WAAS equipment display shall have the following characteristics shown in Table 2-7.

TABLE 2-7 NON-NUMERIC DISPLAY REQUIREMENTS

	Requirement (% of Full-Scale)
Readability*	10%
Minimum Discernible Movement	2%
Accuracy of Centered Display	3%
Linearity of Display	5%

* Readability refers to the ability to determine the magnitude of a deviation (as a percentage of full-scale deflection.

2.2.1.4.3 Active Waypoint Distance Display

When in TO operation, the distance to the active waypoint shall be displayed. When in FROM operation, the distance from the active waypoint shall be displayed. The distance shall be displayed with a resolution of 0.1 nm up to a range of 99.9 nm from the waypoint, and 1 nm between 100 nm and 9999 nm. A moving map may obviate the need for a numerical output.

2.2.1.4.4 Active Waypoint Bearing Display

The equipment shall provide the capability to display bearing to the active waypoint. The equipment may provide the capability to display the bearing from the active waypoint. If this capability is provided, there shall be an indication of whether the displayed bearing is to the waypoint or from the waypoint. The bearing shall be displayed with a resolution of 1 degree. The equipment shall be capable of displaying the bearing in true or magnetic bearing as selected. A moving map may obviate the need for a numerical output.

Note: *Installations may require the display of non-numerical bearing. Consideration should be given to the enhanced situational awareness provided by moving map displays. Alternatively, the equipment should be capable of driving a horizontal situation indicator (HSI).*

2.2.1.4.5 Track Displays

2.2.1.4.5.1 Desired Track

The equipment shall display the desired track (DTK) of the active leg expressed as a course in units of degrees with 1° resolution.

2.2.1.4.5.2 Track Angle

The track angle shall be displayed with 1° resolution.

2.2.1.4.5.3 Track Angle Error

The track angle error shall be displayed with 1° resolution.

2.2.1.4.6 Display of TO or FROM Operation

The equipment shall provide a continuous indication of whether it is in TO or FROM operation (either integrated or on a separate display).

2.2.1.4.7 Waypoint Bearing/Distance Display

The equipment shall be capable of displaying the distance and bearing to any selected waypoint. For waypoints in the active flight plan, the equipment shall be capable of displaying the estimated time to arrive at the waypoint (this calculation may assume current groundspeed). This can be displayed as either estimated time of arrival (ETA) or as the estimated time en route (ETE).

2.2.1.4.8 Estimate of Position Uncertainty

Note: *RTCA/DO-236A, Section 3.1.2, defines a requirement for the display of navigational uncertainty in RNP airspace. GPS/WAAS equipment is not required to provide this capability. For equipment that intends to be RNP-compliant, the HPL may be used as the basis for this display but is not necessarily sufficient.*

2.2.1.4.9 Magnetic Course

For the display of navigation data in magnetic degrees, the following conventions shall be used:

a. DTK: The desired track is based on true-to-magnetic conversion at the user location, using the magnetic model.

b. BRG to or from a waypoint other than a VOR: The bearing is based on true-to-magnetic conversion at the user location, using the magnetic model.

c. BRG to or from a VOR: The bearing is based on the true-to-magnetic conversion at the waypoint location, using the same magnetic conversion as used to define the path.

d. CRS (OBS): The magnetic course is based on the true-to-magnetic conversion at the waypoint location, using the same magnetic conversion as used to define the path.

2.2.1.4.10 Ground Speed

The equipment shall provide a display of ground speed with one knot resolution.

2.2.1.4.11 Aircraft Present Position

The equipment shall provide a display of the aircraft present position in latitude and longitude with 0.1 minute resolution.

2.2.1.5 Database Requirements

2.2.1.5.1 Access

Manual entry/update of the navigation database data defined in Sections 2.2.1.5.2, 2.2.3.5 and 2.2.4.5.1 shall not be possible. (This requirement does not preclude the storage of "user defined data" within the equipment.) When data are recalled from storage they shall also be retained in storage. Updating of the navigation database shall be accomplished using a high-integrity data validation technique such as a cyclic redundancy check (CRC). The system shall provide a means to identify the navigation data base version and valid operating period. The equipment shall indicate if the database is not yet effective or out of date.

2.2.1.5.2 Content

The equipment shall provide an updateable navigation database containing at least the following location and path information, referenced to WGS-84 or equivalent, with a resolution of 0.01 minute (latitude/longitude) and 0.1° (for course information) or better at all of the following for the area(s) in which IFR operations are intended:

a. Airports;

b. VORs, DMEs (including DMEs collocated with localizers), collocated VOR/DME's, VORTACs, and NDBs (including NDBs used as locator outer marker);

c. All named waypoints and intersections shown on en route and terminal area charts; and

d. RNAV departure procedures and arrival routes (STARs), including all waypoints and intersections.

Departures and arrivals shall be retrievable as a procedure (so that selecting the procedure by name results in loading the appropriate waypoints and legs into the flight plan). Waypoints shall be identified as “fly-over” or “fly-by” in accordance with the published procedure.

Notes: ***1.*** *It is recognized that many datums exist other than WGS-84 and that conversions exist between various datums. However, datums and conversions other than WGS-84 cannot be approved without determining acceptable datum equivalency to WGS-84. It is the responsibility of the approving authority to determine if an alternate datum is equivalent.*

2. *There is a considerable benefit to storing Special Use Airspace (SUA) in the database and providing situational awareness to the pilot of the aircraft's position and track relative to the SUA. A moving map display provides awareness of the proximity of the SUA, even when the track is parallel to it. Other methods should also be considered, such as an alert of a potential violation of the SUA. This awareness will become more important in the absence of ground-based navigation aids which currently provide a local reference point.*

3. *Manufacturers should consider the transition to RNP when designing the navigation database and database interface. It is anticipated that procedures will be published with an RNP type that would supersede the default navigation mode as described in Section 2.2.1.7.*

2.2.1.5.3 Database Standard

The equipment navigation databases shall meet the standards specified in Sections 3, 4, and 5 of RTCA/DO-200A, "Standards for Processing Aeronautical Data."

Manufacturers must develop an approved process for updating the database to maintain data currency. This process will be evaluated in conjunction with the equipment.

2.2.1.5.4 Reference Coordinate System

It is recognized that many datums exist other than WGS-84, and that well-established methods exist to convert location information from one datum to another, for many datums other than WGS-84 or NAD83. Documents NIMA TR 8350.2, 3rd edition, 4 July 1997, NIMA TM 8358.1, and NIMA TM 8358.2, published by the Defense Mapping Agency, define conversion methods between a number of local datums in use throughout the world, and WGS-84. Two issues should be addressed with respect to the use of source data in alternate datums:

a. Accuracy of source data: The data that is published in an alternate datum has to be accurate within that datum before it can be used. Unlike WGS-84, which is a worldwide reference system, local datums are subject to offset errors within a region. As long as these offset errors are consistent within a region, they have no impact on conventional ground-based navigation because the errors cancel out. However, these offsets translate directly into errors when used by GPS in a WGS-84 environment.

b. Accuracy of Datum Conversion: Although datum conversions have been published as noted above, many datums are not well defined or consistently applied. This can create errors in converted position data.

2.2.1.5.4.1 Incorporation of Conversion Algorithms

GPS/WAAS equipment (including the data distribution process) may include conversion algorithms from alternate datums to WGS-84. Each algorithm must be clearly defined and tested. It is recommended that standard algorithms specified by the DMA be used. These conversion algorithms may be certified as accomplishing the specified algorithm. Note that operational approval must also be obtained as discussed below.

When designing equipment which can display and enter latitude/longitude information in datums other than WGS-84 or NAD83, an annunciation shall be made to the pilot of the selection of a datum other than WGS-84 or NAD83. This annunciation shall be designed to prevent errors in the latitude/longitude information entered by the pilot, as well as misinterpretation of displayed latitude/ longitude, because of accidental selection of the wrong datum.

2.2.1.5.4.2 Operational Approval

It is anticipated that the operational approval of GPS/WAAS equipment will ensure that the potential error sources identified above are not detrimental to the intended operation. This may be accomplished in a number of different ways, including:

a. the determination that the error sources do not significantly contribute to a position error in the oceanic/domestic en route and terminal phases of flight.

b. the determination that a specific conversion algorithm, in combination with a specific source datum, results in acceptable accuracy. For example, it may be determined that the conversion specified in DMA TR 8350.2 provides an acceptable conversion algorithm for converting data in "Tokyo Mean Value" datum from Japan to WGS-84.

The FAA has determined that NAD83 is equivalent to WGS-84 without a conversion algorithm.

Operational approval of the conversion is not expected to be necessary if the conversion is used for the following purposes: displaying latitude / longitude information; entering latitude/longitude information when defining a user waypoint.

2.2.1.6 Alerts

2.2.1.6.1 Caution Associated with Loss of Integrity Monitoring

Class Gamma equipment shall provide a caution, independent of any operator action, when the equipment has a loss of integrity monitoring. This caution shall be capable of installation in the pilot's normal field of view (ref. Section 3.3.1.1.1). The equipment shall also provide an indication when integrity monitoring capability is restored. The conditions defining loss of integrity monitoring can be found in Sections 2.2.2.6.2, 2.2.3.6.2, 2.2.4.6.2, and 2.2.5.6.2.

Notes: ***1.*** *Example implementations which satisfy this requirement include a pop-up message at the onset of this condition (“Loss of Integrity - Crosscheck Nav.”) and another message when monitoring is restored (“Integrity Restored - Normal Ops”). The first message may be accompanied by a unique and continuous annunciator (“LOI”) that turns on when there is no integrity monitoring and turns off when integrity monitoring is restored.*

2. *The loss of integrity monitoring caution should not result in the removal of navigation information from the navigation display.*

2.2.1.6.2 Caution Associated with Loss of Navigation

Class Gamma equipment shall continuously provide a caution, independent of any operator action, which indicates the loss of navigation capability. This caution shall be a unique annunciator capable of installation in the pilot's primary field of view. This caution may be implemented by flagging the primary navigation display. The conditions for this caution are specified in Sections 2.2.2.6.3, 2.2.3.6.3, 2.2.4.6.3, and 2.2.5.6.3.

Note: *Guidance information will continue to be displayed when the equipment reverts to dead reckoning (2.2.1.3.13), to at least include DTK.*

2.2.1.7 Mode Switching Requirements

The following modes are defined:

Navigation Mode	**HAL** (Nominal)	**Full-Scale Deflection** (Nominal)
En Route	2 nm	2 nm
Terminal	1 nm	1 nm
Nonprecision Approach	0.3 nm	Angular/Linear (Section 2.2.3.7)
Precision Approach (see Note 1)	Database (Section 2.2.4.5 and 2.2.5.5)	Angular/Linear (Section 2.2.4.7)

Note 1: *There are three levels of service within the precision approach mode: LNAV/VNAV, APV-II, and GLS. These services are not all categorized as precision approaches under ICAO Annex 6; however, all provide vertical guidance and are therefore considered precision within the scope of this document.*

a. The equipment shall display the current mode upon user request. The navigation modes are defined in Section 1.4.2: oceanic/remote (optional), en route, terminal, nonprecision approach, LNAV/VNAV, APV-II and GLS. The nonprecision, LNAV/VNAV, APV-II and GLS modes should be displayed as a single mode, where the presence or absence of vertical guidance indicates which internal mode it is in.

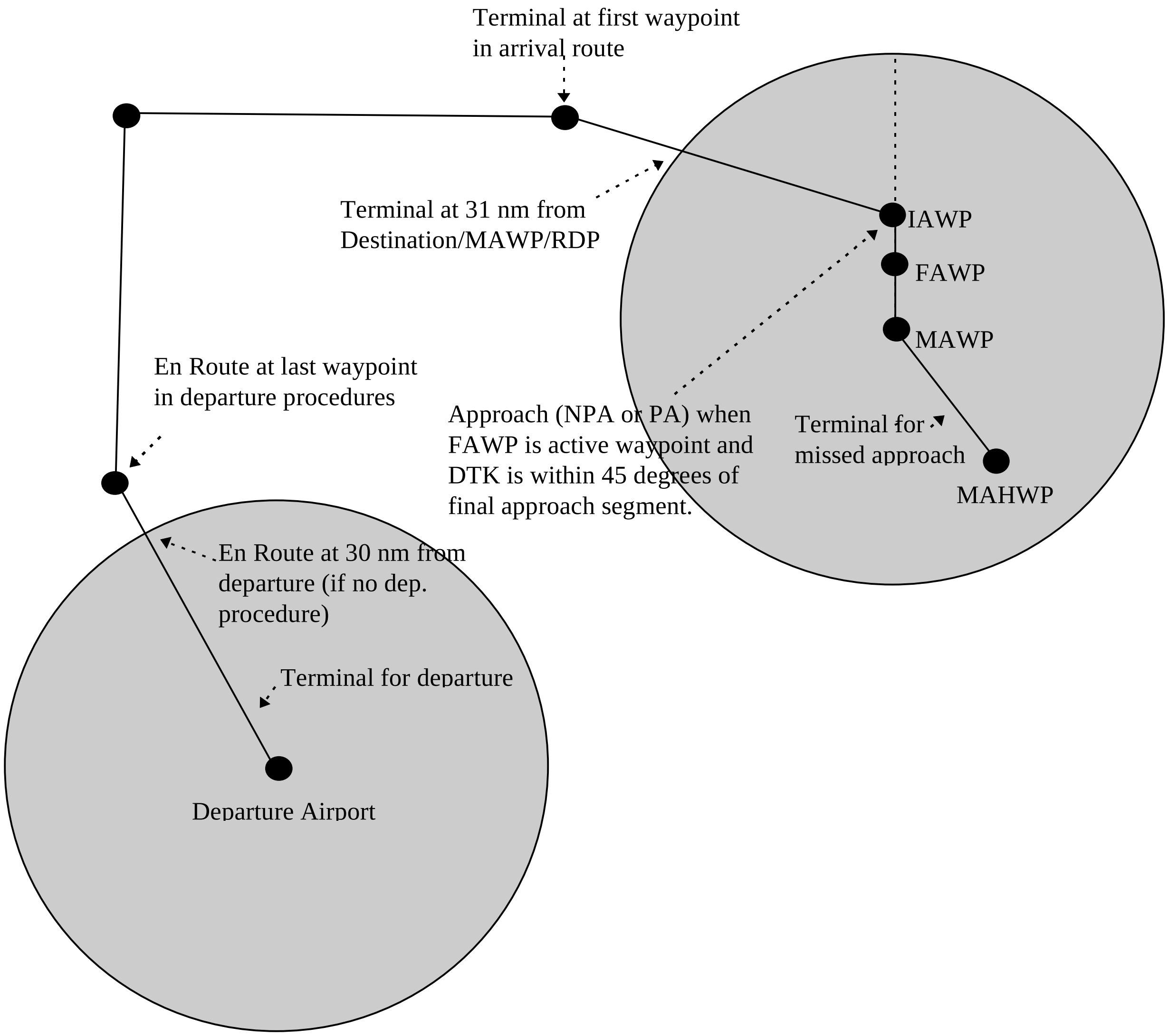
Note 2: *The oceanic/remote mode is not defined in this document, since it is an optional mode. Caution should be used in defining oceanic/remote mode based upon distances to facilities, which will encounter difficulties as ground-based facilities are replaced by GPS/WAAS and begin to disappear.*

b. The equipment shall automatically switch to the default mode upon entering the region defined for that mode. The default modes are defined in Table 2-8 and shown in Figure 2-11. Only those modes that are applicable to the operational class of the equipment apply. Table 2-9 provides a transitional matrix summarizing the automatic switching requirements. Table 2-10 summarizes the required changes in cross-track full-scale deflection during automatic mode switching.

Note 3: *A unique precision departure mode (in addition to the departure guidance provided as part of Class 1, 2 and 3 terminal mode), which combines precision approach integrity and accuracy with a tighter display sensitivity, may provide an additional benefit to a segment of the avia-*

tion community (e.g., rotorcraft). This capability is not precluded by this MOPS.

c. Approach mode shall be annunciated by a unique continuous indication.



<u>FIGURE 2-11</u> DEFAULT NAVIGATION MODES

<u>TABLE 2-8</u> DEFINITION OF DEFAULT NAVIGATION MODES

Default Navigation Mode	**Definition of Region**
En Route	At a radial distance ≥ 30 nm from departure airport; <u>and</u> At a radial distance ≥ 31 nm from the destination airport/MAWP/LTP/FTP; <u>and</u> The last waypoint in a departure has been sequenced (if applicable); <u>and</u> The first waypoint in an arrival route has not been sequenced (if applicable).
Terminal	Not in en route navigation mode region (defined above), <u>and</u> Not in approach navigation mode region (defined below).
Nonprecision Approach or Precision Approach	VTF has been selected; <u>or</u> all of the following conditions are true: On an approach procedure; <u>and</u> the FAWP, MAWP (LTP/FTP), or the first waypoint in the missed approach procedure is the active waypoint and prior to the turn initiation point (the first waypoint in the missed approach procedure only applies if the first leg in the missed approach procedure is a TF leg aligned within 3 degrees of the final approach path); <u>and</u> if FAWP is the active waypoint, the bearing to the FAWP is within 45° of final approach segment track.

<u>TABLE 2-9</u> SUMMARY OF TYPICAL AUTOMATIC MODE SWITCHING TRANSITIONS

To **From**	**En Route**	**Terminal**	**NPA or PA**
En Route	-	Sequence the first waypoint in arrival route; or 31 nm from destination airport/ MAWPLTP/FTP.	N/A
Terminal	Sequence the last departure waypoint, if applicable, and ≥ 30 nm from departure airport.	-	Selection of VTF approach; or the FAWP is the active waypoint and the bearing to FAWP is within 45° of the desired track of the final approach segment.
NPA or PA	N/A	After initiation of missed approach procedure, either sequencing the MAWP (for missed approach procedures that do not start with a TF leg aligned within 3 degrees of the final approach path) or at the turn initiation point for the first waypoint in the missed approach procedure (for missed approach procedures that start with a TF leg within 3 degrees of the final approach path); executing a Direct-To; or end of flight.	-

TABLE 2-10 SUMMARY OF CHANGES IN CROSS-TRACK FULL SCALE DEFLECTION FOR AUTOMATIC MODE SWITCHING

To From	En Route	Terminal	NPA or PA
En Route	-	Change from ±2 nm FSD to ±1 nm FSD over distance of 1 nm; start transition when entering terminal mode	N/A
Terminal	Change from ±1 nm FSD to ±2 nm FSD over distance of 1 nm; start transition when entering en route mode	-	If VTF, switch immediately. Otherwise, change from ±1 nm FSD to approach FSD over distance of 2 NM; start transition at 2 nm from FAWP.
NPA or PA	N/A	Change to ±1 nm (note 1)	-
Terminal (Departure) (Note 2)	N/A	If initial leg is aligned with runway, change from ±0.3 nm FSD to ±1 nm FSD at the turn initiation point of the first fix in the departure procedure	N/A

Notes: ***1.*** *There are also several sensitivity changes within the approach modes, as defined in Sections 2.2.3.4.2, 2.2.4.4.2, and 2.2.5.4.2. The change can take as long as 30 seconds to provide a smooth transition for autopilots.*

2. *Although the indicated mode is terminal, unique departure guidance is only provided by Class 1, 2 and 3 equipment. The requirements for departure operation can be found in Section 2.2.3.7.2.*

2.2.2 Class Gamma Requirements for En Route / Terminal Operation

2.2.2.1 General Human Factors Requirements

There are no additional human factors requirements.

2.2.2.2 Path Selection

There are no additional path selection requirements.

2.2.2.3 Path Definition

There are no additional path definition requirements.

2.2.2.4 Navigation Displays

2.2.2.4.1 Primary Navigation Displays

There are no additional navigation parameters for the primary navigation display.

2.2.2.4.2 Non-Numeric Cross-Track Deviation

Full-scale deflection (FSD) in oceanic/remote mode shall not exceed ± 5 nm.

Full-scale deflection in en route mode shall be ± 2 nm.

Full-scale deflection in terminal mode shall be ± 1 nm.

Note: *Section 2.2.1.7 and 2.2.2.7 discuss the appropriate full-scale deflection during an automatic mode change.*

2.2.2.4.3 Numeric Cross-Track Deviation

When in oceanic/remote, en route, or terminal mode, the equipment shall provide either a display or electrical output of cross-track deviation with a range of at least ± 20 nm (left and right). The equipment shall provide a resolution of 0.1 nm for deviations up to 9.9 nm, and a resolution of 1 nm for deviations greater than 9.9 nm.

2.2.2.4.4 Displayed Data Update Rate

The equipment shall update required data presented by a display at a rate of 1 Hz or more.

Note: *If the navigation information is used to drive an autopilot, the displayed data rate may be required to meet more stringent requirements, depending on the autopilot requirements.*

2.2.2.4.5 Display Update Latency

Latency of the display or electrical output shall not exceed 1 second for required data, from the time of applicability of the position solution to the time the corresponding information is displayed/output.

Note: *If the navigation information is output to a separate display with significant latency, the display update latency may be required to meet more stringent requirements.*

2.2.2.5 Database Requirements

There are no additional database requirements.

2.2.2.6 Alerts

2.2.2.6.1 Alert Limits

The HAL for the navigation modes shall be:

Oceanic/Remote	4 nm
En Route	2 nm
Terminal	1 nm

Note: *Future RNP applications may require the application of additional alert limits beyond those stated above.*

2.2.2.6.2 Caution Associated with Loss of Integrity Monitoring

The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within 30 seconds if the current HPL_{FD} exceeds the HAL.

The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within two seconds if the current HPL_{WAAS} exceeds the HAL.

2.2.2.6.3 Caution Associated with Loss of Navigation

The loss of navigation caution shall be output/displayed within one second of the onset of any of the following conditions:

a. The absence of power (loss of function is an acceptable indicator);

b. Probable equipment malfunction or failure (must consider all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5}/hour);

c. The presence of a condition lasting five seconds or more where there are an inadequate number of satellites to compute a position solution;

d. Fault detection detects a position failure, which cannot be excluded within the time-to-alert.

The fault detection function shall detect positioning failures within the following times-to-alert. A detection results in a loss of navigation caution (see Section 2.2.1.6.2).

Time-to-Alert

Oceanic/Remote:	1 minute
En Route:	30 seconds
Terminal:	10 seconds

The equipment shall distinguish between these different causes of the loss of navigation capability. For example, a single loss of navigation caution can be provided, if it is accompanied by a message for conditions b) through d) indicating the cause of the alert. A blank display could indicate condition a).

The caution shall be returned to its normal state immediately upon termination of the responsible condition.

Note: *A loss of navigation alert does not require removal of navigation information from the navigation display. Consideration should be given to continued display of navigation information concurrent with the failure/status annunciation when conditions warrant.*

2.2.2.7 En Route/Terminal Mode Switching Requirements

2.2.2.7.1 En Route Mode Switching Requirements

2.2.2.7.1.1 Entry Criteria

There are no additional conditions for entering the en route mode.

2.2.2.7.1.2 Exit Criteria

There are no additional conditions for exiting the en route mode.

2.2.2.7.1.3 Display Transition Requirements

Upon automatic transition to en route mode from terminal mode, the non-numeric cross-track sensitivity shall gradually decrease from ±1 nm FSD to ±2 nm FSD over a distance of 1 nm.

2.2.2.7.2 Terminal Mode Switching Requirements

2.2.2.7.2.1 Entry Criteria

Automatic mode switching to terminal mode shall occur at a distance of 31 nm from the destination airport. It is acceptable to assume that the pilot intends to land at any airport in the flight plan.

2.2.2.7.2.2 Exit Criteria

There are no additional conditions for exiting the terminal mode.

2.2.2.7.2.3 Display Transition Requirements

Upon automatic transition from en route mode to the terminal mode, the non-numeric cross-track sensitivity shall increase from ±2 nm FSD to ±1 nm FSD over a distance of 1 nm.

2.2.3 Class Gamma Requirements for Nonprecision Approach Operation

2.2.3.1 General Human Factors Requirements

There are no additional human factor requirements.

2.2.3.2 Path Selection

Note: *The inherent nature of RNAV procedures requires that a series of waypoints can be connected to define a procedure. In this document, the term "flight plan" is used to refer to this basic concept, and can refer to any sequence of waypoints, which are interconnected (such as an approach procedure). The equipment should allow the pilot to select and activate an approach procedure without specifically accessing the flight plan functions defined in Section 2.2.1.2.*

2.2.3.2.1 Approach Selection

For procedures with multiple IAWPs, the system shall present all IAWPs and provide the capability for pilot selection of the desired IAWP. After selection and entry of the desired IAWP into the flight plan, the remaining waypoints for the approach and missed approach shall automatically be inserted in the flight plan in the proper sequence.

The equipment shall provide the capability for the pilot to manually select a VTF approach, indicating that the pilot does not intend to fly the entire procedure. The VTF approach is defined in Section 2.2.3.3.1. Until the FAWP has been sequenced, the equipment shall indicate, either continuously or on the primary navigation display, that a VTF approach has been selected.

For nonprecision approaches that are coincident with precision approaches, the equipment may use the 5-digit channel number described in 2.2.4.2.1 for approach selections.

Notes:

1. *The equipment should also provide the capability to link feeder routes to the selected approach.*
2. *The capability to select a VTF approach is required to enable Air Traffic Control to circumvent a complete approach procedure and to facilitate immediate transitioning onto the final approach segment.*

2.2.3.2.2 Missed Approach Sequencing

The equipment shall allow the pilot to initiate the missed approach with manual action. It shall be possible to take this action before crossing the MAWP, in which case the equipment shall automatically initiate the missed approach procedure at the MAWP. Note that there are many implementations for selecting a missed approach, including canceling NPA mode which automatically selects terminal mode.

Note: *After crossing the MAWP, a prompt should be provided for this action.*

The equipment should provide the capability to readily proceed Direct-To any waypoint in the missed approach procedure.

2.2.3.3 Path Definition

2.2.3.3.1 Approach Path Definition

If the pilot has not selected a VTF approach, deviations shall be provided with respect to the active leg of the approach procedure. See Figure 2-12.

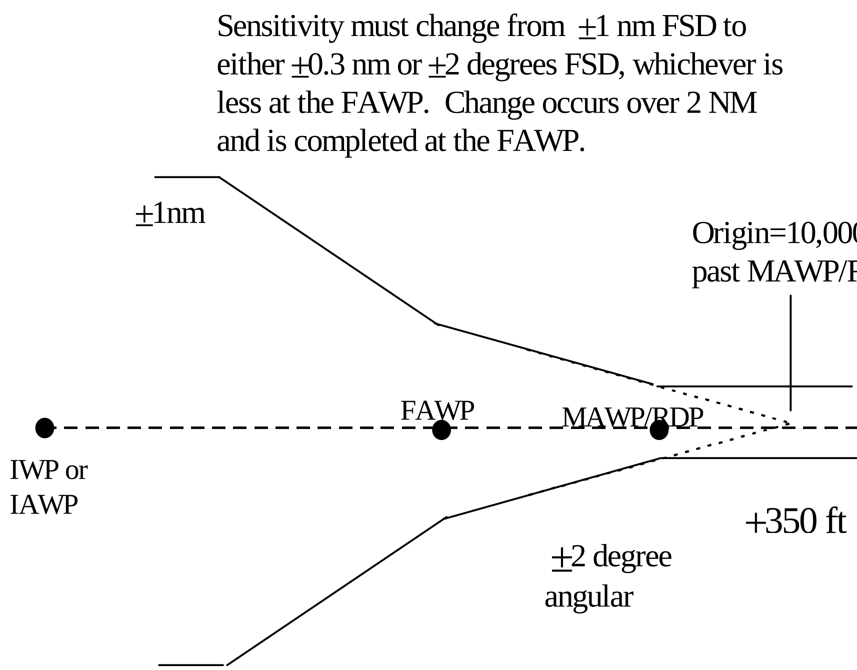
If the pilot has selected a VTF approach, deviations shall be provided relative to the inbound course to the FAF. See Figure 2-13. The active waypoint shall initially be the FAWP. The equipment should also account for short turns onto the final approach where the FAWP may not be crossed.

Note 1: *A VTF approach can be selected at any time.*

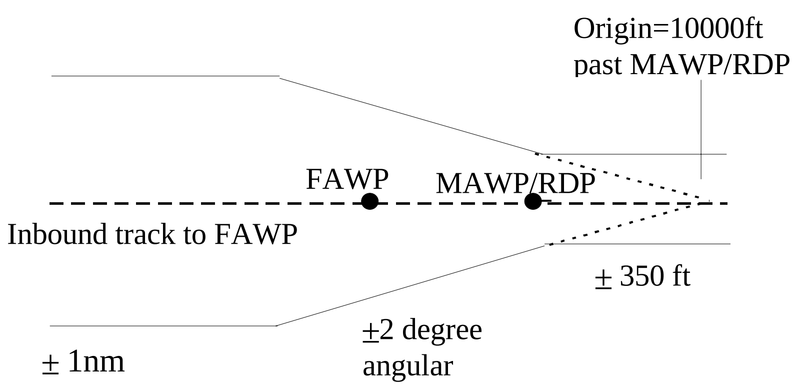
If the pilot has selected Direct-To the FAWP, and the difference between the desired track and the desired track of the final approach segment is greater than 45 degrees, the equipment shall indicate that the FAWP will not be sequenced (the intercept angle at the FAWP is too sharp). In this case, the equipment shall suspend automatic sequencing.

Note 2: *For published procedures where a single waypoint is used for the initial or intermediate waypoint and the final approach waypoint, the procedure should be coded to recognize that this fix will be overflown and a procedure turn conducted. The equipment should automatically recognize that the procedure turn has been completed and the pilot has intercepted the inbound course to the FAWP, and automatic sequencing should be enabled if the resulting desired track is within 45 degrees of the final approach segment track. This is the same point at which the approach mode would become active. The same implementation should be used in the case of a large angle intercept at the FAWP that is not part of a published procedure, since the pilot is expected to conduct a procedure turn.*

The missed approach waypoint shall be a fly-over waypoint unless otherwise designated (see Section 2.2.1.3.7).



<u>FIGURE 2-12</u> FULL-SCALE DEFLECTION AND DEFINED PATH FOR NORMAL APPROACH (NOT VTF APPROACH)



<u>FIGURE 2-13</u> FULL SCALE DEFLECTION AND DEFINED PATH FOR VTF APPROACH

2.2.3.3.2 Missed Approach Path Definition

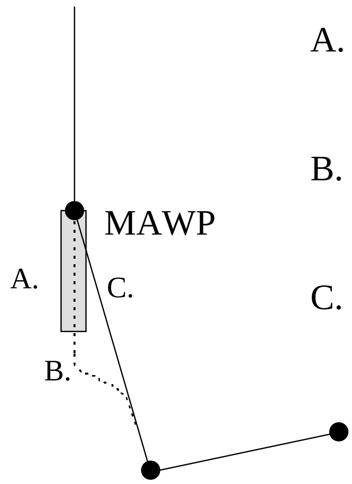
a. If a missed approach is not initiated prior to crossing the MAWP, the equipment shall automatically switch to FROM mode at the MAWP and continue on the same course. If the pilot initiates the missed approach, then the equipment shall provide guidance relative to the procedure.

b. If a missed approach is initiated prior to crossing the MAWP, the desired path to and after the MAWP shall be defined by the procedure.

The equipment shall be capable of using at least the following legs in defining missed approach procedures: TF, CF, and Direct-To. The Direct-To procedure does not result in a repeatable path. Examples are shown in <u>Figure 2-14</u>. Note that the TF leg will frequently be a straight continuation of the approach segment.

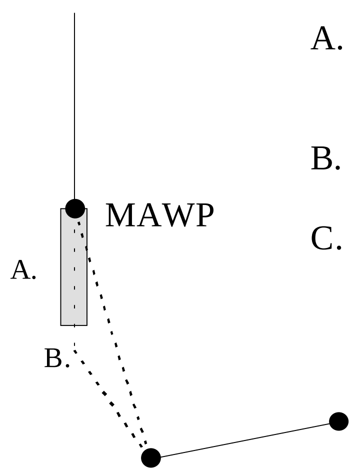
Note: *The scenarios depicted in <u>Figure 2-14</u> are intended to cover different approach procedure designs. The manufacturer should use these scenarios to properly* *code the procedure so that minimal pilot interaction is necessary to fly the missed approach.*

TF LEG



A. If pilot has not selected missed approach, equipment enters FROM mode after crossing MAWP.
B. Pilot selects missed approach, equipment immediately switches to providing guidance relative to TF leg.
C. If pilot selected missed approach before crossing MAWP, equipment sequences to next waypoint after crossing MAWP.
MAWP is fly-over waypoint, unless otherwise designated.

Direct-TO LEG



A. If pilot has not selected missed approach, equipment enters FROM mode after crossing MAWP.
B. Pilot selects missed approach, equipment provides Direct-TO next waypoint.
C. If pilot selected missed approach before crossing MAWP, equipment provides Direct-To from MAWP to next waypoint.
MAWP is fly-over waypoint, unless otherwise designated.

<u>FIGURE 2-14</u> MISSED APPROACH SCENARIOS

2.2.3.3.3 Departure Path Definition

Class 1, 2 and 3 equipment shall provide guidance for departure procedures. The types of departure procedures are identical to the missed approach procedures.

2.2.3.3.4 Vertical Path for NPA Procedures

The equipment may provide a vertical path and display vertical deviations for non-precision approach procedures. When this capability is provided, then:

a. The vertical path shall be defined as described in Section 2.2.4.3.1 for LNAV/VNAV approaches.

Note: *This information is not necessarily defined by the procedure designer. The organization that defines the vertical path is responsible for ensuring consistency with published altitude requirements. This includes the minimum or required altitude associated with each segment and with any step-down fix.*

b. The vertical path shall be selected automatically when the lateral path is selected (Section 2.2.3.2.1).

c. The equipment shall meet the requirements of Section 2.2.4.4.4 for non-numeric vertical deviation display.

d. The equipment shall meet the requirements of Section 2.2.4.4.9 for display of vertical accuracy.

e. The equipment shall meet the requirements of Section 2.2.4.6 for LNAV/VNAV alerts.

2.2.3.4 Navigation Displays

2.2.3.4.1 Primary Navigation Displays

There are no additional parameters for the primary navigation display.

2.2.3.4.2 Non-Numeric Cross-Track Deviation

The full-scale deflection for nonprecision approach mode shall either be identical to the precision approach mode as defined in 2.2.4.4.2 (only possible for procedures with FAS path definition records); or shall be as follows:

1. If a VTF approach has not been selected:
   a. Prior to 2nm from the FAWP, the FSD shall be ± 1 nm;
   b. Between 2 nm from the FAWP and the FAWP, the FSD shall gradually change to the FSD specified in (c) below at the FAWP;
   c. At and beyond the FAWP, but before initiating a missed approach, the full-scale deflection shall be the minimum of: constant FSD of ± 0.3 Nautical Miles (NM); or angular Full-Scale Deflection (FSD) defined by a ± 2.0 degree wedge with origin located 10,000 feet past the MAWP. The FSD shall continue to decrease or shall reach a minimum of ± 350 feet. See Figure 2-12 for an illustration of the linear sensitivity close to the runway.
2. If a Vector-to-Final (Approach) (VTF) has been selected, the FSD shall be the minimum of: constant FSD of ± 1 nm; or angular FSD defined by a ± 2.0 degree wedge with origin located 10,000 feet past the Missed Approach Waypoint (MAWP). The FSD shall continue to decrease or shall reach a minimum of ± 350 feet. See Figure 2-13 for an illustration of the linear sensitivity close to the runway.

The full-scale deflection shall change to ±0.3 nm when a missed approach is initiated.

Note: *Nonprecision approach equipment may provide advisory vertical guidance. This advisory guidance should use the vertical path and deviations defined in Section 2.2.4. This advisory guidance may be provided even when WAAS corrections or integrity information is not available. This advisory guidance cannot be used to descend below the nonprecision approach MDA.*

2.2.3.4.3 Numeric Cross-Track Deviation

When in nonprecision approach mode, the equipment shall provide either a display or electrical output of cross-track deviation with a range of at least ± 9.99 nm (left and right). The equipment shall provide a resolution of 0.01 nm for deviations up to 9.99 nm, and a resolution 0.1 nm for deviations greater than 9.99 nm (if provided).

2.2.3.4.4 Missed Approach Waypoint Distance Display

When in terminal or nonprecision approach mode, the distance to the missed approach waypoint shall be available for display until the MAWP is sequenced. The distance shall be displayed with a resolution of 0.1 nm up to a range of 99.9 nm. If a moving map is provided, the map may obviate the need for a numerical output.

Note: *Design consideration should be given to avoid confusion between the waypoint distance display and the MAWP distance display.*

2.2.3.4.5 Missed Approach Waypoint Bearing Display

When in terminal or nonprecision approach mode, the bearing to the missed approach waypoint shall be available for display until the MAWP is sequenced. The bearing shall be displayed with a resolution of 1 degree. The equipment shall be capable of displaying the bearing in true or magnetic bearing as selected. If a moving map is provided, the map may obviate the need for a numerical output.

Note: *Consideration should be given to the enhanced situational awareness that is provided by moving map displays.*

2.2.3.4.6 Displayed Data Update Rate

Refer to paragraph 2.2.2.4.4.

2.2.3.4.7 Display Update Latency

Refer to paragraph 2.2.2.4.5.

2.2.3.5 Database Requirements

In addition to the requirements of paragraph 2.2.1.5.2, the equipment shall store the nonprecision approach procedures in the area(s) in which IFR operation is intended. The nonprecision approach procedure consists of:

a. Runway number and label (required for approach identification);

b. Initial approach waypoint (IAWP);

c. Intermediate approach waypoint(s) (IWP) (when applicable);

d. Final approach waypoint (FAWP);

e. Missed approach waypoint (MAWP);

f. Designation of a FROM leg at MAWP (if applicable, identifies that equipment should suspend sequencing until manual action is taken);

g. Additional missed approach waypoints (when applicable); and

h. Missed approach holding waypoint (MAHWP).

The complete sequence of waypoints, in the correct order for each approach and departure, shall be retrievable as a procedure (so that selecting the procedure by name results in loading the appropriate waypoints and legs into the flight plan).

Note 1: *There may be cases where the FAS may not be straight-in, and will not line up with the runway centerline.*

Waypoints utilized as a final approach waypoint (FAWP) or missed approach waypoint (MAWP) in a nonprecision approach procedure shall be uniquely identified as such (when appropriate) to provide proper approach mode operation.

The equipment shall also store the departure procedures in the area(s) in which IFR operation is intended. Departure procedures will typically start with a CF leg.

Note 2: *For a given aircraft installation, it is permissible to exclude procedures associated with runways at which the aircraft is not capable of landing.*

2.2.3.6 Alerts

2.2.3.6.1 Alert Limits

The horizontal alert limit for nonprecision approach mode shall be 0.3 nm.

2.2.3.6.2 Caution Associated with Loss of Integrity Monitoring

The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within 30 seconds if the current HPL_{FD} exceeds the HAL.

The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within two seconds if the current HPL_{WAAS} exceeds the HAL.

Notes: ***1.*** *Although this requirement is stated for the nonprecision approach mode, its applicability is limited to outside the FAF since a loss of integrity monitoring after sequencing the FAF is defined to be a loss of navigation as described in Section 2.2.3.6.3, item e.*

2. *Future RNP applications may require the application of additional alert limits beyond those stated above.*

2.2.3.6.3 Caution Associated with Loss of Navigation

Class Gamma nonprecision approach equipment shall provide an indication when the navigation system is no longer adequate to conduct or continue the nonprecision approach by means of a navigation warning flag on the navigation display. The flag shall be displayed within one second of the onset of any of the following conditions:

a. The absence of power (loss of function is an acceptable indicator);

b. Probable equipment malfunction or failure (must consider all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5}/hour);

c. The presence of a condition lasting five seconds or more where there are an inadequate number of satellites to compute a position solution;

d. Fault detection detects a position failure which cannot be excluded within the time to alert. When in NPA mode, the fault detection function shall detect positioning failures within 10 seconds after the onset of the positioning failure.

e. HPL > HAL at any point on the final approach segment.

After sequencing the FAWP, this indication (flag) shall be latched until the equipment is no longer in the nonprecision approach mode.

Note: *A loss of navigation alert does not require removal of navigation information from the navigation display. It is acceptable to continue to display navigation information concurrent with the failure/status annunciation when conditions warrant.*

2.2.3.7 Mode Switching Requirements

2.2.3.7.1 Nonprecision Approach Mode Switching Requirements

2.2.3.7.1.1 Entry Criteria

There are no additional requirements for the entry criteria.

2.2.3.7.1.2 Exit Criteria

When a missed approach is initiated and the first leg in the missed approach procedure is not a TF leg aligned within 3 degrees of the final approach path, the equipment shall automatically switch to terminal mode.

When a missed approach is initiated and the first leg in the missed approach procedure is a TF leg aligned within 3 degrees of the final approach path, the equipment shall automatically switch to terminal mode at the turn initiation point for the first waypoint in the missed approach procedure.

If the pilot initiates Direct-To any waypoint while in nonprecision approach mode, the equipment shall automatically switch to terminal mode.

2.2.3.7.1.3 Display Transition Requirements

Upon entering the nonprecision approach mode when a VTF has not been selected, there is no change in FSD until the aircraft reaches a distance of 2 nm from the FAWP as specified in 2.2.3.4.2.

Upon entering the nonprecision approach mode when a VTF has been selected, the equipment shall immediately transition to the angular/linear guidance relative to the (extended) FAS as defined in Section 2.2.3.4.2.

Display transition when initiating a missed approach are described in Section 2.2.3.4.2.

The sensitivity shall change from ±0.3 nm to ±1 nm when the equipment changes to terminal mode.

Notes: ***1.*** *The approach sensitivity at the FAWP depends upon the length of the final approach segment. It will be the minimum of ±0.3 nm and the angular splay illustrated in Figure 2-12.*

2. *An additional electrical output (constant linear ± 0.3 nm FSD) may also be provided for output to deviation-steered autopilots, but may not be used to drive a display.*

2.2.3.7.2 Departure Requirements

2.2.3.7.2.1 Entry Criteria

Departure guidance may be selected manually. Once a departure procedure is activated, the equipment shall provide nonprecision approach accuracy and integrity. The annunciated mode may be terminal mode (if a unique precision departure mode is not provided).

2.2.3.7.2.2 Exit Criteria

The equipment shall automatically revert to normal terminal mode operation at the turn initiation point of the first waypoint in a departure procedure.

2.2.3.7.2.3 Display Transition Requirements

The full-scale deflection shall change from ± 0.3 nm to ± 1 nm at the turn initiation point of the first waypoint in the departure procedure.

2.2.4 Class Gamma Requirements for LNAV/VNAV Operations

Note: *The requirements in this section apply to WAAS equipment, which provides vertical deviations for LNAV/VNAV approaches. Section 2.2.5 contains requirements for equipment providing horizontal and vertical guidance for GLS and APV-II approaches.*

2.2.4.1 General Human Factors Requirements

There are no additional human factors requirements.

2.2.4.2 Path Selection

The equipment shall enable the pilot to select the approach path of the aircraft through either of two means: (1) by selecting a 5-digit channel number, then selecting the desired initial approach fix or VTF; or (2) by selecting the airport, runway, approach identifier and initial approach fix. Both methods shall be implemented by WAAS Gamma equipment. Once the approach has been selected, the approach name (airport, runway, route indicator) and Reference Path Identifier shall be accessible for display.

2.2.4.2.1 5-Digit Channel Selection

For procedures defined by a FAS data block (see Section 2.2.4.3.1), entry of the channel number shall result in the database providing to the navigation equipment the FAS data block. Subsequent selection of the initial approach fix shall result in selection of the entire approach procedure including missed approach. The equipment shall provide a means for the operator to differentiate between duplicate channel numbers (approaches) in the database.

Notes:

1. *The channel number consists of 5 numeric characters in the range 20000 to 99999 (numbers less than 20000 are reserved for ILS and MLS). The ICAO Global Navigation Satellite Systems (GNSS) Panel has allocated 20001 to 39999 for GBAS, and these assignments are unlikely to be used for WAAS but should be accommodated by the equipment.*
2. *For standalone LNAV/VNAV approaches (see Section 2.2.4.3.1), this requirement does not apply.*

2.2.4.2.2 Approach Name Selection

WAAS equipment shall provide the capability to select approaches as defined in Section 2.2.3.2.1. Once a procedure has been selected, the equipment shall automatically obtain the appropriate Final Approach Segment data for those approaches where it is defined.

2.2.4.2.3 Missed Approach Sequencing

The equipment shall allow the pilot to initiate the missed approach in accordance with Section 2.2.3.2.2.

If the aircraft is past the FPAP - (length offset), and the pilot has not already activated the missed approach, the receiver shall automatically transition to missed approach guidance.

The equipment should provide the capability to readily proceed Direct-To any waypoint in the missed approach procedure.

2.2.4.3 Path Definition

2.2.4.3.1 Approach Path Definition

For procedures defined by a FAS data block, the final approach path shall be defined by the Flight Path Alignment Point (FPAP) and Landing Threshold Point/Fictitious Threshold Point (LTP/FTP), and by the Threshold Crossing Height (TCH) and glidepath angle. The threshold location is referred to as the LTP if it is collocated with the runway and FTP if it is displaced from the runway. The glidepath angle is defined relative to the local tangent plane of the WGS-84 ellipsoid. These parameters are defined in Appendix D. Figure 2-15 shows the path definition for the final approach segment for procedures defined by a FAS data block. The path definition may be based upon a hyperbolic path to mimic ILS glideslope characteristics, where the virtual glidepath antenna location is offset from the runway by less than 500 feet.

The final approach path for standalone LNAV/VNAV approaches (without a FAS data block) is defined by the intersection of the non-precision approach lateral path (as defined in Section 2.2.3.3.1) with the vertical path defined by the threshold location, threshold crossing height, and glidepath angle.

Notes: **1.** *Some approach paths may be offset by a few degrees from the runway centerline. This can be handled by placing the FTP and FPAP at points off the runway surface.*

2. *For LNAV/VNAV approaches that are collocated with a GLS and/or APV-II approach, the LNAV/VNAV path is defined by the FAS data block (i.e., the FPAP and LTP/FTP data).*

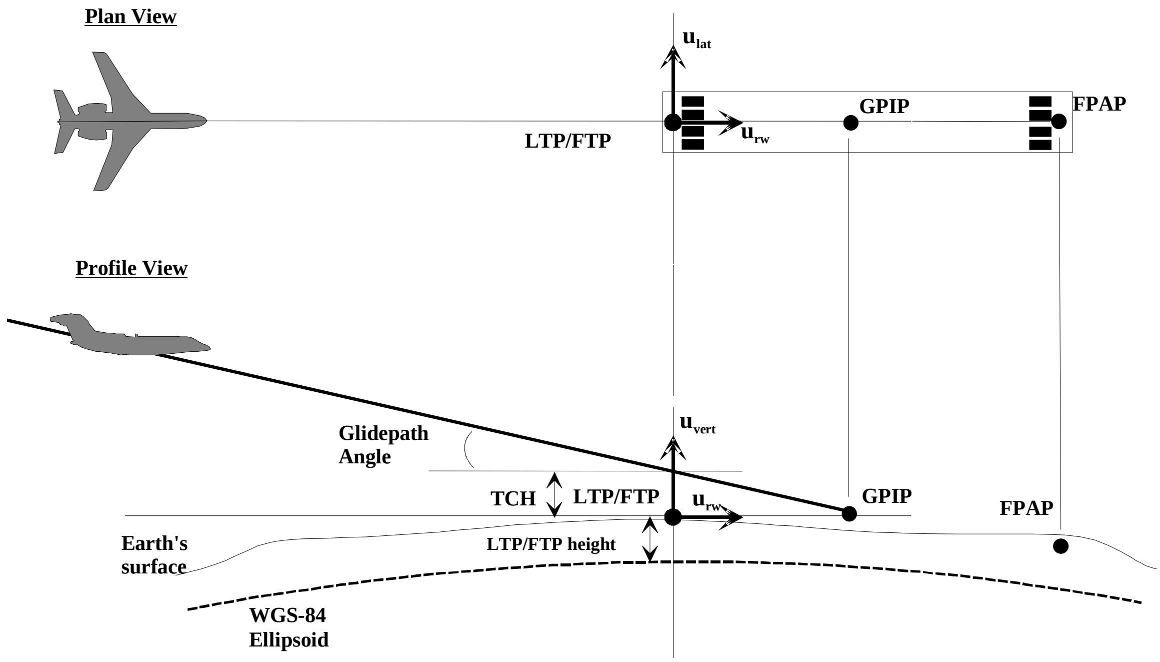


FIGURE 2-15 FINAL APPROACH SEGMENT DEFINITION

2.2.4.3.2 Missed Approach Path Definition

See Section 2.2.3.3.2.

2.2.4.3.3 Navigation Center Offset

The equipment shall provide a means for compensating for the navigation center offset for each installation. The equipment shall not provide the flight crew with a means of changing information associated with this compensation during flight.

Note: *The fact that the GNSS antenna is top-mounted results in several feet of vertical difference between the antenna and the aircraft center of navigation, significantly larger than for ILS antennas. The center-of-navigation to wheel-crossing height will be evaluated for each installation. For most installations, a fixed vertical offset is adequate.*

2.2.4.4 Navigation Displays

2.2.4.4.1 Primary Navigation Displays

Nonnumeric vertical deviation shall be continuously displayed when in LNAV/VNAV.

2.2.4.4.2 Non-Numeric Lateral Cross-Track Deviation

Final approach segment lateral deviations (see Figure 2-16) are defined from the following:

- lateral deviation reference plane: the plane that contains the LTP/FTP vertical direction vector and the flight path alignment point (FPAP).
- vertical direction vector: the vector that passes through the LTP/FTP and is normal to the WGS-84 ellipsoid at the LTP/FTP.
- GNSS Azimuth Reference Point (GARP): the point that lies in the horizontal plane containing the LTP/FTP and is 305 m beyond the point where the vertical projection of the FPAP intersects this plane.

Positive lateral deviation shall correspond to aircraft positions to the left of the lateral deviation reference plane, as observed from the LTP/FTP facing toward the FPAP.

The *final approach segment lateral deviations* are referenced to the lateral deviation reference plane and are defined to be proportional to the angle (α_{lat}) measured at the GARP between the aircraft and the lateral deviation reference plane, with full-scale deflection (FSD) at a lateral cross-track error of:

$$\alpha_{lat,FS} = \pm \tan^{-1}\left(\frac{\text{FAS Course Width at LTP/FTP (m)}}{\text{Distance from LTP/FTP to GARP (m)}}\right)$$

If in LNAV/VNAV and a VTF has not been selected, the lateral deviation shall be as follows:

a. Prior to the FAWP, the deviation shall be either:

   i. Prior to 2 nm from the FAWP, the deviation shall be linear, with FSD for a cross-track error of ± 1 nm. Between 2 nm from the FAWP and the FAWP, the deviation sensitivity shall gradually change to the final approach segment lateral deviation sensitivity (Figure 2-16a); or

   ii. The deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$ (Figure 2-16b).

b. Between the FAWP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$;

c. Between the LTP/FTP and the length offset distance to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ± (Course Width at LTP/FTP).

If in LNAV/VNAV and a VTF has been selected, the lateral deviation shall be as follows:

a. Prior to the LTP/FTP, the deviation shall be either:

   i. At a distance greater than $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP, the deviation shall be linear with FSD for a cross-track error of ± 1 nm. Between $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation (Figure 2-16a); or

   ii. The deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$ (Figure 2-16b).

b. Between the LTP/FTP and a point that is prior to the GARP by a distance equal to either 305 m plus the length offset distance (if the length offset parameter is provided) or 305 m (if the length offset parameter is not provided) to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ± (Course Width at LTP/FTP);

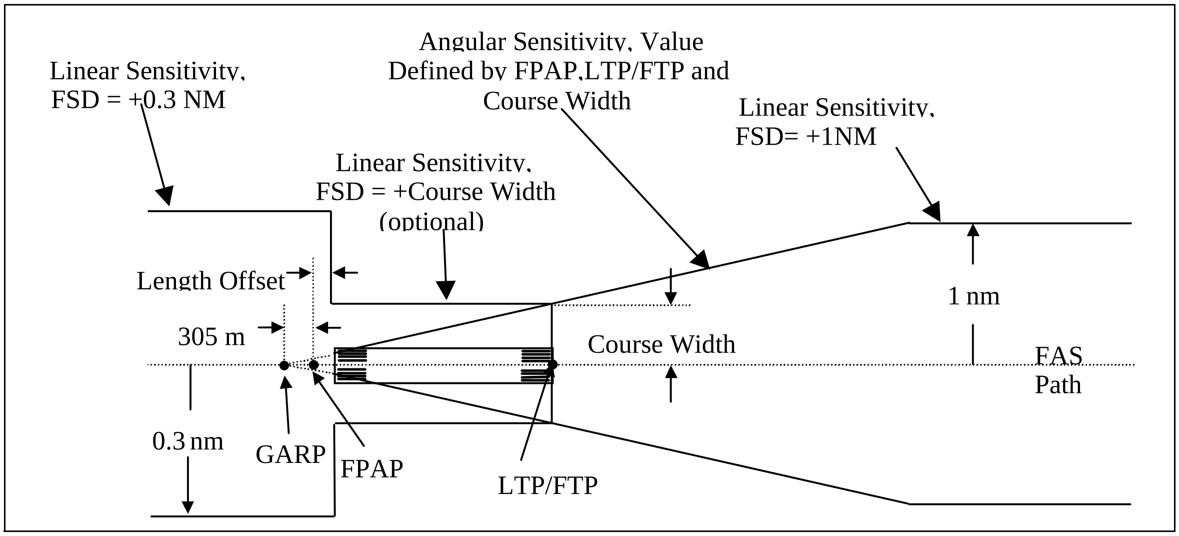
c. Beyond the length offset distance to the FPAP, the deviation shall be linear with FSD for a cross-track displacement of ± 0.3 nm.

When a missed approach is initiated, the deviation shall be linear with FSD for a cross-track error of ± 0.3 nm.

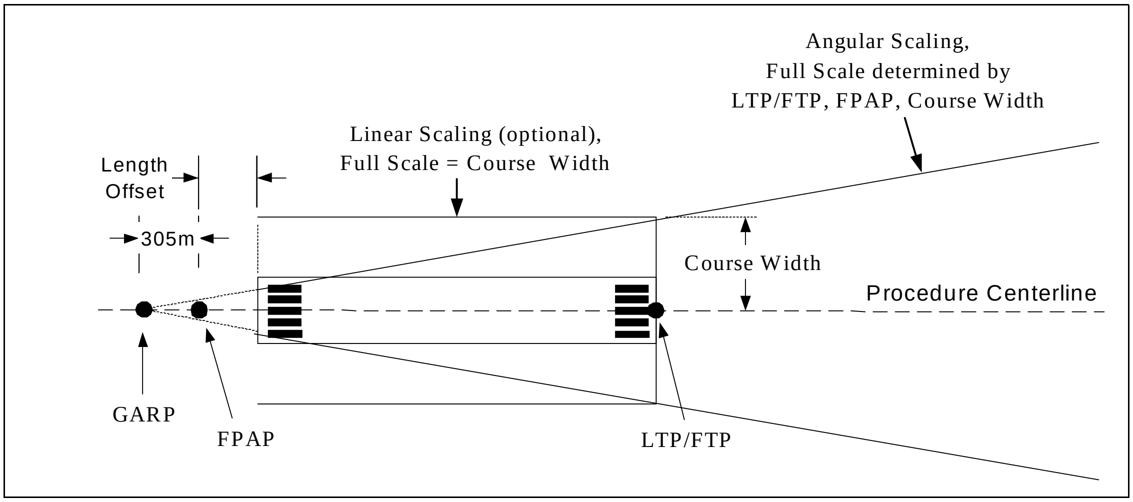
Notes: ***1.*** *Compatibility with ILS display systems can be achieved by converting the lateral deviation to μA (DDM) based upon a FSD at 150 μA (0.155 DDM).*

2. *The final approach path for standalone LNAV/VNAV approaches is defined by the intersection of the non-precision approach lateral path (as defined in Section 2.2.3.3.1) with the vertical path defined by the threshold location, threshold crossing height, and glidepath angle*

.a. Linear Deviation



b. Angular Deviation



<u>FIGURE 2-16</u> FINAL APPROACH SEGMENT LATERAL DEVIATIONS

2.2.4.4.3 Numeric Lateral Cross-Track Deviation

See Section 2.2.3.4.3.

2.2.4.4.4 Non-Numeric Vertical Deviation

When in LNAV/VNAV, the equipment shall continuously provide guidance in the form of an analog or digital output with signals meeting the requirements of Section 2.2.1.4.2.

Final approach segment vertical deviations (see Figure 2-17) are defined from the following:

- horizontal reference plane: the plane that contains the LTP/FTP and is normal to LTP/FTP vertical direction vector.
- glide path intercept point (GPIP): the intersection of the glide-path with the horizontal reference plane.
- vertical deviation reference surface: one of the following:
  a. The conical surface containing the FAS whose apex is at the GPIP and whose axis of symmetry is parallel to the LTP/FTP vertical direction vector;
  b. A conical surface as described in (a) above, but whose apex is offset up to 150 m from the GPIP in a direction normal to the lateral deviation reference plane; or
  c. A hyperbolic surface that asymptotically approaches the conical surface described in (a) above, whose minimum height is not more than 8 m above the GPIP.
- origin: the point on the vertical deviation reference surface with the minimum height above the GPIP (for (a) and (b) above, this point is the apex of the cone)

The *final approach segment vertical deviation* is defined to be proportional to the angle (α_{vert}) measured at the origin between the aircraft and the point on the vertical deviation reference surface that is closest to the aircraft, with full-scale deflection (FSD) for a vertical error of

$$\alpha_{vert,FS} = \pm 0.25(\text{FAS glidepath angle}).$$

The vertical deviation shall be as follows:

a. At a distance greater than $\dfrac{45m}{\tan(\alpha_{vert,FS})}$, the vertical deviation shall be either:

   i. At a distance greater than $\dfrac{150m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be linear with FSD for a vertical error of 150 m. Between $\dfrac{150m}{\tan(\alpha_{vert,FS})}$ and $\dfrac{45m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be the final approach segment vertical deviation (Figure 2-17a); or

   ii. The deviation shall be the final approach segment vertical deviation with FSD for a vertical error of $\alpha_{vert,FS}$ (Figure 2-17b).

b. Closer than $\dfrac{45m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be linear with FSD for a vertical error of ± 45 m.

Vertical deviations shall be flagged as invalid if:

a. The lateral position of the aircraft is outside of a ± 35 degree wedge with origin at the GARP, centered on the FAS; and

b. The aircraft is not on the approach side of the GPIP.

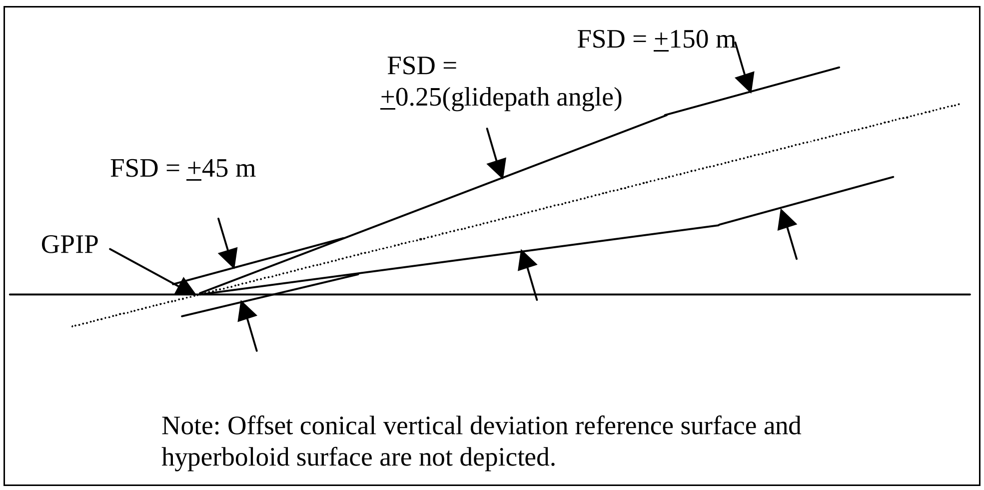
When a missed approach is initiated, the vertical deviations for approach shall be flagged as invalid.

Notes: **1.** *Compatibility with ILS display systems can be achieved by converting the vertical deviation to μA (DDM) based upon a FSD at 150 μA (0.175 DDM).*

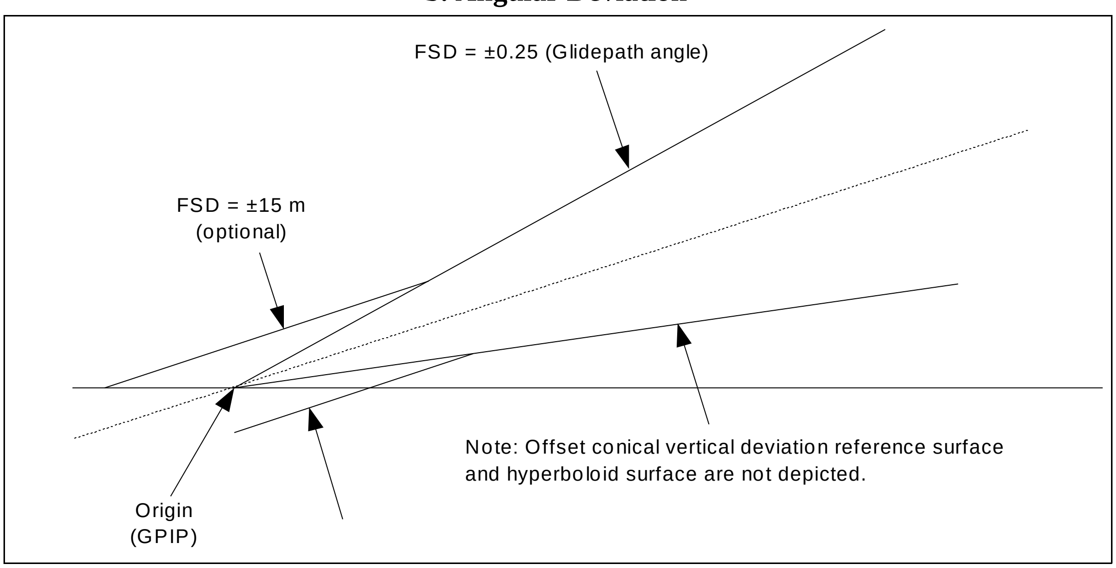
2. *Vertical deviations for the missed approach may be displayed in accordance with Appendix F.*

3. *The final approach path for standalone LNAV/VNAV approaches is defined by the intersection of the non-precision approach lateral path (as defined in Section 2.2.3.3.1) with the vertical path defined by the threshold location, threshold crossing height, and glidepath angle.*

a. Linear Deviation



b. Angular Deviation



<u>FIGURE 2-17</u> FINAL APPROACH SEGMENT VERTICAL DEVIATIONS

Note: *FSD is ±45 meters for LNAV/VNAV in Figure 17b.*

2.2.4.4.5 Missed Approach Waypoint/LTP/FTP Distance Display

When in terminal and approach modes, prior to crossing the LTP/FTP when an approach procedure is selected in the active flight plan, the distance to the LTP/FTP shall be available for display. The distance shall be displayed with a resolution of 0.1 nm up to a range of 99.9 nm. If a moving map is provided, the map may obviate the need for a numerical output.

Note: *Design consideration should be given to avoid confusion between the waypoint distance display and the MAWP/LTP/FTP distance display.*

2.2.4.4.6 Missed Approach Waypoint/LTP/FTP Bearing Display

When in terminal and approach modes, prior to crossing the LTP/FTP when an approach procedure is selected in the active flight plan, the bearing to the LTP/FTP shall be available for display. The displayed bearing shall have a resolution of 1 degree. The equipment shall be capable of displaying the bearing in true or magnetic bearing as selected. If a moving map is provided, the map may obviate the need for a numerical output.

Note: *Consideration should be given to the enhanced situational awareness that is provided by moving map displays.*

2.2.4.4.7 Displayed Data Update Rate

The equipment shall update non-numeric deviation data presented by a display at a rate of 5 Hz or more. The deviation update shall be based on a dynamically independent position (reference 2.1.5.8.1) at a minimum of 1 Hz. Intervening deviation updates may be extrapolated from the velocity vectors resulting from the 1 Hz position.

Note: *If the same information is used to drive an autopilot, the displayed data rate may be required to meet more stringent requirements, depending on the autopilot requirements.*

2.2.4.4.8 Display Update Latency

For the LNAV/VNAV navigator, the overall latency, defined as the interval between the time of measurement and time of applicability of the measurement, shall not exceed 400 milliseconds. The output of the data defining the position shall also be completed prior to 400 milliseconds after the time of the measurement.

Note: *The specified output latency may not be sufficient for all aircraft installations.*

2.2.4.4.9 Display of Vertical Accuracy

The equipment shall make available for display the 95%-confidence vertical accuracy.

Note: *This information can be used by the pilot to increase situational awareness of the current GPS/WAAS performance.*

2.2.4.5 Database Requirements

2.2.4.5.1 Content

In addition to the requirements of paragraph 2.2.1.5.2, the equipment shall store the LNAV/VNAV procedures in the area(s) in which IFR operation is intended. These procedures consist of the data defined in Appendix D (Table D-1), identification of the types of approach with vertical guidance that are published (i.e., GLS, APV-II, and/or LNAV/VNAV), and the naming convention associated with the types of approach (e.g., “GLS”, “LNAV/VNAV”).

The equipment shall also store data necessary to support stand-alone LNAV/VNAV approaches (i.e., LNAV/VNAV approaches to runway ends that do not also have a GLS or APV-II approach). The LNAV/VNAV approach data consists of the height of the runway threshold, threshold crossing height, and glidepath angle.

The complete sequence of waypoints, in the correct order for each approach, must be retrievable as a procedure (so that selecting the procedure by name results in loading the appropriate waypoints and legs into the flight plan).

Waypoints utilized as a final approach waypoint (FAWP) and LTP/FTP in a LNAV/VNAV procedure shall be uniquely identified as such to provide proper approach mode operation.

Notes:

1. *The database must identify which types of approaches are published to enable the equipment to use the appropriate alert limit for the operation. There is no requirement to identify the decision altitude/height or minimum descent altitude in the equipment database for the approach.*

2. *For a given aircraft installation, it is permissible to exclude procedures associated with runways at which the aircraft is not capable of landing.*

3. *The database may include vertical path information for non-precision approaches (the height of the threshold above the ellipsoid, the height of a desired path over the threshold and the glide path angle).*

4. *The FAS defines the desired final approach segment path. Each FAS data set contains parameters that define a single approach. Currently, the FAS data set defines a straight-line approach. Other FAS Data sets (e.g., other than a straight line) may be defined in the future. The FAS path for the straight line approach is defined by four parameters including the Landing Threshold Point/Fictitious Threshold Point (LTP/FTP), Flight Path Alignment Point (FPAP), Threshold Crossing Height (TCH), and the Glide Path Angle (GPA). A typical Final Approach Segment Diagram is shown graphically in Figure 2-15. The Final Approach Segment Data set parameters are defined in Appendix D.*

5. *For standalone LNAV/VNAV approaches, the azimuthal alignment is defined by the vector from the FAWP to the MAP, rather than the LTP/FTP and the FPAP. See Section 2.2.4.3.1.*

2.2.4.5.2 Data Integrity

Once the FAS data block has been decoded, the GPS/WAAS equipment shall apply the CRC to the data block as defined in Appendix D to determine if the data is valid. If the FAS data block does not pass the CRC test, the equipment shall not allow activation of LNAV/VNAV for that approach.

Note: *Vertical guidance may also be provided on a non-precision or LNAV/VNAV approach where FAS data does not exist. In this case, these requirements would not apply.*

2.2.4.6 Alerts

2.2.4.6.1 Alert Limits

Prior to sequencing the FAWP, the HAL shall be 0.3 nm. There is no VAL.

After sequencing the FAWP, the alert limits shall be as follows:

a. LNAV/VNAV: HAL and VAL as stored in the database for each LNAV/VNAV per Section 2.2.4.5.1.

The equipment shall not provide the flight crew a means of changing the alert limit.

As described in Section 2.2.4.7.4, the equipment must provide an advisory of the level of service available. Once that advisory is provided, the level of service shall not change unless the missed approach is initiated or the pilot changes the desired level of service.

The equipment shall use the alert limits for the monitoring described in Sections 2.2.4.6.2 and 2.2.4.6.3.

2.2.4.6.2 Caution Associated with Loss of Integrity Monitoring

The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within 30 seconds if the current HPL_{FD} exceeds the HAL.

The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within two seconds if the current HPL_{WAAS} exceeds the HAL.

Note: *Although this requirement is stated for the precision approach mode, its applicability is limited to outside the FAF since a loss of integrity monitoring after sequencing the FAF is defined to be a loss of navigation as described in Section 2.2.4.6.3).*

2.2.4.6.3 Caution Associated with Loss of Navigation

Class Gamma-2 equipment shall provide an indication that the navigation system is no longer adequate to conduct or continue the LNAV/VNAV approach by means of a warning flag or equivalent indicator on the vertical or lateral navigation display.

Both lateral and vertical flags or equivalent indicators shall be displayed within one second of the onset of any of the following conditions (a-c) when in LNAV/VNAV:

a. The absence of power (loss of function is an acceptable indicator);

b. Probable equipment malfunction or failure (all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5} per approach must be considered); or

c. The presence of a condition where fault detection detects a position failure which cannot be excluded (Section 2.1.4.2.2.2.).

Both lateral and vertical flags or equivalent indicators shall be displayed within one second of the onset of any of the following conditions (d-f) when the reference point, defined as the point on the desired path to which deviations are referenced, is between the FAWP and the LTP/FTP and heading toward the runway, or when the aircraft is below 1000 feet HAT, whichever occurs first:

d. When no valid WAAS message has been received for 4 seconds or more (this indicates a probable communications link problem or WAAS signal blockage);

e. There are an insufficient number of WAAS HEALTHY satellites (e.g., onset of condition is (1) when a satellite is blocked or (2) when the last bit of a WAAS message indicating “Don't Use” arrives at the antenna port);

f. The horizontal protection level exceeds the alert limit as defined in Section 2.2.4.6.1.

In addition, the vertical flag or equivalent indicator shall be displayed within 0.8 seconds of the onset of the following condition:

g. The vertical protection level exceeds the alert limit as defined in Section 2.2.4.6.1.

After sequencing the FAWP, this indication (flag) shall be latched until the equipment is no longer in the LNAV/VNAV approach mode.

Note: *A loss of navigation alert does not require removal of navigation information from the navigation display. It is acceptable to continue to display navigation information concurrent with the failure/status annunciation when conditions warrant.*

2.2.4.6.4 Low Altitude Alert

When in LNAV/VNAV and before sequencing the FAWP, the equipment shall provide an altitude alert if the estimated position is lower than the desired FAWP height by more than 50 m + VPL.

Notes:

1. *An acceptable implementation is to calculate the desired FAWP altitude as the desired ellipsoidal height at the FAWP by using the defined final approach segment. Another acceptable means is to provide VNAV guidance on the intermediate segment (in accordance with Appendix F).*

2. *This function provides additional safety against Controlled Flight Into Terrain (CFIT) during the approach phase. It does not provide vertical guidance on any leg of the approach other than the glidepath itself; on other legs vertical guidance is still provided by the altimeter (based on barometric altitude). It is intended primarily for implementation in classes of aircraft that are not equipped with terrain awareness and warning system (TAWS) equipment and that have no VNAV capability or access to barometric altitude by the GPS/WAAS equipment. Experience suggests that CFIT accidents can be significantly reduced by adding this capability.*

3. *This function is based on the fact that the aircraft should not descend below the FAF altitude prior to the FAF, either as part of the procedure vertical profile or as the result of ATC instructions. The alert altitude as required, provides margin for the accuracy of the geometric altitude provided by GPS/WAAS and for discrepancies between geometric altitude and barometric altitude as accounted for in procedure design.*

2.2.4.6.5 Alerting Scheme

Under normal operation, when a LNAV/VNAV procedure has been entered into the active flight plan and the equipment is in LNAV/VNAV, the vertical and lateral integrity flags shall be out of view, and the guidance displays shall show the deviations from track in vertical and lateral dimensions. Examples of this condition and others are shown in Table 2-11.

TABLE 2-11 **EXAMPLE DISPLAY OF LNAV/VNAV WARNINGS**

CONDITION	VERTICAL FLAG	VERTICAL DEVIATION INDICATOR	CROSS-TRACK FLAG	LATERAL DEVIATION INDICATOR
WAAS Receiver, in LNAV/VNAV	OUT OF VIEW	OPERATING	OUT OF VIEW	OPERATING
Vertical Alert Limit Warning	IN VIEW	OFF SCALE – FLY UP	OUT OF VIEW	ON SCALE – OPERATING
Lateral Alert Limit Warning	IN VIEW	OFF SCALE – FLY UP	IN VIEW	OFF SCALE
No Valid WAAS message for 4 seconds	IN VIEW	OFF SCALE – FLY UP	IN VIEW	OFF SCALE
Insufficient number of WAAS HEALTHY Satellites	IN VIEW	OFF SCALE – FLY UP	IN VIEW	OFF SCALE
Airborne GPS/ WAAS Malfunction	IN VIEW	OFF SCALE – FLY UP	IN VIEW	OFF SCALE

Note: *"OFF SCALE" means that the deviation indicator should be placed out of view to the extent possible for the particular display unit.*

2.2.4.7 LNAV/VNAV Approach Mode Switching Requirements

2.2.4.7.1 Entry Criteria

The LNAV/VNAV mode shall not be allowed to be activated unless all of the following conditions are met:

a. Valid long-term, fast, and ionospheric WAAS corrections are available and being applied to at least 4 satellites;

b. An approach procedure has been selected; and

c. The FAS data associated with the LNAV/VNAV procedure has been verified using the CRC as described in 2.2.4.5.2.

If activation of the LNAV/VNAV mode fails due to any of the conditions above, the equipment shall provide a means to notify the pilot that the selection was attempted and did not succeed.

When LNAV/VNAV is activated, the equipment shall provide an indication of the available service as described in 2.2.4.7.4.

Note: *Vertical guidance is provided for LNAV/VNAV and may also be provided on a non-precision approach where FAS data does not exist. In these cases, condition c would not apply.*

2.2.4.7.2 Exit Criteria

When a missed approach is initiated and the first leg in the missed approach procedure is not a TF leg, the equipment shall automatically switch to the terminal mode.

When a missed approach is initiated and the first leg in the missed approach procedure is a TF leg, the equipment shall automatically switch to terminal mode at the turn initiation point for the first waypoint in the missed approach procedure.

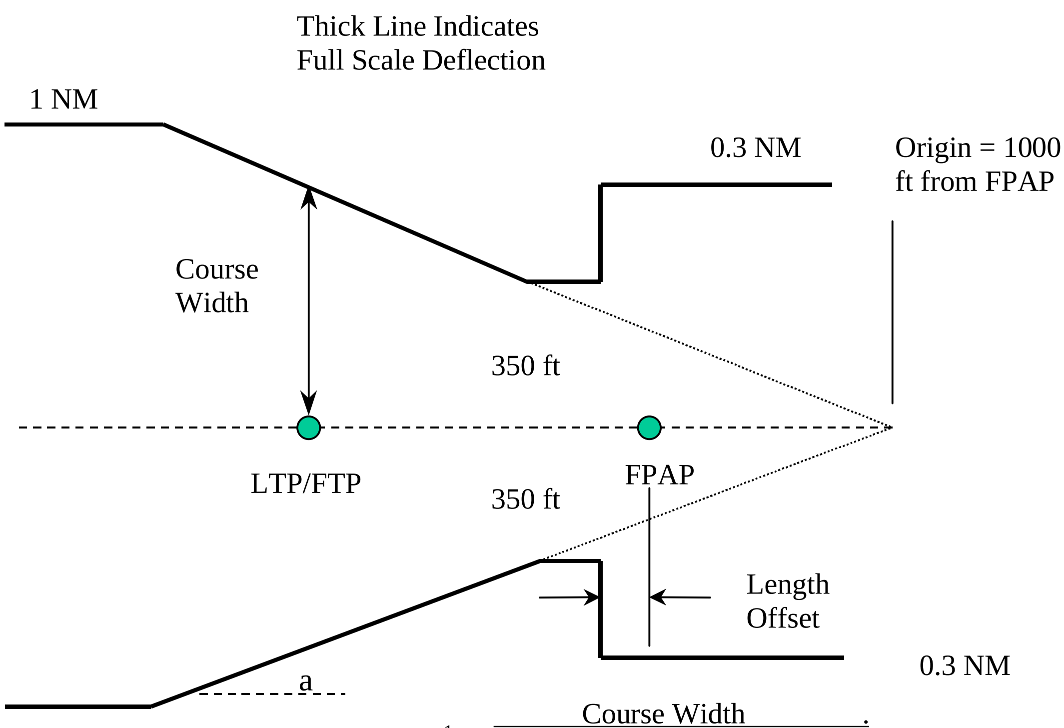
If the pilot initiates Direct-To any waypoint while in LNAV/VNAV, the equipment shall automatically switch to terminal mode.

2.2.4.7.3 Display Transition

Upon entering the LNAV/VNAV when a VTF has not been selected, there is no change in FSD until the aircraft reaches a distance of 2 nm from the FAWP as specified in 2.2.4.4.2.

Upon entering the LNAV/VNAV when a VTF has been selected, the equipment shall immediately transition to the angular/linear guidance relative to the (extended) FAS as defined in Section 2.2.4.4.2.

Display transitions when initiating a missed approach are described in Section 2.2.3.4.2 and shown in Figure 2-18. The sensitivity shall change immediately from ± 0.3 nm to ± 1 nm when the equipment changes to terminal mode.



$$a = \tan^{-1}\frac{\text{Course Width}}{\text{Length LTP/FTP to FPAP + 1000}}$$

FIGURE 2-18 FULL SCALE DEFLECTION AND DEFINED PATH FOR PRECISION APPROACH MODE

2.2.4.7.4 Advisory of LNAV/VNAV Availability

For approach procedures that support GLS or APV-II, equipment supporting only LNAV/VNAV operations shall indicate that the GLS or APV-II approach is not available. For example, if an approach is published with a GLS minimum, the equipment must indicate “GLS not available – Use LNAV/VNAV minima”. Also see Section 2.2.5.7.4.

2.2.5 Class Gamma Requirements for APV-II and GLS Precision Approach Operations

Note: *The requirements in this section apply to all types of approaches for which the WAAS equipment provides vertical deviations. This includes two levels of approach with vertical guidance: GLS, and APV-II. Section 2.2.4 contains requirements for another approach with vertical guidance, LNAV/VNAV. These approach classifications are generically called approach or precision approach in this MOPS. Except when specifically noted every requirement for precision approach applies to GLS and APV-II .*

2.2.5.1 General Human Factors Requirements

There are no additional human factors requirements.

2.2.5.2 Path Selection

See Section 2.2.4.2.

2.2.5.2.1 5-Digit Channel Selection

See Section 2.2.4.2.1.

2.2.5.2.2 Approach Name Selection

See Section 2.2.4.2.2.

2.2.5.2.3 Missed Approach Sequencing

See Section 2.2.4.2.3.

2.2.5.2.4 Selection of the Type of Approach with Vertical Guidance

The equipment shall provide a means to select which type of approach with vertical guidance will be conducted. This selection may be manual (pilot selects GLS, APV-II and LNAV/VNAV) or automatic as described in Section 2.2.5.7.4.

2.2.5.3 Path Definition

2.2.5.3.1 Approach Path Definition

APV-II and GLS approaches shall only be available for procedures defined by a FAS data block. See Section 2.2.4.3.1.

2.2.5.3.2 Missed Approach Path Definition

See Section 2.2.3.3.2.

2.2.5.3.3 Navigation Center Offset

See Section 2.2.4.3.3.

2.2.5.4 Navigation Displays

2.2.5.4.1 Primary Navigation Displays

Nonnumeric vertical deviation shall be continuously displayed when in GLS or APV-II.

2.2.5.4.2 Non-Numeric Lateral Cross-Track Deviation

Final approach segment lateral deviations (see Figure 2-16) are defined from the following:

- lateral deviation reference plane: the plane that contains the LTP/FTP vertical direction vector and the flight path alignment point (FPAP).

- vertical direction vector: the vector that passes through the LTP/FTP and is normal to the WGS-84 ellipsoid at the LTP/FTP.
- GNSS Azimuth Reference Point (GARP): the point that lies in the horizontal plane containing the LTP/FTP and is 305 m beyond the point where the vertical projection of the FPAP intersects this plane.

Positive lateral deviation shall correspond to aircraft positions to the left of the lateral deviation reference plane, as observed from the LTP/FTP facing toward the FPAP.

The *final approach segment lateral deviations* are referenced to the lateral deviation reference plane and are defined to be proportional to the angle ($\alpha_{\alpha \mathrm{lat}}$) measured at the GARP between the aircraft and the lateral deviation reference plane, with full-scale deflection (FSD) at a lateral cross-track error of:

$$\alpha_{lat,FS} = \pm \tan^{-1}\left(\frac{\text{FAS Course Width at LTP/FTP (m)}}{\text{Distance from LTP/FTP to GARP (m)}}\right)$$

If in GLS or APV-II and a VTF has not been selected, the lateral deviation shall be as follows:

a. Prior to the FAWP, the deviation shall be either:

   i. Prior to 2 nm from the FAWP, the deviation shall be linear, with FSD for a cross-track error of ±1 nm. Between 2 nm from the FAWP and the FAWP, the deviation sensitivity shall gradually change to the final approach segment lateral deviation sensitivity (Figure 2-16a); or

   ii. The deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{\mathrm{lat,FS}}$ (Figure 2-16b).

b. Between the FAWP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{\mathrm{lat,FS}}$;

c. Between the LTP/FTP and the length offset distance to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ± (Course Width at LTP/FTP).

If in GLS or APV-II and a VTF has been selected, the lateral deviation shall be either:

a. Prior to the LTP/FTP, the deviation shall be as follows:

   i. At a distance greater than $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP, the deviation shall be linear with FSD for a cross-track error of ±1 nm. Between $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation (Figure 2-16a); or

   ii. The deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{\mathrm{lat,FS}}$ (Figure 2-16b).

b. Between the LTP/FTP and a point that is prior to the GARP by a distance equal to either 305 m plus the length offset distance (if the length offset parameter is provided) or 305 m (if the length offset parameter is not provided) to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ± (Course Width at LTP/FTP);

c. Beyond the length offset distance to the FPAP, the deviation shall be linear with FSD for a cross-track displacement of ±0.3 nm.

When a missed approach is initiated, the deviation shall be linear with FSD for a cross-track error of ±0.3 nm.

Note: *Compatibility with ILS display systems can be achieved by converting the lateral deviation to μA (DDM) based upon a FSD at 150 μA (0.155 DDM).*

2.2.5.4.3 Numeric Lateral Cross-Track Deviation

See Section 2.2.3.4.3.

2.2.5.4.4 Non-Numeric Vertical Deviation

When in GLS or APV-II, the equipment shall continuously provide guidance in the form of an analog or digital output with signals meeting the requirements of Section 2.2.1.4.2.

Final approach segment vertical deviations (see Figure 2-17) are defined from the terms described in Section 2.2.4.4.4.

The *final approach segment vertical deviation* is defined to be proportional to the angle (α_{vert}) measured at the origin between the aircraft and the point on the vertical deviation reference surface that is closest to the aircraft, with full-scale deflection (FSD) for a vertical error of

$$\alpha_{vert,FS} = \pm 0.25(\text{FAS glidepath angle}).$$

The vertical deviation shall be as follows:

a. At a distance greater than $\dfrac{15m}{\tan(\alpha_{vert,FS})}$, the vertical deviation shall be either:

   i. At a distance greater than $\dfrac{150m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be linear with FSD for a vertical error of 150 m. Between $\dfrac{150m}{\tan(\alpha_{vert,FS})}$ and $\dfrac{15m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be the final approach segment vertical deviation (Figure 2-17a); or

   ii. The deviation shall be the final approach segment vertical deviation with FSD for a vertical error of $\alpha_{vert,FS}$ (Figure 2-17b).

b. Closer than $\dfrac{15m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be either the final approach segment vertical deviation or linear with FSD for a vertical error of ±15 m.

Vertical deviations shall be flagged as invalid if:

a. The lateral position of the aircraft is outside of a ±35 degree wedge with origin at the GARP, centered on the FAS; and

b. The aircraft is not on the approach side of the GPIP.

When a missed approach is initiated, the vertical deviations for approach shall be flagged as invalid.

Notes: ***1.*** *Compatibility with ILS display systems can be achieved by converting the vertical deviation to μA (DDM) based upon a FSD at 150 μA (0.175 DDM).*

2. Vertical deviations for the missed approach may be displayed in accordance with Appendix F.

2.2.5.4.5 Missed Approach Waypoint/LTP/FTP Distance Display

See Section 2.2.4.4.5.

2.2.5.4.6 Missed Approach Waypoint/LTP/FTP Bearing Display

See Section 2.2.4.4.6.

2.2.5.4.7 Displayed Data Update Rate

The equipment shall update non-numeric deviation data presented by a display at a rate of 5 Hz or more. Each deviation update shall be dynamically independent (Reference Section 2.1.5.8.1)

Note: *If the same information is used to drive an autopilot, the displayed data rate may be required to meet more stringent requirements, depending on the autopilot requirements.*

2.2.5.4.8 Display Update Latency

For the GLS or APV-II navigator, the overall latency, defined as the interval between the time of measurement and time of applicability of the measurement, shall not exceed 400 milliseconds. The output of the data defining the position shall also be completed prior to 400 milliseconds after the time of the measurement.

Note: *The specified output latency may not be sufficient for all aircraft installations*

2.2.5.4.9 Display of Vertical Accuracy

See Section 2.2.4.4.9.

2.2.5.5 Database Requirements

2.2.5.5.1 Content

In addition to the requirements of paragraph 2.2.1.5.2, the equipment shall store the GLS and APV-II procedures in the area(s) in which IFR operation is intended. For each procedure, the equipment shall also identify the types of approach with vertical guidance that are published (i.e., GLS, APV-II, and/or LNAV/VNAV), and the naming convention associated with the types of approach (e.g., “GLS”, “LNAV/VNAV”).

Note: *The expected HAL and VAL for GLS approaches are 40 m and 12 m, respectively. The expected HAL and VAL for APV-II approaches are 40 m and 20 m, respectively. The FAA is investigating the potential operational benefits for APV-II of increasing the VAL to 50 m.*

The complete sequence of waypoints, in the correct order for each approach, must be retrievable as a procedure (so that selecting the procedure by name results in loading the appropriate waypoints and legs into the flight plan).

Waypoints utilized as a final approach waypoint (FAWP) and LTP/FTP in a GLS and APV-II procedure shall be uniquely identified as such to provide proper approach mode operation.

In addition to the above requirements, the equipment shall store the VAL for each GLS and APV-II approach.

Notes: ***1.*** *The database must identify which types of approaches are published to enable the equipment to use the appropriate alert limit for the operation.*

There is no requirement to identify the decision altitude/height or minimum descent altitude in the equipment database for the approach.

2. *For a given aircraft installation, it is permissible to exclude procedures associated with runways at which the aircraft is not capable of landing.*

3. *The FAS defines the desired final approach segment path. Each FAS data set contains parameters that define a single approach. Currently, the FAS data set defines a straight-line approach. Other FAS Data sets (e.g., other than a straight line) may be defined in the future. The FAS path for the straight line approach is defined by four parameters including the Landing Threshold Point/Fictitious Threshold Point (LTP/FTP), Flight Path Alignment Point (FPAP), Threshold Crossing Height (TCH), and the Glide Path Angle (GPA). A typical Final Approach Segment Diagram is shown graphically in Figure 2-15. The Final Approach Segment Data set parameters are defined in Appendix D.*

2.2.5.5.2 Data Integrity

Once the FAS data block has been decoded, the GPS/WAAS equipment shall apply the CRC to the data block as defined in Appendix D to determine if the data is valid. If the FAS data block does not pass the CRC test, the equipment shall not allow activation of GLS or APV-II for that approach.

2.2.5.6 Alerts

2.2.5.6.1 Alert Limits

Prior to sequencing the FAWP, the HAL shall be 0.3 nm. There is no VAL.

After sequencing the FAWP, the alert limits for APV-II and GLS shall be as follows:

a. APV-II: HAL and VAL as stored in the database for each APV-II per Section 2.2.5.5.1

b. GLS: HAL and VAL as stored in the database for each GLS per Section 2.2.5.5.1

The equipment shall not provide the flight crew a means of changing the alert limit.

As described in Section 2.2.5.7.4, the equipment must provide an advisory of the level of service available. Once that advisory is provided, the level of service shall not change unless the missed approach is initiated or the pilot changes the desired level of service.

The equipment shall use the alert limits associated with the selected level of service for the monitoring described in Sections 2.2.5.6.2 and 2.2.5.6.3.

2.2.5.6.2 Caution Associated with Loss of Integrity Monitoring

The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within 30 seconds if the current HPL_{FD} exceeds the HAL.

The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within two seconds if the current HPL_{WAAS} exceeds the HAL.

Note: *Although this requirement is stated for the precision approach mode, its applicability is limited to outside the FAF since a loss of integrity monitoring after sequencing the FAF is defined to be a loss of navigation as described in Section 2.2.5.6.3).*

2.2.5.6.3 Caution Associated with Loss of Navigation

Class Gamma-3 equipment shall provide an indication that the navigation system is no longer adequate to conduct or continue the GLS or APV-II, approach by means of a warning flag or equivalent indicator on the vertical or lateral navigation display.

Both lateral and vertical flags or equivalent indicators shall be displayed within one second of the onset of any of the following conditions (a-c) when in GLS or APV-II:

a. The absence of power (loss of function is an acceptable indicator);

b. Probable equipment malfunction or failure (all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5} per approach must be considered); or

c. The presence of a condition where fault detection detects a position failure which cannot be excluded (Section 2.1.4.2.2.2.).

Both lateral and vertical flags or equivalent indicators shall be displayed within one second of the onset of any of the following conditions (d-f) when the reference point, defined as the point on the desired path to which deviations are referenced, is between the FAWP and the LTP/FTP and heading toward the runway, or when the aircraft is below 1000 feet HAT, whichever occurs first:

d. When no valid WAAS message has been received for 4 seconds or more (this indicates a probable communications link problem or WAAS signal blockage);

e. There are an insufficient number of WAAS HEALTHY satellites (onset of condition is either (1) when a satellite is blocked or (2) when the last bit of a WAAS message indicating "Don't Use" arrives at the antenna port)

f. The horizontal protection level exceeds the alert limit as defined in Section 2.2.5.6.1.

In addition, the vertical flag or equivalent indicator shall be displayed within 0.8 seconds of the onset of the following condition:

g. The vertical protection level exceeds the alert limit as defined in Section 2.2.5.6.1.

After sequencing the FAWP, this indication (flag) shall be latched until the equipment is no longer in the GLS or APV-II.

Note: *A loss of navigation alert does not require removal of navigation information from the navigation display. It is acceptable to continue to display navigation information concurrent with the failure/status annunciation when conditions warrant.*

2.2.5.6.4 Low Altitude Alert

When in GLS or APV-II and before sequencing the FAWP, the equipment shall provide an altitude alert if the estimated position is lower than the desired FAWP height by more than 20 m + (APV-II), or the applicable VAL for GLS.

2.2.5.6.5 Alerting Scheme

Under normal operation, when a GLS or APV-II procedure has been entered into the active flight plan and the equipment is in GLS or APV-II, the vertical and lateral integrity flags shall be out of view, and the guidance displays shall show the deviations from track in vertical and lateral dimensions. Examples of this condition and others are shown in Table 2-11A.

<u>TABLE 2-11A</u> EXAMPLE DISPLAY OF GLS or APV-II WARNINGS

CONDITION	VERTICAL FLAG	VERTICAL DEVIATION INDICATOR	CROSS-TRACK FLAG	LATERAL DEVIATION INDICATOR
WAAS Receiver, in GLS or APV-II	OUT OF VIEW	OPERATING	OUT OF VIEW	OPERATING
Vertical Alert Limit Warning	IN VIEW	OFF SCALE – FLY UP	OUT OF VIEW	ON SCALE – OPERATING
Lateral Alert Limit Warning	IN VIEW	OFF SCALE – FLY UP	IN VIEW	OFF SCALE
No Valid WAAS message for 4 seconds	IN VIEW	OFF SCALE – FLY UP	IN VIEW	OFF SCALE
Insufficient number of WAAS HEALTHY Satellites	IN VIEW	OFF SCALE – FLY UP	IN VIEW	OFF SCALE
Airborne GPS/ WAAS Malfunction	IN VIEW	OFF SCALE – FLY UP	IN VIEW	OFF SCALE

Note: *"OFF SCALE" means that the deviation indicator should be placed out of view to the extent possible for the particular display unit.*

2.2.5.7 Precision Approach Mode Switching Requirements

2.2.5.7.1 Entry Criteria

The GLS or APV-II mode shall not be allowed to be activated unless all of the following conditions are met:

a. Valid long-term, fast, and ionospheric WAAS corrections are available and being applied to at least 4 satellites;

b. An approach procedure has been selected; and

c. The FAS data associated with the precision approach procedure has been verified using the CRC as described in 2.2.4.5.2.

If activation of the GLS or APV-II mode fails due to any of the conditions above, the equipment shall provide a means to notify the pilot that the selection was attempted and did not succeed.

When GLS or APV-II is activated, the equipment shall provide an indication of the available service as described in 2.2.4.7.4.

2.2.5.7.2 Exit Criteria

When a missed approach is initiated and the first leg in the missed approach procedure is not a TF leg, the equipment shall automatically switch to the terminal mode.

When a missed approach is initiated and the first leg in the missed approach procedure is a TF leg, the equipment shall automatically switch to terminal mode at the turn initiation point for the first waypoint in the missed approach procedure.

If the pilot initiates Direct-To any waypoint while in GLS or APV-II, the equipment shall automatically switch to terminal mode.

2.2.5.7.3 Display Transition

Upon entering the GLS or APV-II when a VTF has not been selected, there is no change in FSD until the aircraft reaches a distance of 2 nm from the FAWP as specified in 2.2.4.4.2.

Upon entering the GLS or APV-II when a VTF has been selected, the equipment shall immediately transition to the angular/linear guidance relative to the (extended) FAS as defined in Section 2.2.4.4.2.

Display transitions when initiating a missed approach are described in Section 2.2.3.4.2 and shown in Figure 2-18. The sensitivity shall change immediately from ± 0.3 nm to ± 1 nm when the equipment changes to terminal mode.

2.2.5.7.4 Advisory of GLS or APV-II Availability

For manual selection of the type of approach with vertical guidance, the equipment shall indicate whether the applicable alert limit requirements are met. This indication shall be provided continuously once the equipment is in GLS or APV-II.

For automatic selection of the type of approach with vertical guidance, the equipment shall display the level of service that is available when entering precision approach mode (using the naming convention stored in the database for each of the GLS, APV-II, LNAV/VNAV, and LNAV services). The selected level of service shall be the most accurate level of service for which both the vertical and horizontal alert limits are supported and for which a minimum is published for the selected procedure.

If the most accurate level of service for which a minimum is published is available, the equipment shall indicate that it is available. If the most accurate level of service for which a minimum is published is not available, the equipment shall indicate that it is not available and shall indicate the level of service that is available (e.g., "GLS not available – Use LNAV/VNAV minima").

Note: *The chart naming convention for these levels of service has not been internationally standardized. Therefore, this MOPS requires that the naming convention can be stored in the navigation database.*

2.3 Class Delta-4 Requirements for Precision Approach Operations

Class Delta equipment provides path deviation data to a flight director or flight management system computer, and may or may not directly drive a display. The Class 4 designation applies to equipment which provides an "ILS look-alike signal" only for approach and landing operations, but does not necessarily support other modes of operation. Class Delta-4 equipment receives database data from a flight computer and defines the desired path. Class Delta-4 equipment shall meet the requirements of this section, as well as all the requirements in Sections 2.1.1 and 2.1.5, except for specific cases described in this section.

2.3.1 General Human Factors Requirements

Class Delta-4 must satisfy the requirements of Section 2.2.1.1, as applicable.

2.3.2 Path Selection

There are no path selection requirements. The path is indirectly selected by accepting a precision approach data record from an external source.

2.3.3 Path Definition

Class Delta-4 equipment shall output deviations relative to the FAS. The FAS is defined by the vector defined by the Flight Path Alignment Point (FPAP) and Landing Threshold Point/Fictitious Threshold Point (LTP/FTP), and by the Threshold Crossing Height (TCH) and glidepath angle. The glidepath angle is defined relative to the local tangent plane of the WGS-84 ellipsoid. These parameters are defined in Appendix D.

2.3.4 Navigation Displays

2.3.4.1 Non-Numeric Cross-Track Deviation

The equipment shall provide an output of non-numeric deviations that meets the requirements of Section 2.2.1.4.2. The lateral deviation shall be as follows:

a. At a distance greater than $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP, the deviation shall be linear with FSD for a cross-track error of ±1 nm;

b. Between $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation as defined in Section 2.2.5.4.2;

c. Between the LTP/FTP and the length offset distance to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ± (Course Width at LTP/FTP);

Beyond the length offset distance to the FPAP, the deviation should be linear with FSD for a cross-track error of ± 0.3 nm.

Note: *Compatibility with ILS display systems can be achieved by converting the lateral deviation to μA (DDM) based upon a FSD at 150 μA (0.155 DDM).*

2.3.4.2 Non-Numeric Vertical Deviation

The equipment shall provide an output of non-numeric deviations that meets the requirements of Section 2.2.1.4.2. The equipment shall meet the requirements of Section 2.2.5.4.4.

2.3.4.3 Landing Threshold Point/Fictitious Threshold Point Distance Display

Prior to crossing the LTP/FTP, the distance (length of the slant range vector projected onto the plane tangent to the WGS-84 ellipsoid at the LTP/FTP) to the LTP/FTP shall be output or displayed. The distance shall be output or displayed with a resolution of 0.1 nm up to a range of 99.9 nm from the waypoint. If a moving map is provided, the map may obviate the need for a numerical output.

2.3.4.4 Displayed Data Update Rate

The equipment shall meet the requirements of Section 2.2.5.4.7.

2.3.4.5 Displayed Data Update Latency

The overall latency, defined as the interval between the time of measurement and the completion of transmission of the deviation output reflecting the measurement, shall not exceed 400 msec.

2.3.5 Database Requirements

The database functions do not reside in the GPS/WAAS Delta-4 equipment. However, the applicable FAS data block is transferred in its entirety, including the CRC, to the GPS/

WAAS equipment. The GPS/WAAS equipment shall verify the CRC. If the FAS data block does not pass the CRC, the equipment shall indicate a loss of navigation. The applicable HAL and VAL for the GLS approach also shall be transferred to the GPS/WAAS equipment.

2.3.6 Alerts

The equipment shall meet the requirements of Section 2.2.5.6 applicable to GLS. The equipment shall accommodate the configuration of horizontal and vertical alert limits.

If the equipment provides APV-II and LNAV/VNAV capability, it must also meet the requirements in Section 2.2.4.7.4 and 2.2.5.7.4.

2.4 Airborne Equipment Performance — Environmental Conditions

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

The environmental performance requirements identified in this section must be met for all components in the airborne GPS/WAAS system.

Some of the environmental tests contained in this subsection need not be performed unless the manufacturer wishes to qualify the equipment for the particular environmental condition. The unshaded columns of Tables 2-12 through 2-18 identify the environmental tests, which are required to qualify the equipment. The shaded columns identify the optional environmental tests, which are to be performed if the manufacturer wishes to qualify the equipment for these additional environmental conditions. An "X" in the rows of Tables 2-12 through 2-18 identifies the GPS/WAAS requirements which must be met while the equipment is subjected to environmental test condition specified in the columns.

Unless otherwise specified, the pass/fail criteria are those specified in the test procedures applicable to the requirements listed in Tables 2-12 through 2-18, as modified by Section 2.4.1.1. The test procedures applicable to a determination of equipment performance under environmental test conditions are set forth in RTCA document DO-160D, Environmental Conditions and Test Procedures for Airborne Equipment.

Some of the performance requirements in Sections 2.1 and 2.2 of this document are not required to be tested to all of the conditions contained in RTCA/DO-160D. Judgment and experience have indicated that these particular performance parameters are not susceptible to certain environmental conditions and that the level of performance specified in Sections 2.1 and 2.2 will not be measurably degraded by exposure to these particular environmental conditions.

2.4.1 Environmental Tests

Tables 2-12 through 2-18 show matrix charts that define the tests required for a particular class of equipment. They show the paragraph numbers in RTCA/DO-160D that describe the individual environmental tests. These tests must be performed on the test article as specified in the tables. They are as follows:

Table 2-12	Class Beta-1 Environmental Test Requirements
Table 2-13	Class Gamma-1 Environmental Test Requirements
Table 2-14	Class Beta-2 Environmental Test Requirements
Table 2-15	Class Gamma-2 Environmental Test Requirements
Table 2-16	Class Beta-3 Environmental Test Requirements

Table 2-17 Class Gamma-3 Environmental Test Requirements

Table 2-18 Class Delta-4 Environmental Test Requirements

RTCA/DO-160D contains equipment categories for each environmental condition with different environmental test limits for each category. The equipment manufacturer is allowed to choose to which environmental category the article is to be qualified, except for Lightning and Radio Frequency Susceptibility tests, for which a minimum test level is specified. The manufacturer's certification must specifically state the environmental categories for which the article is qualified.

2.4.1.1 Required Performance

The following paragraphs state procedure requirements for demonstrating performance requirements stated in Tables 2-12 through 2-18.

2.4.1.1.1 Accuracy

The demonstration of accuracy while subjecting the equipment to environmental tests described in RTCA/DO-160D must be done in accordance with Section 2.5.8.1 of this MOPS only for the test case with a noise bandwidth of 20 MHz. For all environmental tests except for temperature tests (RTCA/DO-160D, Section 4.5.1 and 4.5.3) the procedure will not need to last longer than the minimum duration of the particular test as specified in RTCA/DO-160D. The test threshold has been defined in Table 2-26 to yield a 80% probability of failing equipment with a true accuracy of 125% of the required accuracy (e.g., 0.5 m for GPS at minimum signal power).

Accuracy demonstrations must be performed to the tightest requirement for all navigation modes capable by the equipment.

Note: *For other than PA, a simpler test procedure may be used to demonstrate accuracy under environmental conditions.*

2.4.1.1.2 Loss of Navigation Indication

While demonstrating this performance requirement any of the sources that generate this indication may be used.

2.4.1.1.3 Loss of Integrity Indication

While demonstrating this performance requirement any of the sources that generate this indication may be used.

2.4.1.1.4 Reserved

2.4.1.1.5 Sensitivity and Dynamic Range

Demonstration of this requirement should be done in conjunction with demonstration of accuracy.

2.4.1.1.6 Navigation Display

Class Gamma equipment should provide the appropriate displays throughout the test.

2.4.1.1.7 Database

Demonstration of this requirement shall consist of the following after each appropriate environmental test has been performed:

1. Demonstrate the integrity of the database by verifying a CRC or other appropriate error detection scheme.

2. Demonstrate the loading and verification of an updated database by loading several data items from the data base.

2.4.1.1.8 Mode Annunciation

The manufacturer must demonstrate this requirement as noted.

2.4.1.1.9 TO-TO and TO-FROM Capability

If the Class Gamma equipment only supplies an electrical output and does not display TO-TO or TO-FROM indicators, demonstration of this requirement is not necessary.

2.4.1.1.10 System Operating

The "System Operating " row in Tables 2-12 through 2-18 exist for the environmental tests that require the system to simply be powered and operational while the environmental test is being performed.

2.4.1.2 Clarification of Environmental Tests

The following paragraphs provide additional guidance for the environmental tests described in RTCA/DO-160D.

2.4.1.2.1 Power Input Tests

When Normal Operating Conditions Tests, outlined in RTCA/DO-160D par. 16.5.1 & 2, are being performed, the equipment shall operate during the tests without interruption, so that the accuracy requirement shall continue to be met. When Abnormal Operating Conditions Tests, par. 16.5.3 & 4, are being performed, the equipment is not required to operate normally during the specified minimum voltage period, but must not provide misleading information during and after the test, and must meet the initial acquisition time requirement after the minimum voltage period.

2.4.1.2.2 Icing Tests

Icing tests are required primarily for the antenna and only if the manufacturer wants to qualify the antenna as part of the GPS/WAAS equipment. If an antenna is used that already has been qualified in this area, this environmental test is not required.

2.4.1.2.3 RF Susceptibility Tests

Note: *The GPS/WAAS equipment shall be qualified to at least equipment Category T of Section 20 of RTCA/DO-160D for conducted and radiated radio frequency susceptibility, and provide the required accuracy during the test. The high level radiated susceptibility does not apply between 1500 MHz and 1640 MHz. In addition, the GPS equipment shall provide the required accuracy when subjected to a radiated signal with continuous wave 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-160D, 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).*

2.4.1.2.4 Lightning Induced Transient Susceptibility Tests

The GPS/WAAS equipment should at least be qualified with an appropriate wave form set and test level from Section 22 of RTCA/ DO-160D for lightning induced transient susceptibility which is compatible with the GPS/WAAS antenna(s) specified to be used with the equipment by the manufacturer. The equipment is not required to operate normally during the lightning transient test, and must automatically become operational within the specified acquisition time requirement.

2.4.1.2.5 Lightning Direct Effects Tests

Lightning Direct Effects Tests outlined in Section 23 of RTCA/DO-160D are required for the antenna. The antenna(s) should function normally after the lightning direct effects tests have been conducted.

Note: *Because of GPS/WAAS antenna mounting requirements, the antenna should be qualified for mounting in at least Lightning Zone 2A.*

2.4.1.2.6 Crash Safety Shock

All equipment shall pass the crash safety shock test as specified in of RTCA/DO-160D, Section 7.3. Applicants shall select the aircraft type and the appropriate shock levels to which they wish to qualify their equipment.

<u>TABLE 2-12</u> CLASS BETA-1 ENVIRONMENTAL TEST REQUIREMENTS

	Class BETA-1	**DO-160D Requirement**	Low Operating Temp. Test	High Short-Time Temp. Test	High Operating Temp. Test	*In-Flight Loss of Cooling*	Altitude Test	*Decompression Test*	*Overpressure Test*	Temperature Variation Test	Humidity Test	Operational Shocks	Crash Safety Shocks	Vibration Test	*Explosion Proofness Test*	*Drip Proof Test*	*Spray Proof Test*	*Cont. Stream Proof Test*	*Spray Test*	*Immersion Test*	*Sand and Dust Test*	*Fungus Resistance Test*	*Salt Spray Test*	Magnetic Effect Test	Normal Operation Conditions	Abnormal Operation Cond.	Volt. Spike Cond. Test	Audio Freq. Cond. Susc. Test	Induced Signal Susc. Test	RF Susceptibility Test	Emission of RF Energy Test	Lightning Ind. Trans. Susc.	Lightning Direct Effects	Icing	*Electrostatic Discharge*
MOPS Section	**Requirement**	**Section**	4.5.2	4.5.2	4.5.3	*4.5.4*	4.6.1	*4.6.2*	*4.6.3*	5	6	7.2	7.3	8	*9*	*10.3.1*	*10.3.2*	*10.3.3*	*11.4.1*	*11.4.2*	*12*	*13*	*14*	15	16.5.1,2	16.5.3,4	17	18	19	20	21	22	23	24	*25*
2.1.2.1	Accuracy		X	X	X	*X*	X	*X*	*X*	X	X	X		X	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X		X	X	X	*X*
2.1.1.13.2	Loss of Nav.		X		X																														
2.1.1.13.1	Loss of Integrity		X		X																														
2.1.1.10	Sensitivity		X	X	X	*X*	X	*X*	*X*	X	X	X		X	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X		X	X	X	*X*
2.1.1.7	Acquisition Time																									X						X	X		
2.1.1.9	Reacquisition Time																								X									X	
NA	Sys. Operating																							X							X				

TABLE 2-13 CLASS GAMMA-1 ENVIRONMENTAL TEST REQUIREMENTS

Class GAMMA-1 MOPS Section	Requirement	DO-160D Requirement Section	Low Operating Temp. Test 4.5.1	High Short-Time Temp. Test 4.5.2	High Operating Temp. Test 4.5.3	*In-Flight Loss of Cooling 4.5.4*	Altitude Test 4.6.1	*Decompression Test 4.6.2*	*Overpressure Test 4.6.3*	Temperature Variation Test 5	Humidity Test 6	Operational Shocks 7.2	Crash Safety Shocks 7.3	Vibration Test 8	*Explosion Proofness Test 9*	*Drip Proof Test 10.3.1*	*Spray Proof Test 10.3.2*	*Cont. Stream Proof Test 10.3.3*	*Spray Test 11.4.1*	*Immersion Test 11.4.2*	*Sand and Dust Test 12*	*Fungus Resistance Test 13*	*Salt Spray Test 14*	Magnetic Effect Test 15	Normal Operation Conditions 16.5.1,2	Abnormal Operation Cond. 16.5.3,4	Volt. Spike Cond. Test 17	Audio Freq. Cond. Susc. Test 18	Induced Signal Susc. Test 19	RF Susceptibility Test 20	Emission of RF Energy Test 21	Lightning Ind. Trans. Susc. 22	Lightning Direct Effects 23	Icing 24	*Electrostatic Discharge 25*
2.1.3.1	2-D Accuracy		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X
2.2.3.6.3	Loss of Nav.		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					
2.2.3.6.2	Loss of Integrity		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					
2.1.1.10	Sensitivity		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X
2.1.1.7	Acquisition Time																									X						X	X		
2.1.1.9	Reacquisition Time																								X									X	
NA	Sys. Operating																							X							X				
2.2.1.4	Nav Disp		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					
2.2.1.5	Database		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X		X			X
2.2.1.7	Mode Annunc.		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					

TABLE 2-14 **CLASS BETA-2 ENVIRONMENTAL TEST REQUIREMENTS**

Class BETA-2		DO-160D Requirement	Low Operating Temp. Test	High Short-Time Temp. Test	High Operating Temp. Test	*In-Flight Loss of Cooling*	Altitude Test	*Decompression Test*	*Overpressure Test*	Temperature Variation Test	Humidity Test	Operational Shocks	Crash Safety Shocks	Vibration Test	*Explosion Proofness Test*	*Drip Proof Test*	*Spray Proof Test*	*Cont. Stream Proof Test*	*Spray Test*	*Immersion Test*	*Sand and Dust Test*	*Fungus Resistance Test*	*Salt Spray Test*	Magnetic Effect Test	Normal Operation Conditions	Abnormal Operation Cond.	Volt. Spike Cond. Test	Audio Freq. Cond. Susc. Test	Induced Signal Susc. Test	RF Susceptibility Test	Emission of RF Energy Test	Lightning Ind. Trans. Susc.	Lightning Direct Effects	Icing	*Electrostatic Discharge*
MOPS Section	**Requirement**	**Section**	4.5.1	4.5.2	4.5.3	*4.5.4*	4.6.1	*4.6.2*	*4.6.3*	5	6	7.2	7.3	8	*9*	*10.3.1*	*10.3.2*	*10.3.3*	*11.4.1*	*11.4.2*	*12*	*13*	*14*	15	16.5.1,2	16.5.3,4	17	18	19	20	21	22	23	24	*25*
2.1.4.1	2-D Accuracy		X	X	X	*X*	X	*X*	*X*	X	X	X		X	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X		X	X	X	*X*
2.1.4.12.2	Loss of Nav.		X		X																														
2.1.4.12.1	Loss of Integrity		X		X																														
2.1.1.10	Sensitivity		X	X	X	*X*	X	*X*	*X*	X	X	X		X	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X		X	X	X	*X*
2.1.1.7	Acquisition Time																									X						X	X		
2.1.1.9	Reacquisition Time																								X									X	
NA	Sys. Operating																							X							X				

TABLE 2-15 CLASS GAMMA-2 ENVIRONMENTAL TEST REQUIREMENTS

Class GAMMA-2 MOPS Section	Requirement	DO-160D Requirement Section	Low Operating Temp. Test 4.5.1	High Short-Time Temp. Test 4.5.2	High Operating Temp. Test 4.5.3	*In-Flight Loss of Cooling* *4.5.4*	Altitude Test 4.6.1	*Decompression Test* *4.6.2*	*Overpressure Test* *4.6.3*	Temperature Variation Test 5	Humidity Test 6	Operational Shocks 7.2	Crash Safety Shocks 7.3	Vibration Test 8	*Explosion Proofness Test* *9*	*Drip Proof Test* *10.3.1*	*Spray Proof Test* *10.3.2*	*Cont. Stream Proof Test* *10.3.3*	*Spray Test* *11.4.1*	*Immersion Test* *11.4.2*	*Sand and Dust Test* *12*	*Fungus Resistance Test* *13*	*Salt Spray Test* *14*	Magnetic Effect Test 15	Normal Operation Conditions 16.5.1,2	Abnormal Operation Cond. 16.5.3,4	Volt. Spike Cond. Test 17	Audio Freq. Cond. Susc. Test 18	Induced Signal Susc. Test 19	RF Susceptibility Test 20	Emission of RF Energy Test 21	Lightning Ind. Trans. Susc. 22	Lightning Direct Effects 23	Icing 24	*Electrostatic Discharge* *25*
2.1.4.1	Accuracy Req.		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X
2.2.4.6.3	Loss of Nav.		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					
2.2.4.6.2	Loss of Integrity		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					
2.1.1.10	Sensitivity		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X
2.1.1.7	Acquisition Time																									X						X	X		
2.1.1.9	Reacquisition Time																								X									X	
NA	Sys. Operating																							X							X				
2.2.4.4	Nav Disp		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					
2.2.4.5	Database		X		X						X			X		X	X	X	X	X	X	X	X		X	X	X	X	X	X		X			X
2.2.1.7	Mode Annunc.		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					

TABLE 2-16 CLASS BETA-3 ENVIRONMENTAL TEST REQUIREMENTS

Class BETA-3 MOPS Section	Requirement	DO-160D Requirement Section	Low Operating Temp. Test 4.5.1	High Short-Time Temp. Test 4.5.2	High Operating Temp. Test 4.5.3	*In-Flight Loss of Cooling* *4.5.4*	Altitude Test 4.6.1	*Decompression Test* *4.6.2*	*Overpressure Test* *4.6.3*	Temperature Variation Test 5	Humidity Test 6	Operational Shocks 7.2	Crash Safety Shocks 7.3	Vibration Test 8	*Explosion Proofness Test* *9*	*Drip Proof Test* *10.3.1*	*Spray Proof Test* *10.3.2*	*Cont. Stream Proof Test* *10.3.3*	*Spray Test* *11.4.1*	*Immersion Test* *11.4.2*	*Sand and Dust Test* *12*	*Fungus Resistance Test* *13*	*Salt Spray Test* *14*	Magnetic Effect Test 15	Normal Operation Conditions 16.5.1,2	Abnormal Operation Cond. 16.5.3,4	Volt. Spike Cond. Test 17	Audio Freq. Cond. Susc. Test 18	Induced Signal Susc. Test 19	RF Susceptibility Test 20	Emission of RF Energy Test 21	Lightning Ind. Trans. Susc. 22	Lightning Direct Effects 23	Icing 24	*Electrostatic Discharge* *25*
2.1.5.1	Accuracy Req.		X	X	X	*X*	X	*X*	*X*	X	X	X		X	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X		X	X	X	*X*
2.1.5.12.2	Loss of Nav.		X		X																														
2.1.5.12.1	Loss of Integrity		X		X																														
2.1.1.10	Sensitivity		X	X	X	*X*	X	*X*	*X*	X	X	X		X	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X		X	X	X	*X*
2.1.1.7	Acquisition Time																									X						X	X		
2.1.1.9	Reacquisition Time																								X									X	
NA	Sys. Operating																							X							X				

TABLE 2-17 CLASS GAMMA-3 ENVIRONMENTAL TEST REQUIREMENTS

Class Gamma 3 MOPS Section	Requirement	DO-160D Requirement Section	Low Operating Temp. Test 4.5.1	High Short-Time Temp. Test 4.5.2	High Operating Temp. Test 4.5.3	*In-Flight Loss of Cooling 4.5.4*	Altitude Test 4.6.1	*Decompression Test 4.6.2*	*Overpressure Test 4.6.3*	Temperature Variation Test 5	Humidity Test 6	Operational Shocks 7.2	Crash Safety Shocks 7.3	Vibration Test 8	*Explosion Proofness Test 9*	*Drip Proof Test 10.3.1*	*Spray Proof Test 10.3.2*	*Cont. Stream Proof Test 10.3.3*	*Spray Test 11.4.1*	*Immersion Test 11.4.2*	*Sand and Dust Test 12*	*Fungus Resistance Test 13*	*Salt Spray Test 14*	Magnetic Effect Test 15	Normal Operation Conditions 16.5.1,2	Abnormal Operation Cond. 16.5.3,4	Volt. Spike Cond. Test 17	Audio Freq. Cond. Susc. Test 18	Induced Signal Susc. Test 19	RF Susceptibility Test 20	Emission of RF Energy Test 21	Lightning Ind. Trans. Susc. 22	Lightning Direct Effects 23	Icing 24	*Electrostatic Discharge 25*
2.1.5.1	Accuracy Req.		X	X	X	*X*	X	*X*	*X*	X	X	X		X	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X		X	X	X	*X*
2.2.5.6.3	Loss of Nav.		X		X		X				X	X		X		*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X					
2.2.5.6.2	Loss of Integrity		X		X		X				X	X		X		*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X					
2.1.1.10	Sensitivity		X	X	X	*X*	X	*X*	*X*	X	X	X		X	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X		X	X	X	*X*
2.1.1.7	Acquisition Time																									X						X	X		
2.1.1.9	Reacquisition Time																								X									X	
NA	Sys. Operating																							X							X				
2.2.5.4	Nav Disp		X		X		X				X	X		X		*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X					
2.2.5.5	Database		X		X						X			X		*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X		X			*X*
2.2.1.7	Mode Annunc.		X		X		X				X	X		X		*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*		X	X	X	X	X	X					

TABLE 2-18 **CLASS DELTA-4 ENVIRONMENTAL TEST REQUIREMENTS**

Class Delta 4		DO-160D Requirement	Low Operating Temp. Test	High Short-Time Temp. Test	High Operating Temp. Test	*In-Flight Loss of Cooling*	Altitude Test	*Decompression Test*	*Overpressure Test*	Temperature Variation Test	Humidity Test	Operational Shocks	Crash Safety Shocks	Vibration Test	*Explosion Proofness Test*	*Drip Proof Test*	*Spray Proof Test*	*Cont. Stream Proof Test*	*Spray Test*	*Immersion Test*	*Sand and Dust Test*	*Fungus Resistance Test*	*Salt Spray Test*	Magnetic Effect Test	Normal Operation Conditions	Abnormal Operation Cond.	Volt. Spike Cond. Test	Audio Freq. Cond. Susc. Test	Induced Signal Susc. Test	RF Susceptibility Test	Emission of RF Energy Test	Lightning Ind. Trans. Susc.	Lightning Direct Effects	Icing	*Electrostatic Discharge*
MOPS Section	**Requirement**	**Section**	4.5.1	4.5.2	4.5.3	*4.5.4*	4.6.1	*4.6.2*	*4.6.3*	5	6	7.2	7.3	8	*9*	*10.3.1*	*10.3.2*	*10.3.3*	*11.4.1*	*11.4.2*	*12*	*13*	*14*	15	16.5.1,2	16.5.3,4	17	18	19	20	21	22	23	24	*25*
2.1.5.1	Accuracy Req.		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X
2.2.5.6.3	Loss of Nav.		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					
2.2.5.6.2	Loss of Integrity		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					
2.1.1.10	Sensitivity		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X
2.1.1.7	Acquisition Time																									X						X	X		
2.1.1.9	Reacquisition Time																								X									X	
NA	Sys. Operating																							X							X				
2.2.5.4	Nav Disp		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					
2.3.5	Database		X		X						X			X		X	X	X	X	X	X	X	X		X	X	X	X	X	X		X			X
2.2.1.7	Mode Annunc.		X		X		X				X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X	X					

2.5 Test Methods and Procedures

The following definitions of terms and conditions of tests are applicable to equipment tests specified herein:

a. Power Input Voltage

Unless otherwise specified, all tests shall be conducted with the power input voltage adjusted to design voltage ±2 percent. The input voltage shall be measured at the input terminals of the equipment under test.

b. Power Input Frequency

(1) In the case of equipment designed for operation from an AC power source of essentially constant frequency (e.g., 400 Hz), the input frequency shall be adjusted to design frequency ±2 percent.

(2) In the case of equipment designed for operation from an AC power source of variable frequency (e.g., 300-1000 Hz), unless otherwise specified, tests shall be conducted with the input frequency adjusted to within ±5 percent of a selected frequency and within the range for which the equipment is designed.

c. Standard Test Signals and Simulator Requirements

(1) The GPS/WAAS simulator shall operate in accordance with the GPS SPS Performance Standard, Navstar GPS Interface Control Document (ICD-GPS-200C), specification for Wide Area Augmentation System (FAA-E-2892B, Change 2), and Appendix A.

(2) The test signals presented to the equipment under test, unless otherwise specified, shall be the minimum input signal at receiver port or antenna port, as specified in Section 2.1.1.10. If the manufacturer chooses to be interoperable with the standard antenna as specified in RTCA/DO-228, the minimum input signal power at the receiver port is -136 dBm for GPS satellites and -137 dBm for WAAS satellites. If the manufacturer chooses to include the antenna and preamplifier as a component of his equipment, a suitable configuration shall be used to yield the minimum signal power at the antenna port; i.e., the maximum cable loss shall be assumed. See Figures 2-19 and 2-20.

Note: *The signal power can be increased to maintain the same C/N_o as would occur with the background thermal noise density specified in Section 2.1.1.10.*

(3) Unless otherwise specified, all GPS and WAAS signals will not indicate unhealthy, erroneous, failed, abnormal, or marginal conditions. The signals will contain ranging errors and WAAS corrections as calculated by approved models of the troposphere, ionosphere, satellite clock, satellite ephemeris, and selective availability.

(4) The broadband noise used to simulate external interference shall be equivalent to additive white gaussian noise filtered through a fourth order bandpass filter with no more than 1 dB of ripple in the passband. The pulsed interference source requires an on/off ratio of 164.5 dB in order to achieve the necessary isolation. The CWI interference generator shall be accurate to within 1 kHz.

(5) Unless otherwise specified, the interference-to-signal (I/S) ratios cited in the following test procedures are made with respect to the minimum GPS signal level, and are used to determine the appropriate level of external interference (CW or broadband noise) to inject into the test. This value is assumed in the test procedures below to be –134.5 dBm (at the antenna port). Manufacturers deviating from this convention must show equivalence.

Note: *The development of software to RTCA/DO-178B includes tool qualification of the GPS/WAAS simulator.*

(6) Unless otherwise specified, the interference tests are conducted with one satellite at maximum power (including maximum antenna gain), one satellite at minimum power (including minimum antenna gain), and remaining satellites 3 dB above minimum signal and representative antenna gain.

Notes: ***1.*** *The specified test procedures provide a representative level of self-interference when acquiring, re-acquiring, and tracking the minimum signal. The test represents a reasonable baseline scenario with respect to self-interference caused by C/A, P(Y), and Earth Coverage M code signals. P(Y) and Earth coverage M are not strictly included in the test because their effects are negligible when compared to C/A code self-interference. The currently defined GPS earth coverage M code signal uses Binary Offset Carrier (BOC) modulation and has spectral lobes centered ± 9.5 MHz from the L1 center frequency with 5.115 Mchip/sec "random" spreading code. The worst-case received power for earth coverage M code is –121 dBm from all angles at the surface of the earth, per satellite.*

2. *The number of satellites included in the test procedures is also representative because when many satellites are visible, the aggregate self-interference level may be higher but the low-elevation (low-gain) satellites are not considered critical to receiver performance. In addition, authorized emissions are regulated to a level below the external interference levels (as described in Appendix C) to provide a safety margin.*

3. *In the future, new signals at significantly higher power levels, will be broadcast by the GPS satellites as part of the GPS III. These signals are being designed to be backward-compatible with civilian GPS equipment. It is important to recognize that these signals are not broadband white noise. Once these signals are defined, their inclusion in these test procedures for GPS-self-interference will be revisited. RTCA is updating RTCA/DO-235 to address these new signals.*

d. Adjustment of Equipment

The circuits of the equipment under test shall be aligned and adjusted in accordance with the manufacturers' recommended practices prior to the application of the specified tests.

e. Test Instrument Precautions

Due precautions shall be taken during the tests to prevent the introduction of errors or misleading data resulting from the connection of voltmeters, oscilloscopes and other test instruments across the input and output impedance of the equipment under test.

f. Ambient Conditions

Unless otherwise specified, all tests shall be conducted under the conditions of ambient room temperature, pressure and humidity. However, room temperature shall not be lower than 10 degrees Celsius.

g. Warm-up

Unless otherwise specified, all tests shall be conducted after the manufacturers' specified warm-up period.

h. Connected Loads

Unless otherwise specified, all tests shall be conducted with the equipment connected to loads having the impedance values for which it is designed.

i. Analysis

Analysis is the method of verification which consists of comparing hardware or software design with known scientific and technical principles, technical data, or procedures and practices to validate that the proposed design will meet the specified functional or performance requirements

j. Demonstration

Demonstration is the method of verification where qualitative versus quantitative validation of a requirement is made during a dynamic test of the equipment. Additional definition applied to this term includes:

(1) In general, software functional requirements are validated by demonstration since the functionality must be observed through some secondary media.

k. Inspection

Inspection is the method of verification to determine compliance with specification requirements and consists primarily of visual observations or mechanical measurements of the equipment, physical location, or technical examination of engineering support documentation.

l. Test

Test is the method of verification that will measure equipment performance under specific configuration load conditions and after the controlled application of known stimuli. Quantitative values are measured, compared against previous predicated success criteria and then evaluated to determine the degree of compliance.

The following subsections define the minimum test procedures required to substantiate the minimum operation performance required for sensors using GPS/WAAS. Alternative procedures may be used if they provide an equivalent evaluation of the GPS/WAAS equipment. These test procedures assume the GPS/WAAS equipment is compliant with the minimum standard, and no additional augmentations (e.g., barometric aiding) are incorporated.

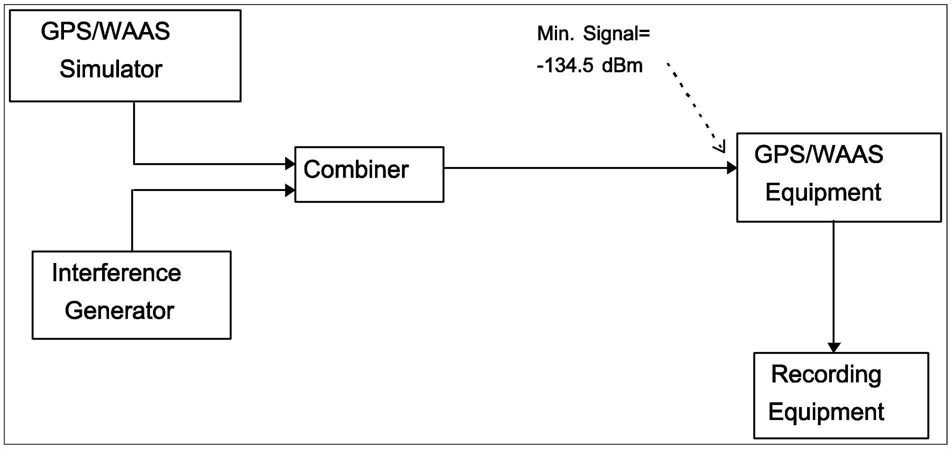


FIGURE 2-19 GENERIC TEST CONFIGURATION FOR BENCH TESTS USING ANTENNA WITHOUT PREAMPLIFIER

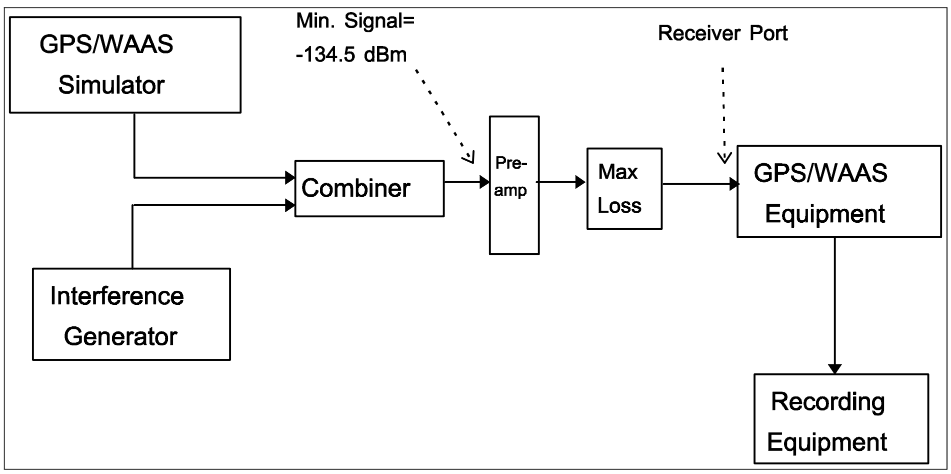


FIGURE 2-20 GENERIC TEST CONFIGURATION FOR BENCH TESTS USING ANTENNA WITH PREAMPLIFIER

2.5.1 Test Cross Reference Matrix

The test cross reference matrixes for the Beta and Gamma GPS/WAAS equipment bench test procedures are shown in Table 2-19. This table includes information on (1) the requirement paragraph, (2) the test paragraph associated with the corresponding requirement paragraph, (3) the method of testing, (4) a concise version of the requirement, (5) the pass/fail criteria for each test, and (6) comments. The paraphrased version of the requirements in column four is provided as a quick reference for the test matrix and does not replace or supersede the actual requirements. The first column of the table lists the paragraph in Section 2 that contains the Beta or Gamma equipment requirement. Often, one section will contain more than one requirement. As a general rule, anytime the word "shall" appears in the requirement section, a test method is associated with that requirement. This is illustrated in the following example on how to read the tables.

Example: The test cross reference matrix for the Gamma equipment begins with Section 2.2.1.1 (General Human Factors Requirements). This section contains four requirements which require verification. The first column lists the requirement paragraph, in this case 2.2.1.1. The second column is the subsection in Section 2.5 where tests for these requirements can be found. In some cases individual tests are assigned to each requirement in the section. In this case, three of the four requirements in Section 2.2.1.1 have tests specified in Section 2.5.10. The manufacturer is responsible for satisfying all equipment requirements whether or not specific tests are identified.

The third column of the table lists the method for testing each requirement. The definitions of the four types of test methods (Inspection, Demonstration, Analysis, and Test) are found in Section 2.5 (Test Methods and Procedures). The first requirement is verified through compliance with specifications. This is accomplished with the test method of 'Inspection' or 'I'. This example illustrates how the 'Inspection' test method is used to verify different manufacturer designs against the referenced design guidance documents and regulations. Other verifications by this method can include inspection of equipment handbooks, equipment design documentation, test results, and functional or software design documents that are used to follow development requirements such as RTCA/DO-178B. The remaining three requirements in Section 2.2.1.1 are verified qualitatively, which corresponds to a Demonstration or D. Any requirements specified as test (T) or analysis (A) must be validated by the manufacturer by showing the appropriate analysis, and the results of any testing performed to support the analysis. The expression not applicable (N/A) is used when no verification is required. The expression is used for statements that are provided as design information and are not testable requirements. The next column specifies the pass/fail criteria for each requirement. Conducting the test method allocated to each requirement satisfies the pass/fail criteria. In this example, the pass/fail criteria for the requirements in Section 2.2.1.1 that are verified by 'D', will be satisfied with acceptable results from the appropriate human factors bench test. The final column lists remarks or references related requirements.

Note: *The use of “,” is equivalent to “and”.*

<u>TABLE 2-19</u> TEST CROSS REFERENCE MATRIX

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.1.1 Airworthiness		I	a) Airborne equip. does not impair airworthiness.	Airworthiness assured.	
2.1.1.1.2 General Performance	2.5 and all sub-sections	A,D,I,T	a) Equip. performs as specified by this MOPS and the manufacturer.	Equip. is compliant with this MOPS and manufacturer specified requirements.	
2.1.1.1.3 Fire Resistance		I	a) Equip. does not contribute to fire propagation and is self-extinguishing.	No fire propagation.	
2.1.1.1.4 Equipment Interfaces		A or D or I	a) Equip. does not affect, nor is affected by, normal or abnormal operation of other airborne equipment.	Equip. is not affected by or affects performance of other aircraft equip.	
2.1.1.1.5 Effects of Test		I	a) Equip. doees not be detrimentally affected by these test procedures.	Equip. is not damaged by tests.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.2 GPS Signal Processing Requirements	2.5.3-2.5.9	T I or T I or T I or T I or T I or T I or T I or T I or T	a) Processes and uses GPS signals and data under interference conditions. b) GPS-provided iono correction model used when WAAS iono corrections are not used c) GPS iono model not applied to satellite measurements pseudoranges using WAAS iono corrections. d) Tropospheric corrections are applied. e) Data decoded continuously. f) Clock and ephemeris parameters are used after they have been successfully collected twice. g) Iono data is used after is has been successfully collected twice. h) Satellite clock corrections, include relativistic corrections, are applied to pseudorange after smoothing (if applicable). i) GPS satellites are not mistaken due to cross-correlation during acquisition or reacquisition.	Equip. navigates with GPS. Equip. properly selects and uses iono models. Tropo corrections are properly applied. Downlink data is decoded continuously. Equip. validates ephem. before use. Equip. validates iono. data before use. Equip. properly applies satellite clock correction parameters. Equip. protects against cross-correlation.	2.1.1.7 2.1.1.8 2.1.1.9 2.1.1.10 2.1.1.12 2.1.2.1 2.1.3.1 2.1.4.1
2.1.1.3.1 Acquisition and Track	2.5.4	T I or T I or T	a) Acquires and tracks SBAS PRN codes at specified power levels and interference conditions. b) WAAS satellites are not mistaken due to cross-correlation during acquisition or reacquisition. c) Only PRN codes specified in Appendix A are used to track SBAS satellites.	SBAS signals are acquired and tracked under specified interference and power levels. Equip. protects against cross-correlation of WAAS satellites. Equip. only uses specified SBAS PRN codes to track SBAS satellites.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.3.2 Demodulation and FEC Decoding	2.5.2 2.5.2	T I and T A and T A and T	a) Demodulates and decodes WAAS data b) FEC correction applied to minimize data errors. c) Equip. does not utilize any message with CRC failures. d) The WAAS message loss rate is less than 1 message in 10^3 for the interference conditions described in Appendix C and under the minimum signal conditions defined in Section 2.1.1.10.	Equip. demods, decodes, and uses WAAS data using FEC; messages are not used if CRC fails. Message loss rate, due to signal processing compliant signals is < 10^{-3}. for all modes.	
2.1.1.3.3 WAAS Satellite Pseudorange Determination	2.5.8	T I T I, T I,T	a) Equipment computes pseudorange for each WAAS satellite used in position computation. b) WAAS pseudoranges referenced to the same time base as GPS satellites. c) WAAS pseudorange is properly corrected for earth rotation. d)WAAS pseudoranges corrected using GPS iono coefficients if WAAS iono corrections are not used. e) Tropospheric corrections are applied.	Tests show equip. can incorporate WAAS p-rng. into position solution. Documentation proves WAAS p-rng's are referenced to GPS time base. WAAS p-rng's are corrected for iono using WAAS iono corrections or, if WAAS corrections unavailable, GPS iono corrections. Tropo. corrections are applied to WAAS pseudoranges.	
2.1.1.4 WAAS Message Processing	2.5.2-2.5.9	T I or T T I or T	a) Message Types 0-7, 9, 17, 24-25, 27, and 28 are utilized in all navigation modes. b) Other decoded messages are compliant with their respective requirements. c) Loss of optional messages will not cause loss of function. d) Message types the equip. is not specifically designed to decode, are ignored.	Specified msgs. are decoded. Others may be decoded as specified by this MOPS. Any other messages are ignored.	2.1.1.2. 2.1.3.7 2.1.4.9

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.4.1 Message Type 0 - Don't Use for Safety Applications		I and T I I and T	Upon receipt of this message for safety-of-life applications; a) Data (from message types 1-7, 9-10, 18, 24-28) and ranging is no longer used from the issuing PRN code. b) The issuing PRN code is deselected for one minute.	Data and ranging from the issuing PRN code is not used and discarded, and the PRN code deselected for one minute (for safety-of-life users).	
2.1.1.4.2 Message Type 1 - PRN Mask Assignments		I or T I or T	Two PRN masks can be stored and used. During mask transitions, corrections with different IODPs can be used simultaneously.	Service is not interrupted during PRN mask switching.	
2.1.1.4.3 Message Type 2-5 and 24 - Fast Clock Corrections		I and T I and T T	a) Message Types 2, 3, 4, 5, and 24 are decoded. b) Integrity and correction data not used until IODP matches IODP from last Type 1 msg. c) Fast corrections applied to all WAAS HEALTHY satellites used in the position solution.	Msgs. 2, 3, 4, 5, and 24 are decoded. WAAS integrity and correction data not used until IODPs match. Fast corrections are applied to all WAAS HEALTHY satellites used in the position solution.	
2.1.1.4.4 Message Type 6 - Integrity Information		T T T T	a) Message Type 6 is decoded. b) UDREI is used to compute integrity of the corrected position. c) If $IODF_j = 3$ then UDREs are used regardless of the value of $IODF_j$ in the associated fast correction message. d) If $IODF_j < 3$ then UDREs are not used if the value of $IODF_j$ in the associated fast correction message does not match.	Msg. Type 6 is decoded. UDREI is used to compute the integrity of the corrected position. If $IODF_j = 3$ then UDREs are used regardless of the value of $IODF_j$ in the associated fast correction message, otherwise if $IODF_j < 3$ the $IODF_j$ of the associated fast correction must match the $IODF_j$ in Msg. Type 6.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.4.5 Message Type 7 – Fast Correction Degradation		I or T I or T	a) Message Type 7 is decoded. b) Timeout intervals for fast corrections are computed.	Msg. Type 7 is decoded. Timeout intervals for fast corrections are computed.	
2.1.1.4.6 Message Type 9 - WAAS Satellite Navigation Message		I and T I and T	a) Message Type 9 is processed for orbital information, used to compute WAAS satellite locations. b) Most recent Message Type 9 is used.	Msg. 9 data used to compute WAAS satellite locations. Most recent Msg. 9 is used.	
2.1.1.4.7 Message Type 17 - WAAS Satellite Almanac		I	a) Most recent almanac data for 2 WAAS satellites above the minimum mask angle are stored.	Equip. obtains, stores, and maintains most recent almanac data for 2 or more WAAS satellites.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.4.8 Message Type 27 - WAAS Service Message		T T D or T I, T or I I, T or I I, T or I	a) Message Type 27 is decoded to determine the δUDRE factor applicable to the user location. b) Equip uses the applicable δUDRE factor to inflate the values of σ_{UDRE} indicated in a Type 2-6 or 24 message for each satellite. c) Equip retains Message Type 27, for appropriate time-out interval, even after power-off. d) When a Type 27 message with a new IODS indicates a higher δUDRE for the user location, the higher δUDRE will be applied immediately. e) A lower δUDRE in a new Type 27 message will not be used until the complete set of messages with the new IODS has been received. f) Once the complete set of Type 27 messages with a given IODS has been received, all previously received Type 27 messages with different IODS will be discarded.	Equip. uses msg. 27 to determine if equip. is in region of applicability. Equip uses UDRE factor to inflate the values of σ_{UDRE} indicated in a Type 2-6 or 24 message. The equip. uses the higher δUDRE unless a complete set of messages with the new IODS has been received. When a complete set of Type 27 messages are received with a given IODS, all previous Type 27 messages are purged.	
2.1.1.4.9 Message Timeout Periods		T T	a) Data used until it has timed out. b) Most recently decoded a_{ij} applies. c) Data, for which there is no time out, is used until replaced.	Data will be used until it has either timed out or is replaced.	
2.1.1.4.10 Combining Data from Separate Broadcasts		T I and T	a) When not in PA, and when combining data from separate broadcasts, equip. accounts for time differences in data from multiple WAAS PRNs. b) For each sat., only use fast and long-term corrections data, iono data, degradation data and δUDRE from WAAS signal (PRN code).	When in the PA mode, for each sat., integrity and correction data is used from only one PRN.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.4.11 Message Type 24 and 25 Long-Term Corrections and Message Type 9 GEO Navigation Data		I and T I and T I and T I and T I and T I and T I and T I and T I and T I and T I and T	a) Message Types 24 and 25 are decoded and resulting long-term clock corrections applied for all satellites used in the position solution, except for the SBAS satellites operated by the same service providing these corrections. b) For SBAS satellites providing Message Types 24 and 25, Message Type 9 will be decoded and applied to that SBAS range measurement. c) For SBAS satellites not providing Message Types 24 and 25, but used for ranging, its Message Type 9 will be used in addition to a correction derived from Messge Types 24 and 25. d) Long-term corrections will not be utilized unless IODP matches that obtained from a Type 1 message. f) For GPS satellites, the equipment will compare the Issue of Data (WAAS IOD) in the WAAS Type 24 or 25 message for each GPS satellite with the IODE of that GPS satellite being utilized by the equipment. g) The WAAS IOD and GPS IODE match (the normal condition), in which case the WAAS correction are applied using the current GPS IODE to compute satellite position; h) The WAAS IOD and GPS IODE do not match, but the WAAS IOD matches the previous GPS IODE (a condition which will happen for a few minutes each hour), in which case the WAAS corrections are applied using the previous GPS IODE to compute satellite position;	Long-term corrections are decoded and applied properly to all GPS satellites, GEO ranging data obtained from the SBAS service provider, and GEO ranging data obtained from other SBAS satellites, not of the service provider which provides the SBAS integrity.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
			i) They do not match, nor does the WAAS IOD match the previous GPS IODE (a rare condition), then the equipment will not apply the fast or long-term correction. Satellite integrity information from Message Types 2-6 and 24 can still be used. j) The equipment will retain old ephemeris information for at least 5 minutes, or until a match between WAAS IOD and GPS IODE is obtained. k) Long term corrections will not be applied without active fast corrections. l) The airborne equipment uses the active long term correction with latest time of applicability which is less (earlier) than the current time whenever possible. If long term corrections are received with a time of applicability in the future, those corrections should not be used until: 1) the current time equals the time of applicability; or 2) the previous long term corrections time out.		

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.4.12 Application of Differential Corrections		I I and T I and T I and T I and T	a) Corrections applied after filtering of code or Doppler measurements, and immediately prior to computing a position. b) Long term, fast and range rate corrections are applied when available; when not available, the model variance of fast and long term corrections residuals are defined in J.2.2. c) Range-Rate Corrections computed from data contained in Message Types 2-5 and 24. d) Pseudorange corrected as specified. e) Clock offset and clock drift error corrections are computed from data in Message Types 24 and 25,and added to the t_{SV} obtained from the satellite navigation data.	The equip. applies corrections to Code phase and Doppler measurements as specified.	
2.1.1.4.13 Message Type 28 – Clock-Ephemeris Covariance Matrix Message		T T D or T I, D or T	a) Message Type 28 is processed to determine if equip. is within region of applicability. b) Equip. uses the applicable δUDRE factor to calculate the value of σ_{flt} for each satellite indicated in Type 2-6 or 24 messages. c) If a Type 28 is received on a satellite, then UDREIs for satellites without an active Type 28 are not to be used, unless the UDREIs indicate “Don’t Use” or “Not Monitored”. d) Message Type 28 is only used if the IODP agrees with the IODP associated with the PRN mask in Message Type 1.	Equip. uses msg. 28 to calculate σ_{flt} as defined in Appendix A, A.4.4.3. The equip. will ensure that the IODP agrees with the IODP associated with the PRN mask in msg. 1. Satellites without Type 28s when other satellites have active Type 28s will use Appendix J.2.2 to determine variance of residual errors.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.5 Satellite Integrity Status		I and T I and T	a) Equip. designates each GPS and WAAS satellite as WAAS HEALTHY, WAAS UNHEALTHY, or WAAS UNMONITORED. b) Equip. designates each GPS satellite as GPS HEALTHY or GPS UNHEALTHY.	Each GPS/WAAS satellites are evaluated and assigned a WAAS integrity status. Each GPS satellites is assigned a GPS health status.	2.1.1.5.2 - 2.1.1.5.6 2.1.1.13 2.1.4.10
2.1.1.5.1 Step Detector	2.5.3	I and T A or T I or T	a) Pseudorange step errors > 700 m on any satellite used in the position solution are detected, including steps which cause loss of lock for less than 10 seconds. b) False pseudorange step error declarations will occur < 10^{-5} /hr. c) P-range step error declaration cleared only by FD.	700 m steps on any satellite used in the position solution. Analysis or test documentation infers false detections occur < 10^{-5} /hr. Pseudorange step declarations are cleared only by FD.	
2.1.1.5.2 WAAS UNHEALTHY Designation		I and T I and T	a) GPS or WAAS satellite designated WAAS UNHEALTHY when: UDREI = 15; or step detection function has declared an error. WAAS sats also WAAS UNHEALTHY if failure of CRC on 4 successive msgs. b) Satellites declared WAAS UNHEALTHY, change status only after condition has cleared.	GPS/WAAS satellites are designated WAAS UNHEALTHY for the specified conditions. GPS/WAAS satellite is assigned new WAAS integrity status when the condition has cleared.	
2.1.1.5.3 WAAS UNMONI-TORED Designation		I and T I and T	a) GPS or WAAS satellites are designated as WAAS UNMONITORED if: the WAAS UDREI = 14; or WAAS data is not provided (satellite not in mask); or WAAS signals are not received; WAAS data has timed-out; or WAAS IOD and GPS IODE cannot be reconciled (if corrections applied). b) Satellites declared WAAS UNMONITORED, change status only after condition has cleared and no condition exists.	GPS/WAAS satellite is designated UNMONITORED for the specified conditions. GPS/WAAS satellite is assigned new WAAS integrity status when the condition has cleared.	2.1.3.7.3

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.5.4 WAAS HEALTHY Designation		I and T	GPS or WAAS satellite designated WAAS HEALTHY and if not designated as WAAS UNHEALTHY or WAAS UNMONITORED when the step detector has not declared a step error and UDREI of 14 or 15 for the satellite.	GPS/WAAS satellites reflect WAAS health designation, if a step error has not been detected on the satellite.	
2.1.1.5.5 GPS UNHEALTHY Designation		I and T I and T	a) GPS satellites are designated as GPS UNHEALTHY if: 6 bit health word in subframe 1: MSB=1 except when other bits =“11101”, satellite out of service but not at this time; or parity fails on 5 successive words (3 seconds); IODE not match 8 least-significant bits of IODC; or URA user range accuracy index ≥8; Bit 18 of the HOW = 1; bits =0 in subframe 1, 2, or 3; default navigation data is transmitted in subframes 1, 2, or 3; preamble ≠ 8B or 139. b) Satellites declared GPS UNHEALTHY, change status only after condition has cleared.	GPS satellites are designated GPS UNHEALTHY when space segment declares it unhealthy. New GPS health is assigned after the current unhealthy condition clears.	
2.1.1.5.6 GPS HEALTHY		I and T	GPS satellites are designated GPS HEALTHY if it does not meet the criteria listed in Section 2.1.1.5.5.	GPS satellites are declared healthy when GPS space segment declares it healthy and continuity is maintained on reception of health data.	2.1.1.5.5

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.6 Satellite Selection		D D D I and T T I and T I and T I I, D, and/or T D or T	a) Selects and uses at least one WAAS satellite which is providing valid integrity information, if available. b) Equip. selects the best WAAS satellite based on the correction and integrity data being provided. c) Selects satellites to ensure continued integrity in the event of loss of the WAAS satellite by; selecting another WAAS satellite; or selecting GPS satellites to minimize HPL_{FD}. d) Equip automatically selects satellites for use in the navigational computation, and FDE, if being applied. e) WAAS UNHEALTHY or GPS UNHEALTHY if due to failure of parity on five successive words or due to default navigation data satellites are not used. f) Select a set of satellites that can satisfy the performance requirements of the navigation mode, or that provide the smallest HPL or VPL, or as shown in Figure 2-1. g) GPS/WAAS equip. transitions between acceptable satellites within time-to-alert. h) If implemented, deselection issues will be addressed by the manufacturer. i) If deselection is implemented, manual deselections are cleared at power-up. j) Manual selection of WAAS UNHEALTHY or GPS UNHEALTHY satellites is prohibited.	The equip. automatically selects a complement of satellites for nav and FDE. At least one WAAS satellite is selected. Continuity of integrity is maximized. WAAS UNHEALTHY satellites are not used. Specified satellite selection hierarchy is implemented. UNHEALTHY satellites cannot be selected.	1.3.3 2.1.2.2.2.2.1 2.1.3.2.2.2.1

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.7 Initial Acquisition Time	2.5.4	D or T T	a) Equip. acquires satellites and determines position without initialization information. b) TTFF ≤ 5 minutes, given; initialization of LAT/LONG within 60 nm., TIME/DATE within 1 minute, valid almanac, and unobstructed satellite visibility; under the specified interference conditions; and within the criteria specified in Section 2.1.1.10.	Equip. tracks satellites and navigates without initialization date. Equip. demonstrates satellites can be acquired and steady-state nav. can be obtained within 5 min.	
2.1.1.8.1 GPS Satellite Acquisition Time		T	a) During steady state operation, GPS satellites are acquired and incorporated into position solution within 80 seconds.	During steady-state operation, new risen GPS satellites can be acquired and used in the nav. solution within 80 seconds.	
2.1.1.8.2 WAAS Satellite Acquisition Time		T	a) During steady state operation, a WAAS satellite can be acquired, its data used, and incorporated into the nav solution within 134 sec.	During steady state operations, newly visible WAAS satellites can be acquired and used in the nav. solution within 134 sec.	
2.1.1.9 Satellite Reacquisition Time	2.5.5	T	a) Reacquires GPS or WAAS satellite and computes pseudorange within 10 seconds when the remaining satellites provide a GDOP of 6 or less (from point when signal is available after a loss interval up to 30 seconds).	Satellites that have loss lock temporarily are reacquired and used in the position solution within 10 seconds.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.10 Sensitivity and Dynamic Range	2.5.2 - 8 2.5.2 - 8 2.5.8 2.5.2 - 8 2.5.2 - 8 2.5.8	T T T I T T T A A	a) Equip. interoperable with a standard antenna tracks GPS satellites at -136 dBm. b) Equip. interoperable with a standard antenna tracks WAAS satellites at -137 dBm. c) Equip interoperable with a standard antenna tracks GPS/WAAS sat. at -116 dBm. or a) Manufacturer-provided-antenna satisfies performance of RTCA/DO-228. b) The preamp accommodates GPS signals with a minimum input power of -134.5 dB. c) The preamp accommodates WAAS signals with a minimum input power of -135.5 dB. d) Maximum signal power is -116dBm. e) Maximum loss determined for installation. f) Minimum loss determined for installation.	Equip. operable with standard antenna acquires and tracks satellites at specified ranges of signal power and interference. or Documentation validates delivered antenna is compliant with RTCA/DO-228. Equip. operates with manufacturer's preamp at the minimum and maximum signal power, specified interference. Analysis documentation validates min. and max. installation losses.	
2.1.1.11 Equipment Burnout Protection		T	a) Equip. withstands, without damage, in-band CWI @ +20 dBm at the antenna.	Application of CWI +20dBm signal does not damage equip.	
2.1.1.12 Integrity in the Presence of Interference	2.5.7	T T	a) Equip. does not produce misleading information in presence of high interference. b) Equip. recovers within 5 minutes after the interference is removed.	Equip. does not produce misleading information when subjected to high interference power levels.	2.1.1.7 2.1.2.2.2.2.1 2.1.3.2.2.2.1

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.1.13.1 Protection Level		D I or T D	a) Class Beta equip. outputs HPL as specified in Sections 2.1.2.2.2, 2.1.3.2.2, 2.1.4.2.2 and 2.1.5.2.2. b) Class Gamma and delta equip. supporting ADS-B outputs HPL. c) WAAS-based protection level latencies do not exceed 4.8 seconds. d) Equip. indicates if HPL not calculated.	It is shown the equip. can produce and output HPLs within 4.8 seconds of the arrival of UDRE/GIVE data, and indicate when HPL not calculated. If supporting ADS-B, all equip. outputs HPL.	2.1.2.2.2 2.1.3.2.2 2.1.4.2.2 2.1.5.2.2
2.1.1.13.2 Navigation Alert		D A T T (I and T) or T	Loss of navigation indication within 1 second: a) Loss of power causes loss of navigation indication. b) Equip. malfunctions or failures causes loss of navigation indication. c) Indicates loss of navigation when, for 5 sec., an insufficient number of satellites available to compute a position solution. d) Indicates loss of navigation if a fault is detected but cannot be excluded within TTA. e) Alert returns to normal state immediately upon termination of the responsible condition.	Equip. indicates loss of navigation for: loss of power; equip. malfunctions or failures; when insufficient number of satellites available to compute a position fix for five seconds; detected but cannot be excluded within TTA. Loss of navigation indication is cleared upon termination of the condition.	
2.1.2.1 Accuracy	2.5.8 2.5.7 2.5.8	T T T	a) Horizontal radial position fixing error does not exceed 100 meters, 95th percentile, HDOP normalized to 1.5. b) Accuracy maintained under minimum signal conditions and in presence of interference. c) Time, if provided, is within 1 sec of UTC.	Equip. performs with the required accuracy under the specified signal and interference conditions. Equip. provides time within 1 sec of UTC.	2.1.1.10
2.1.2.2.1 Development Assurance	2.5.7	(A, I) or (A,I, and T)	a) HW and SW designed such that output display of misleading information, considered a major failure, is improbable.	The equip. design assures misleading information is improbable.	2.1.2.2.1.1 2.1.2.2.1.2

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.2.2.2 Integrity Monitoring		D D	a) Equip. is capable of computing HPL_{WAAS} and HPL_{FD}. b) Equip. computes HPL_{WAAS} when available, otherwise compute HPL_{FD}. c) If equip. uses GPS/inertial and does not use WAAS integrity and correction data, it meets requirements and accomplishes tests in Appendix R.	Equip. computes HPL_{WAAS} and HPL_{FD} as appropriate.	
2.1.2.2.2.1 WAAS - Provided Integrity Monitoring		I and T	a) HPL_{WAAS} is computed as defined in Appendix J.	Equip. produces an HPL_{WAAS}.	
2.1.2.2.2.2 FDE - Provided Integrity Monitoring	2.5.9	I,T I or T I and T I and T I and T I T T T	a) Equip. has autonomous FDE capability. b) FDE is used whenever WAAS integrity is not available. c) FDE uses URA broadcast to modify modes. d) FDE algorithm sets: (1) an SA mode, if any satellite URA's are greater than 16 meters; (2) an SA off mode, if the URA for every satellite being used is less than or equal to 16 meters. e) Baro-aided FDE is compliant to Appendix G. f) Inertial-aided FDE is compliant to Appendix R. g) The equip. computes HPL_{FD} . h) FDE requirements are met under conditions specified in Appendix B. i) Equip. accounts for WNT and GPS time differences if a mixture of corrected and uncorrected satellites are used.	Equip. that provides an autonomous FDE capability which is used whenever WAAS integrity is not available. Tests validate the FDE algorithms are compliant to this specification. Documentation or tests prove equip. produces an HPL_{FD} that bounds the horz. position error.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.2.2.2.2.1 Time to Alert	2.5.9	T	a) Time to alert for Class Beta is 8 seconds.	Equip provides alert within TTA.	
2.1.2.2.2.2.2 Missed Alert Probability	2.5.9	A and T	a) Probability of missed alert ≤ 0.001.	Analysis validates documentation and tests prove equip.'s missed alert probability is ≤ 0.001.	1.7.3
2.1.2.2.2.2.3 False Alert Probability	2.5.9	A and T A and T	a) Probability of false alert ≤ 10^{-5}/hour. Average duration and probability of a false alert will be < 3.33×10^{-7}.	Analysis validates documentation and tests prove equip.'s false alert probability is compliant. ≤ 10^{-5}/hour.	1.7.3
2.1.2.2.2.2.4 Failed Exclusion Probability	2.5.9	A and T	Probability of failed exclusion ≤ 10^{-3}/hour.	Analysis validates documentation and tests prove equip.'s failed exclusion probability is ≤ 10^{-3}/hour.	1.7.3
2.1.2.2.2.2.5 Availability	2.5.9	A and T A and T A and T A and T	a) Case 1, Availability of detection ≥ 99.80 %. b) Case 1, Availability of exclusion ≥ 94.55 %. c) Case 2, Availability of detection ≥ 99.9%. d) Case 2, Availability of exclusion ≥ 98.0%.	Analysis validate proves availability of detection ≥ 99.80 % and availability of and exclusion ≥ 94.55 % for case 1. Analysis validate proves availability of detection ≥ 99.9 % and availability of and exclusion ≥ 98.0 % for case 2.	
2.1.2.4 Satellite Tracking Requirements	2.5.3, 2.5.6, 2.5.7 2.5.7	T I and T	a) Equipment capable of tracking a minimum of 8 GPS satellites (and no WAAS satellites). b) Equipment capable of tracking at least six GPS satellites and two WAAS satellites, including the demod and storing of data from both WAAS satellites.	Equip. is shown to be capable of tracking 8 GPS satellites simultaneously. Equip. is shown to be capable of tracking 6 GPS and 2 WAAS satellites simultaneously.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.2.5 Dynamic Tracking	2.5.8	T T T T	a) Equipment maintains accuracy during normal dynamics specified in 2.1.2.5, 2.1.2.1, 2.1.1.8, and 2.1.1.9. b) Equipment does not produce misleading information during abnormal maneuvers specified in 2.1.2.5. c) Meets steady-state reacquisition requirements in 2.1.1.9 when abnormal maneuvers complete. d) Loss-of-navigation and loss-of-integrity alerts operate as specified during abnormal maneuvers.	Equip. maintains accuracy during normal dynamics under the specified signal power and interference conditions. Abnormal maneuvers do not cause misleading information. Reacquisitions are performed, as specified, when the abnormal maneuvers complete. Proper indication of loss of navigation and loss of integrity is shown during abnormal maneuvers.	2.1.1.8 2.1.1.9 2.1.1.13.2 2.1.2.1
2.1.2.6 Position Output		D or I I or T D	a) Equip. determines position for navigation. b) Position is referenced to WGS-84. c) Equip. electronically outputs the position.	Equip. produces a position referenced to the WGS-84 standard. Class Beta equip. outputs the nav. solution.	
2.1.2.6.1 Position Output Update Rate		D or T	a) Update rate is once per second.	The equip. is shown to update and output the nav. solution once per second.	
2.1.2.6.2 Position Output Latency		T or (T+A) T	a) Latency of the position output is 0.5 seconds or less. b) Data output prior to 200 msec after the time of applicability.	It is shown the equip. produces a position output with a latency of 0.5 sec. (with respect to the measurement time of the pseudorange) and is output prior to 200 msec after the time of applicability.	
2.1.3.1 Accuracy	2.5.8	T	a) Horizontal radial position error does not exceed 100 meters, 95th percentile, HDOP normalized to 1.5. Accuracy maintained under minimum signal conditions and in presence of interference.	Equip. performs with the required accuracy under the specified signal and interference conditions.	2.1.1.10
2.1.3.2.1 Development Assurance		-	a) Equip. is compliant to 2.1.2.2.1.	-	2.1.2.2.1

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.3.2.2 Integrity Monitoring		-	a) Equip. is compliant to 2.1.2.2.2.	-	2.1.2.2.2
2.1.3.2.2.1 WAAS - Provided Integrity Monitoring		-	a) Equip. is compliant to 2.1.2.2.2.1.	-	2.1.2.2.2.1
2.1.3.2.2.2 FDE - Provided Integrity		-	a) Equip. is compliant to 2.1.2.2.2.2	-	2.1.2.2.2.2
2.1.3.2.2.2.1 Time-to-Alert		-	a) Equip. is compliant to 2.1.2.2.2.2.1.	-	2.1.2.2.2.2.1
2.1.3.2.2.2.2 Missed Alert Probability		-	a) Equip. is compliant to 2.1.2.2.2.2.2.	-	2.1.2.2.2.2.2
2.1.3.2.2.2.3 False Alert Probability		-	Equip. is compliant to 2.1.2.2.2.2.3.	-	2.1.2.2.2.2.3
2.1.3.2.2.2.4 Failed Exclusion Probability		-	a) Equip. is compliant to 2.1.2.2.2.2.4.	-	2.1.2.2.2.2.4
2.1.3.2.2.2.5 Availability	2.5.9	A and T A and T A and T A and T	a) Case 1, Availability of detection ≥ 97.06 %. b) Case 1, Availability of exclusion ≥ 57.30 %. c) Case 2, Availability of detection ≥ 99.7%. d) Case 2, Availability of exclusion ≥ 92.0%.	Analysis validates availability of detection and exclusion requirements.	
2.1.3.3 Equipment Reliability		-	a) Equip. is compliant with 2.1.2.3	-	2.1.2.3

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.3.4 Satellite Tracking Capability		-	a) Equip. is compliant with Section 2.1.2.4.	-	2.1.2.4
2.1.3.5 Dynamic Tracking		T T T T	a) Equipment maintains accuracy during normal dynamics specified in 2.1.3.5 2.1.3.1, 2.1.1.8, and 2.1.1.9. b) Equipment does not produce misleading during abnormal maneuvers specified in 2.1.3.5. c) Meets steady-state reacquisition requirements in 2.1.1.11 when abnormal maneuvers complete. d) Loss-of-navigation and loss-of-integrity alerts operate as specified during abnormal maneuvers.	Equip. maintains accuracy during normal dynamics under the specified signal power and interference conditions. Abnormal maneuvers do not cause misleading information. Reacquisitions are performed, as specified, when the abnormal maneuvers complete. Proper indication of loss of navigation and loss of integrity is shown during abnormal maneuvers.	2.1.3.1 2.1.3.5 2.1.1.9
2.1.3.6 Position Output		-	a) Equip. is compliant with 2.1.2.6.	Equip. is compliant with 2.1.2.6.	2.1.2.6
2.1.3.6.1 Position Output Update Rate		-	a) Equip. is compliant with 2.1.2.6.1.	Equip. is compliant with 2.1.2.6.1.	2.1.2.6.1
2.1.3.6.2 Position Output Latency		-	a) Equip. is compliant with 2.1.2.6.2.	Equip. is compliant with 2.1.2.6.2.	2.1.2.6.2
2.1.3.7 WAAS Message Processing		-	a) Processes messages as per Section 2.1.1.4	Equip. properly processes Message Types per Section 2.1.1.4.	2.1.1.4
2.1.3.8 Application of Differential Correction Terms		-	a) Equip meets the requirements specified in 2.1.1.4.12	Differential corrections are applied properly.	2.1.1.4.12

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.3.9 Satellite Selection		- D or T T	a) Equip is compliant to 2.1.1.6 b) Two WAAS satellites are selected, when available. c) Equip. is capable of switching between WAAS data streams to maximize continuity of function.	It is shown the equip. will select two WAAS satellites when two or more are visible. Documentation shows the equip. is capable of switching between sets of current, valid WAAS data, from different WAAS satellites, to maximize continuity of function.	2.1.1.6
2.1.4.1.1 Smoothing		A A	a) Equip. performs carrier smoothing. b) Smoothing filter error less than 0.25 m within 200 seconds in presence of code-carrier divergence of up to 0.018 m/s.	Smoothing algorithm described. Analysis data shows error cannot exceed 0.25 m with code-carrier divergence of up to 0.018 m/s.	
2.1.4.1.2 Measurement Quality Monitoring		A	Signal monitored to determine if allocated integrity risk is within manufacturer's allocation.	Analysis data to show that undetected cycle slips or other undetected measurement faults within manufacturer's allocation.	
2.1.4.1.3.1 GPS Satellites	2.5.8	T	$RMS_{pr\_air,GPS}$ is ≤ 0.36 m for airborne Accuracy Designator (AD) A and ≤ 0.15 m for AD B at the minimum signal level and ≤ 0.15 m for airborne AD A and ≤ 0.11 m for AD B at the maximum signal level.	Equipment contribution to GPS satellite errors meets values in the requirement.	
2.1.4.1.3.2 WAAS Satellites	2.5.8	T	$RMS_{pr\_air,GEO}$ is ≤ 1.8 m at the minimum signal level and ≤ 1.0 m at the maximum signal level.	Equipment contribution to GEO satellite errors meets values in the requirement.	
2.1.4.1.4 Position Solution	2.5.8	T	Equip. computes 3D position using a linearized, weighted least-squares solution, defined in Appendix J	Equip. uses the linearized, weighted least-squares solution, defined in Appendix J	Appendix J
2.1.4.2.1 Development Assurance			a) Equip. is compliant to 2.1.2.2.1.		2.1.2.2.1

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.4.2.2 Integrity Monitoring		D T	a) When in LNAV/VNAV, HPL_{WAAS} and VPL_{WAAS} are computed. b) The equipment performs fault detection, if more than four satellites are available.	Equip. computes HPL_{WAAS} and VPL_{WAAS} when in LNAV/VNAV. Equip. performs fault detection when in LNAV/VNAV.	
2.1.4.2.2.1 WAAS - Provided Integrity Monitoring		D	a) HPL_{WAAS} and VPL_{WAAS}, are computed.	Equip. produces an HPL_{WAAS} and VPL_{WAAS} that bounds the horz. and vertical position errors.	2.1.4.10 Appendix J
2.1.4.2.2.2 Fault Detection-Provided Integrity Monitoring	2.5.9	I and T	a) Equip. has FD integrity monitoring capability that uses redundant GPS and WAAS ranging measurements.	Equip. is shown to have an FD capability.	2.1.4.10
2.1.4.2.2.2.1 Frequency of Fault Detection		I and T	a) FD computed once per minute or within 6 seconds of change in satellites used for position computation.	Equip. executes FD once per minute or within 6 seconds of a constellation change.	
2.1.4.2.2.2.3 False Alert		A A	a) Probability of false alert $\leq 2 \times 10^{-5}$ per approach. b) False alert rate maintained for every geometry.	Probability of false alert $\leq 2 \times 10^{-5}$ per approach is maintained for every geometry.	
2.1.4.2.2.2.4 Availability	2.5.9	A and T	a) Availability of LNAV/VNAV FD is $\geq$ 95%.	Availability of LNAV/VNAV FD is $\geq$ 95%.	
2.1.4.4 Satellite Tracking Capability		T T T	a) Equip. is compliant to 2.1.2.4.	Equip. is compliant to 2.1.2.4.	2.1.2.4
2.1.4.5 Tracking Constraints		I	Depending on the pre-correlation bandwidth of the equipment, the correlator spacing, d, and the differential group delay is within the range as defined in Table 2-3A-C.		

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.4.5.1 GPS Tracking Constraints		I I I I	a) For E-L discriminator tracking GPS satellites, the pre-correlation bandwidth, correlator spacing, and differential group delay within ranges in Table 2-3A. b) The discriminator is within the specified range. c) For DD discriminators tracking GPS satellites, the pre-correlation bandwidth, correlator spacing, and differential group delay within ranges in Table 2-3B. d) For Double Delta discriminators tracking GPS satellites, the pre-correlation filter rolls-off 30 dB per octave.	Equipment meets values in the requirement.	
2.1.4.5.2 SBAS Tracking Constraints		I I	a) For E-L and DD discriminator tracking SBAS satellites, the pre-correlation bandwidth, correlator spacing, and differential group delay within ranges in Table 2-3C. b) For Double Delta discriminators tracking SBAS satellites, the pre-correlation filter rolls-off 30 dB per octave.	Equipment meets values in the requirement.	
2.1.4.6 Correlation Peak Validation		D D	a) The equipment acquires the main C/A code correlation peak for each GPS and SBAS ranging source used in the navigation solution. b) For Double Delta DLL discriminators, the equipment operates at the correct tracking point within the main C/A correlation peak.	Demonstrate that the main C/A code correlation peak is acquired. For double delta DLL discriminators, demonstrate that the strongest peak is tracked during acquisition and reacquisition.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.4.7 Dynamic Tracking	2.5.8	T T T T	a) Equipment maintains accuracy during normal maneuvers specified is compliant within 2.1.4.1, 2.1.1.8, and 2.1.1.9 during specified normal maneuvers. b) Equipment does not produce misleading information during abnormal maneuvers. c) Meets reacquisition requirements in 2.1.1.9 when abnormal maneuvers complete. d) Loss-of-navigation and loss-of-integrity monitoring operates as specified during abnormal maneuvers.	Equip. maintains accuracy during normal dynamics under the specified signal power and interference conditions. Abnormal maneuvers do not cause misleading information. Reacquisitions are performed, as specified, when the abnormal maneuvers complete. Proper indication of loss of navigation and loss of integrity is shown during abnormal maneuvers.	2.1.1.8 2.1.1.9 2.1.4.1
2.1.4.8 Position Output			a) Equip. is compliant with Section 2.1.2.6.		2.1.2.6
2.1.4.8.1 Position Output Update Rate			a) Equip. is compliant with Section 2.1.2.6.1.2		2.1.2.6.1
2.1.4.8.2 Position Output Latency		T	a) Equip. is compliant with Section 2.1.2.6.2.2		2.1.2.6.2
2.1.4.9.1 Message Type 2-5, 6 and 24 Fast Clock Corrections		I and T T T	a) Message Types 2-5 and 24 processed in accordance with Section 2.1.1.4.3. b) Message Types 6 processed in accordance with Section 2.1.1.4.4. c) Satellite is not used if its associated $UDREI_i \geq 12$.	Message Type 2-6 and 24 are decoded. Any satellite with a UDREI ≥12is not used in PA mode.	2.1.1.4.3 2.1.1.4.4 A.4.4.3 A.4.4.8

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.4.9.2 Message Type 24 and 25 Long-Term Corrections and Message Type 9 GEO Navigation Data		I and T	Meet requirements specified in Section 2.1.1.4.11.		2.1.1.4.11
2.1.4.9.3 Message Type 18 Ionospheric Grid Point Masks		I and T I or D	a) Equipment decodes Message Types 18 to accurately and unambiguously identify the grid point latitude and longitude for each correction in Message 26. b) The equipment store and uses two IGPmasks per GEO PRN signal. c) During IGP mask transition, corrections with different IODIs can be used simultaneously.	Equip. identifies grid point latitudes and longitudes for each correction in Message Type 26.	A.4.4.9
2.1.4.9.4 Message Type 26 – Ionospheric Grid Point Delays		T T	a) Equipment decodes Message Type 26 and stores these vertical delay and GIVEI for each grid point needed to compute ionospheric corrections. b) Previous data is used if IODI in Msg Type 26 does not match that in Msg Types 18, until a match is achieved.		A.4.4.10
2.1.4.9.5 Message Types 7 and 10 – Degradation Parameters		I and T	a) Equipment decodes Message Types 7 and 10 as specified in Appendix A.	Equip. decodes Msg. Types 7 and 10.	A.4.4.5 A.4.4.6

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.4.10 Application of Differential Correction Terms		I and T	a) Equip. properly applies differential correction as specified in 2.1.1.4.12 and as modified by this section.		2.1.1.4.12 2.1.4.10.3 2.1.4.10.2
2.1.4.10.1 Application of Clock and Ephemeris Corrections		T	a) Clock and ephemeris corrections are applied as described in section 2.1.1.4.12.	The equip. applies corrections to Code phase and Doppler measurements as specified.	2.1.1.4.12
2.1.4.10.2 Application of Ionospheric Corrections		T T T	a) Equip. computes iono pierce point and obliquity angle for each satellite used in the position computation. b) The equipment computes the ionospheric slant range delay and σ^2_{UIRE} as defined in Appendix A, Section A.4.4.10.3. c) Satellites for which correction cannot be computed not used in position solution for LNAV/VNAV.	Test prove the equip.; computes the iono pierce point and obliquity angle for each satellite used in the position; iono correction is computed and used as specified.	A.4.4.10
2.1.4.10.3 Application of Tropospheric Corrections		I and T	a) Tropospheric corrections are computed and applied as defined in A.4.2.4.	Documentation or tests show tropo. corrections are applied per A.4.2.4.	A.4.2.4

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.4.11 Satellite Selection		T D or T T T T	a) At least two WAAS satellites are selected, that provide data for the user's location. b) Equip. capable of switching between WAAS data streams to maximize continuity. c) Only uses data from service provider specified in the FAS data block. d) No satellites below 5 degrees are used in the position solution. e) Only WAAS HEALTHY satellites are used in the position solution. f) Equip is compliant with 2.1.1.6	The equip. is capable of: selecting at least two WAAS satellites that provide data for the user's location; switching between WAAS data streams to maximize continuity; using data only from service provider specified in the FAS data block; will not use satellites below 5 degrees in the position solution; uses only WAAS HEALTHY satellites in the position solution.	2.1.1.6
2.1.4.12.1 Protection Level		D T D	a) Class Beta-2 outputs HPL_{WAAS} and VPL_{WAAS} once per second. b) Latency of WAAS-based protection levels < 0.7 s. c) Indicate if HPL_{WAAS} and VPL_{WAAS} cannot be calculated.	It shown the Class Beta-2 outputs HPL_{WAAS} and VPL_{WAAS} once per second. Test shows the equip.'s latency for the protection levels is less than 0.7 s. LNAV/ VNAV not avail when protection levels cannot be calculated.	2.2.4.6 2.3.6

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.4.12.2 Navigation Alert		 D A T T T (D, I and T) or T	Beta-2 equip.provides an indication of loss of navigation within one second at the of the onset of the following conditions: a) Loss of power causes loss of nav. indication. b) Equip. malfunctions or failures causes loss of nav indication. c) Indicates loss of nav. if a position failure is detected. d) Indicates loss of nav. if no valid WAAS message has not been received for 4 seconds. e) Class Beta-2 indicates loss of navigation if there are fewer than 4 WAAS HEALTHY satellites, within 0.6 seconds. f) Alert returns to normal state immediately upon termination of the responsible condition.	Equip. indicates loss of nav. for: loss of power; equip. malfunctions or failures; FD detects a fault; a valid WAAS msg. has not been received for 4 sec.; Class Beta-2 equip. indicates it has fewer than 4 WAAS HEALTHY satellite within 0.6 seconds. Loss of nav indication is cleared upon termination of the condition.	
2.1.5.1 Accuracy			a) Equip. is compliant with 2.1.4.1.		2.1.4.1
2.1.5.2.1 Development Assurance		(A, I) or (A, I, T)	a) Hardware and software designed so that the output of misleading information is a sever-major/hazardous failure condition and is extremely remote during 150-second approach. b) Conduct a safety assessment to evaluate the system's implementation against known failure conditions.		
2.1.5.2.2 Integrity Monitoring		D T	a) When in GLS or APV-II, HPL_{WAAS} and VPL_{WAAS} are computed. b) The equipment performs fault detection, if more than four satellites are available.	Equip. computes HPL_{WAAS} and VPL_{WAAS} when in GLS or APV-II. Equip. performs fault detection when in GLS or APV-II.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.5.2.2.1 WAAS-Provided Integrity Monitoring			a) Equip. is compliant with 2.1.4.2.2.1.		2.1.4.2.2.1
2.1.5.2.2.2 Fault Detection-Provided Integrity Monitoring	2.5.9	I and T	a) Equip. has FD integrity monitoring capability that uses redundant GPS and WAAS ranging measurements.	Equip. is shown to have an FD capability.	2.1.4.10
2.1.5.2.2.2.1 Frequency of Fault Detection		I and T	a) FD computed once per minute or within 6 seconds of change in satellites used for position computation.	Equip. executes FD once per minute or within 6 seconds of a constellation change.	
2.1.5.2.2.2.3 False Alert			a) Equip. is compliant with 2.1.4.2.2.2.3.		2.1.4.2.2.2.3
2.1.5.2.2.2.4 Availability		A A	Availability is 95% under conditions described in requirement.	95% availability.	
2.1.5.4 Satellite Tracking Capability			a) Equip. is compliant with 2.1.2.4.		2.1.2.4
2.1.5.5 Tracking Constraints			a) Equip. is compliant with 2.1.4.5.		2.1.4.5
2.1.5.5.1 GPS Tracking Constraints			a) Equip. is compliant with 2.1.4.5.1.		2.1.4.5.1
2.1.5.5.2 SBAS Tracking Constraints			a) Equip. is compliant with 2.1.4.5.2.		2.1.4.5.2

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.5.6 Correlation Peak Validation			a) Equip. is compliant with 2.1.4.6.		2.1.4.6
2.1.5.7 Dynamic Tracking			a) Equip. is compliant with 2.1.4.7.		2.1.4.7
2.1.5.8 Position Output		T	a) Determine a position for navigation in WGS-84. b) Output this position (latitude, longitude and height above WGS-84 ellipsoid).		
2.1.5.8.1 Position Output Update Rate		T	a) Compute and output a position at a 5 Hz rate to support an unaided GLS and APV-II navigator. b) Compute and output a position at a 1 Hz rate to support an GLS and APV-II navigator that is aided by a separate sensor providing at least 5 Hz data. c) Each position is dynamically independent of the previous position.		
2.1.5.8.2 Position Output Latency		T T T T	a) Beta-3 equipment that supports an unaided GLS and APV-II navigator, the latency is ≤300 milliseconds. b) Output of the position defining data is <300 milliseconds after measurement time. c) Beta-3 equipment that supports an aided GLS and APV-II navigator, the latency is ≤400 milliseconds. d) Output of the position defining data is <400 milliseconds after measurement time.		

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.5.9 WAAS Message Processing			a) Equip. is compliant with 2.1.4.9.		2.1.4.9
2.1.5.9.1 Message Types 2-5, 6 and 24 Fast Clock Corrections		I and T T	a) Message Types 2-5 and 24 processed in accordance with Section 2.1.1.4.3. b) Message Types 6 processed in accordance with Section 2.1.1.4.4. c) Satellite is not used if its associated $UDREI_i \geq$ 12.	Message Type 2-6 and 24 are decoded. Any satellite with a UDREI ≥12is not used.	2.1.1.4.3 2.1.1.4.4 A.4.4.3 A.4.4.8
2.1.5.9.2 Message Types 24 and 25 LTC Corrections and Message Type 9 GEO Navigation Data			a) Equip. is compliant with 2.1.4.9.2.		2.1.4.9.2
2.1.5.9.3 Message Type 18 – Ionospheric Grid Point Masks			a) Equip. is compliant with 2.1.4.9.3.		2.1.4.9.3
2.1.5.9.4 Message Type 26 – Ionospheric Grid Point Delays			a) Equip. is compliant with 2.1.4.9.4.		2.1.4.9.4
2.1.5.9.5 Message Types 7 and 10 Degradation Parameters			a) Equip. is compliant with 2.1.4.9.5.		2.1.4.9.5

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.5.10 Applications of Differential Correction Terms			a) Equip. is compliant with 2.1.4.10.		2.1.4.10
2.1.5.10.1 Applications of Clock and Ephemeris Corrections			a) Equip. is compliant with 2.1.1.4.12.		2.1.1.4.12
2.1.5.10.2 Applications of Ionospheric Corrections		T T T	a) Equip. computes iono pierce point and obliquity angle for each satellite used in the position computation. b) The equipment computes the ionospheric slant range delay and σ^2_{UIRE} as defined in Appendix A, Section A.4.4.10.4. c) When corrections cannot be computed the satellite is not to be used in the position computation for GLS or APV-II.	Test prove the equip.; computes the iono pierce point and obliquity angle for each satellite used in the position; iono correction is computed and used as specified, satellite eliminated from position computation when correction cannot be computed.	A.4.4.10
2.1.5.10.3 Applications of Tropospheric Corrections			a) Equip. is compliant with 2.1.4.10.3.		2.1.4.10.3

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.5.11 Satellite Selection		T D or T T T T	a) At least two WAAS satellites are selected, that provide data for the user's location. b) Equip. capable of switching between WAAS data streams to maximize continuity. c) Only uses data from service provider specified in the FAS data block. d) No satellites below 5 degrees are used in the position solution. e) Only WAAS HEALTHY satellites are used in the position solution. f) Equip is compliant with 2.1.1.6	The equip. is capable of: selecting at least two WAAS satellites that provide data for the user's location; switching between WAAS data streams to maximize continuity; using data only from service provider specified in the FAS data block; will not use satellites below 5 degrees in the position solution; uses only WAAS HEALTHY satellites in the position solution.	2.1.1.6
2.1.5.12.1 Protection Level		D T D	a) Class Beta-3 outputs HPL_{WAAS} and VPL_{WAAS} once per second. b) Latency of WAAS-based protection levels < 0.7 s. c) Indicate if HPL_{WAAS} and VPL_{WAAS} cannot be calculated.	It shown the Class Beta-2 outputs HPL_{WAAS} and VPL_{WAAS} once per second. Test shows the equip's latency for the protection levels is less than 0.7 s. GLS or APV-II not avail when protection levels cannot be calculated.	2.2.4.6 2.3.6

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.1.5.12.2 Navigation Alert		D A T T T (D, I and T) or T	Beta-3 equip.provides an indication of loss of navigation within one second at the of the onset of the following conditions: a) Loss of power causes loss of nav. indication. b) Equip. malfunctions or failures causes loss of nav indication. c) Indicates loss of nav. if a position failure is detected. d) Indicates loss of nav. if no valid WAAS message has not been received for 4 seconds. e) Class Beta-3 indicates loss of navigation if there are fewer than 4 WAAS HEALTHY satellites, within 0.6 seconds. f) Alert returns to normal state immediately upon termination of the responsible condition.	Equip. indicates loss of nav. for: loss of power; equip. malfunctions or failures; FD detects a fault; a valid WAAS msg. has not been received for 4 sec.; Class Beta-3 equip. indicates it has fewer than 4 WAAS HEALTHY satellite within 0.6 seconds. Loss of nav indication is cleared upon termination of the condition.	
Requirement Paragraph	Test Para.	Test Method	Gamma Equipment General Requirements	Pass/Fail Criteria	Related Rqts
2.2.1.1.1.1 Operation	2.5.11.3.1 2.5.11.3.4 2.5.11.3.4 2.5.11.3.4 2.5.11.3.1	D D D D D	a) Controls are accessible. b) Use of controls does not interfere with display of critical information. c) Controls provide tactile feedback without excessive effort. d) Controls avoid inadvertent activation. e) Controls operable with one hand.	Frequently used flight controls easily adjustable. Use of controls does not obstruct displays. Feedback is adequate, minimal risk of inadvertent activation or deactivation. Knob shape & size is distinguishable and aids in pilot's use. Detents are well defined. Operations of controls accomplished with use of one hand.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.1.1.2 Control Labels	2.5.11.3.2 2.5.11.3.2 2.5.11.3.4 - -	D D D N/A N/A	a) Labels readable from 30 inches. b) Readable under all light conditions. c) Next to controls and not obstructed. d) Placement should be consistent. e) Label terminology should be appropriate and consistent.	Labels are readable under various lighting conditions from up to 30 in. Not obstructed by use of controls.	2.2.1.1.3.1 2.2.1.1.5
2.2.1.1.2 Operating Procedures	2.5.11.3.1 2.5.11.3 2.5.11.3 2.5.11.3.1 2.5.11.3.1	D D D D I & D I	a) Minimize pilot workload, reliance on pilot memory. b) Maximize operational suitability. c) Easy operator detection and recovery from operating errors. d) If used, prompting is consistent. e) Operating rules consistent in all operating modes. f) Prompting cues are consistent.	Minimal need for handbook procedures. Displays and control labels easily convey information, proper operation of controls with one hand and feedback provided. Minimum number of controls needed to complete tasks. Data entry procedures are simple and easy. Prompts are easily understood and documentation verifies consistent use of prompts in each mode. Documents and bench testing verify that a minimum number of control actions are necessary for each situation listed.	2.2.1.1
2.2.1.1.3 Minimum Workload Functions		D	a) Tasks in <u>Table 2-3</u> can be accomplished within times provided.	Demonstrate that each task in <u>Table 2-3</u> can be accomplished with the time provided.	
2.2.1.1.4.1 Discriminability	2.5.11.2	D D D	a) Alerts, alarms, and symbols are distinctive and discriminable from one another. b) Functionality clearly distinguished if control performs multiple functions. c) Clear indication when control is not in default mode.	Alerts, alarms, and symbols are distinctive and discriminable from one another.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.1.4.2 Displays - Brightness, Contrast, & Color	2.5.11.2.2 2.5.11.2.2	D D I	a) Readable under all ambient light conditions. b) Colors are distinct from one another. c) Colors follow aviation conventions: Red not used except for instrument flags, Yellow = caution.	Display is readable. Display brightness is adjustable. Colors are distinguishable from one another under all ambient light conditions. Documents verify colors follow aviation conventions.	
2.2.1.1.4.3 Angle of Regard	2.5.11.2.2 2.5.11.2.2	D D	a) Displays are usable in horizontal view of ± 35 degrees to normal. b) Displays are usable in vertical view of ± 20 degrees to normal.	Display is readable in all ambient light conditions up to an angle of 35 degrees in the horizontal plane, and up to 20 degrees in vertical plane normal to the equipment display.	
2.2.1.1.4.4 Symbology	- 2.5.11.2.2	D	Minimal misinterpretation of symbols.	Symbols can be discriminated.	
2.2.1.1.4.5 Alphanumeric	2.5.11.2.2 - 2.5.11.1.1.2	D N/A D	a) Displays are readable from 30 inches under all light conditions. b) Location and closure rate on the active WPT should facilitate cross-checking by pilot. c) Initial, Final, Missed Approach and Missed Approach Holding WPTs are labeled clearly.	Displays are readable, symbols & letters are distinguishable under various ambient light conditions. Initial, Final Missed Approach, Missed Approach Holding WPTs are clearly labeled.	2.2.1.1.1.2
2.2.1.1.4.6 Moving Map	- 2.5.11.2.1 2.5.11.2.1 2.5.11.2.1 2.5.11.2.1 2.5.11.2.1 2.5.11.2.1	N/A D D D D D D	a) Map formats should be easily cross-checked with paper renditions. b) Map scale is appropriate & clear. c) Map display update rates appropriate. d) Map orientation clearly indicated and selectable for multiple orientations. e) Aircraft location & heading shown. f) Track lines distinct from course lines. g) Obstructions depicted on map displays consistent with data base precision.	Symbology is distinct and symbols in close proximity are distinguishable. Map motion and display update is not distracting, symbols maintain integrity. Clear indication of orientation: track-up and north-up. Aircraft location & heading appear on map. Track lines are distinguishable from course lines. Ground obstructions consistent with database & sectionals.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.1.4.7 Primary Nav Display	-	I	a) If primary nav display page is used (in lieu of continuous), can be obtained with maximum of two operator actions.	Information can be obtained with maximum of two actions.	2.2.2.4.1 2.2.3.4.1 2.2.4.4.1
2.2.1.1.4.8 Bearing labels		I I	Bearing data fields labels have "°" to the right of the bearing value. True bearing data fields labels have "°T" to the right of bearing value.	All bearing labels have "O" to the right of the bearing value. Documentation verifies placement of "°T" to right of bearing value.	
2.2.1.1.5 Annunciations	2.5.11.2.2 2.5.11.2.2 - - 2.5.11.2.3 2.5.11.2.3 2.5.11.2.3 -	D D N/A N/A D D D N/A	a) Visual alerts gain attention under all cockpits conditions. b) Visual alerts not disruptive in dark. c) Annunicator and warning labels are expected to be readable. d) Use of colors should follow conventions and regulations. e) Auditory alerts should be consistent with ARP 4102-4 and aircraft annunciator philosophy. f) Auditory alerts should not be sole source of information. g) Annunicators should be detectable when wearing a headset. h) Warnings, messages not critical during instrument approaches should be suppressed during that phase of flight.	Visual alerts are distinguishable under all light conditions. Alert illumination is not disruptive to pilot's dark adaptation. If the equipment implements audible alerts the bench test 2.5.10.2.3 must be executed. In addition the auditory alerts should be consistent with ARP 4102-4.	
2.2.1.1.5.1 Annunciators	- - 2.5.11.2.2	N/A N/A D D	a) Simple font should be used. b) Alert characters should be readable without errors. c) Brightness is pilot selectable. d) Capability to test external annunciators.	The brightness is manually controllable. Demonstrate capability provided to test external annunciators.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.1.5.2 Messages	- - - -	N/A I I N/A	a) Grouped by urgency and listed chronologically within group. b) All current messages are retrievable. c) Indication provided of new messages. d) Equipment indicate current messages.	Messages of higher criticality should supersede lower urgency levels that are current. Documentation shows current messages are retrievable, and Indication provided for new message.	
2.2.1.1.6 Set of Std Function Labels		I I I	Equip. uses labels or messages in Table 2-4. Each discrete action has one label. Abbreviations are not be used to represent a different term, except waypoint identifiers.	Documentation shows that Table 2-4 labels and messages are used for applicable functions.	
2.2.1.1.7 Set of Std Abbreviations		I I	a) The equipment uses the standard set of abbreviations. b) The abbreviations are used in checklists, messages, etc.	Documentation shows that the standard set of abbreviations are used consistently in the equipment displays, checklists, labels, etc.	2.2.1.1.1.2 2.2.1.1.1.3
2.2.1.2.1 FP Selection	2.5.11.1.1.1 2.5.11.1.1.1(-) .2 2.5.11.1.1.1 (-) .2 2.5.11.1.1.1 2.5.11.1.1.1	D D I & D D D	a) Hold at least 2 FPs, one with ≥ 20 WPTs. b) Select by name and automatically include series of waypoints and paths c) WPT names are consistent published names and Airport identifiers use ICAO nomenclature. f) Ability to manually select user-defined waypoints as part of FP. g) Differentiate between duplicate waypoint identifiers in the database and user defined.	Enter, store, select, & edit at least 2 FPs, one with ≥ 20 WPTs. Equipment can process FPs, which consist of the selection methods listed. Inspection of documentation states WPT names are consistent with published names. Airport identifiers are ICAO compliant nomenclature. Operator provided differentiation between identical database and user defined WPT identifiers.	2.2.4.2 2.2.3.5 2.2.4.5 2.2.5.5 2.2.1.2.6

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.2.2 FP Review	2.5.11.1.1.1, (-).2 2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1 2.5.10.1.1.1, (-).10.1.3	D D D I I I T D T	a) Readily display each WPT of any FP. b) Active leg or WPT identified. c) Ability to edit FP and insert & delete wpts. c.1) Ability to bypass WPTs in a published procedure. c.2) Modifying the FAS (WPT between FAWP & MAWP) disables the approach mode. e) Allow operator to replace procedure without first deleting the procedure, but will promt before replacing. f) Active FP unaffected during review and editing. g) Edited FP is accepted. h) FP changes activated in £ 5 seconds	WPTs are displayed in sequence for a FP. Display all WPTs, intersections & nav. aids in correct order. Documentation verifies user ability to bypass WPTs in a published procedure and that modifying the FAS disables the approach mode. Ability to edit FP (including replacing a procedure) with no changes to Active FP until accepted and activated. Output of guidance after accept FP changes does not exceed 5 seconds. Equipment can recall a WPT and not process unless activated as FP change.	
2.2.1.2.3 FP Activation	2.5.11.1.1.1	D I or A D	a) Ability to select & activate a FP. b) Verify data from the database c) Access to user defined WPT functions when no database is available.	FP selection can be activated. Documentation verifies equipment data validation techniques. Documentation verifies that invalid data cannot be accessed. User defined WPTs can be entered, stored & edited when no database is available.	
2.2.1.2.4 Waypoint Sequencing	2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1	D D D D	"To-To" navigation, automatically sequence WPTs in active FP. Equip. retains active FP if automatic sequencing is suspended. Equip. has ability to SUSP, equip annunciates when waypoint sequencing is suspended. Automatic sequencing of WPTs resume upon reaching current WPT in FP.	Automatic sequence of WPTS during "To-To". Active FP retained for suspended automatic sequencing. Annunciate for WPT sequence suspension. Resumption of automatic WPT sequencing of FP WPTS.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.2.5.1 Direct To	2.5.11.1.1	D	a) Equipment supports ‘Direct To’ a WPT.	Equipment provides guidance from present position direct to a waypoint.	
2.2.1.2.5.2 TO/FROM Course Selection	2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1	D D D D	a) Permit selection, display and course "TO" or “FROM” active WPT. b) Entry/display resolution = 1. degree. c) Intercept a course to a WPT (CF). d) Indication of TO or FROM operation.	Display and guidance to active WPTs and sequencing between "TO" WPTs. Verify Course with 1 degree resolution. CP path intercepting a course to a WPT and CF leg to a WPT. Display indication of TO or FROM operation.	
2.2.1.2.5.3 Manually-Selected WPT and WPT sequencing	2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1	D D D D	a) Auto seqn. of remaining WPTs in active flight plan following "TO" if "TO" WPT in active FP. b) If selected ‘TO’ WPT is not in FP, FP is retained and not deleted. c) FROM operations for manually selected track maintains prior track. d) Equipment remains in FROM indication until another "TO" WPT.	If TO WPT is in active FP, equipment auto. sequences remaining WPTs after "TO", active FP remains after selecting TO. IF ‘TO’ WPT is not in active FP, WPTs are retained. FROM operation automatically entered after crossing manually selected WPT. Provides guidance FROM WPT following the prior track. Remains in FROM until manually selected.	
2.2.1.2.6 User Defined WPTs	2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1	D D D	a) Enter & display WPT coordinates in lat./long. with 0.1 min.s. resolution. b) Create waypoint at current position. c) WPTs entered by range/bearing.	Enter & display coordinates in lat./long with better than 0.1 min's. User Defined WPT can be created at current position. Range resolution of 0.1 nm & bearing of 1 degree or better with local declination. Documentation verifies use of local declination for bearing or verifies Std mag-var model.	
2.2.1.2.7 Emergency Procedures	2.5.11.1.3	D	a) Capability to identify nearest nine airports to a position. Airports can be selected to provide direct to guidance.	Verify activating [NRST] function(s) identify nearest 9 airports and permit Direct To any of the airports.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.3 Path Definition	2.5.10.1.1.1, (-).2 2.5.10.1.6, (-).7 2.5.10.1.1.1 2.5.10.1.1.1	D D D D I I I	a) Flight path is based upon active FP. b) Position relative to path used in cross-track deviation. c) Auto-seqn between WPTs. d) Paths defined in TF, CF, and FROM legs. e) Legs defined with local declination, otherwise Std mag-var model. f) If DME arcs or RF legs are supported 2.2.1.3.3 requirements must be met. g) Procedures and routes, not supported by the equipment, will not be selected manually or automatically.	Flight path uses active FP including determining cross-tack deviation. Equipment automatically seq.'s between WPTs. Desired paths can be defined by any leg type (TF, CF, & FROM). Documentation verifies use of local declination otherwise Std mag-var. Documentation verifies 2.2.1.3.3	2.2.4.3
2.2.1.3.2 Fixed WPT - Fixed WPT	2.5.10.1.1.1	D & I	a) TF leg defined by the WGS-84 geodesic path between two fixed WPTs.	Equipment processes the path TF leg and documentation verifies use of geodesic path.	
2.2.1.3.3 DME Arcs and Constant Radius to Fix	2.5.11.1.1.2 2.5.11.1.1.2	I D I D	a) If DME arcs are supported, equipment accomplishes published non-precision approach procedures. b) If RF legs are supported, RF leg defined properly, includes constant radius circular path arc. c) Equipment properly computes radius. d) RF leg begins with previous leg WPT.	If DME arcs are supported they support published non-precision approach procedures. IF RF legs are supported, equipment processes the path RF leg using WPT from previous leg as beginning of leg. Documentation verifies computation techniques for radius.	
2.2.1.3.4 Direct-To	2.5.11.1.1.1 2.5.11.1.1.1 2.5.11.1.1.1	D D I & D	a) Equipment defines DIRECT TO path. b) Path connects present position TO WPT. c) Path prevents S-turns.	Equipment processes DIRECT TO with path from present position TO WPT. Demonstration executes DIRECT TO without S-turns.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.3.5 Course to a Fix WPT	2.5.11.1.1.1, (-).2	D	a) CF leg defined properly, includes WGS-84 geodesic path along course to fixed WPT.	Equipment processes the path CF leg and documentation verifies use of geodesic path.	
2.2.1.3.6 FROM leg	2.5.11.1.1.1 ,(-).2	D D	a) Provide guidance FROM a WPT. b) course is WGS84 geodesic.	Equipment provides FROM guidance and documentation verifies use of geodesic path.	
2.2.1.3.7 Fly by Turns	2.5.11.1.1.1, (-).2 2.5.11.1.1.2	D D	a) Turns with heading changes less than or equal to 120 degrees use fly-by turns unless designated by database procedure. b) Equipment provides guidance for fly-by turns.	Equipment provides guidance for Fly By Turns for heading changes less than or equal to 120 degrees.	
2.2.1.3.7.1 Fly-by Turn Indications	2.5.11.1.1.1 ,(-).2 2.5.11.1.1.1 ,(-).2 2.5.11.1.1. , (-).2	D D D	Indication at start of turn. Indication prior to start of fly-by turn. Indication of course of next leg not later than turn anticipation indication.	Indication provided to user prior to, and at the start of a defined Fly-by turn. Indication of course for next leg no later than turn anticipation.	
2.2.1.3.7.2 Fly-by Theoretical Transition Area		A	a) Defined path of fly-by turn accomplished within Theoretical Transition areas listed.	Documentation and analysis (See 2.2.1.3.7.3 Acceptable means) verifies that the equipment will provide guidance within the Theoretical Transition areas listed.	
2.2.1.3.8 Fly over Turns	2.5.11.1.1.1	D	a) Equipment defines path for fly-over turns.	Equipment defines flight path for fly over turns through transition WPT.	
2.2.1.3.9 Fixed Radius Turns	-	N/A	a) Recommended the equipment defines path for defining fixed path turn radius.		

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.3.10 Waypoint Sequencing	2.5.11.1.1.1 2.5.11.1.1.1, (-).2 2.5.11.1.1.1	D D D D D	a) Indication when WPT is sequenced. b) If cross-track deviations are for curved path waypoints sequenced at bisector. c) If cross-track not provided relative to curve, WPTs sequenced at turn initiation and deviations are relative to next leg. d) Ability to recall WPT after crossing. e) FROM operation after last WPT.	Equipment indicates when WPT is being seqn'd. Cross-track deviations are relative to curve path and WPTs sequenced at the bisector. If cross-track is not relative to curve, demonstrate that WPTs are sequenced at turn initiation, and deviation is relative to the next leg. Ability to recall a WPT after sequencing past the WPT. After sequencing last WPT, equipment enters FROM operation.	
2.2.1.3.11 Holding Patterns / Turns	2.5.11.1.1.1 2.5.11.1.1.2	D D D D	a) Ability of holding patterns at any WPT. b) Equipment supports published procedures. c) If Suspend autosequencing function is available, suspension is annunciated. d) Resume autosequencing on canceling suspend function(s).	Supports holding patterns and procedure turns. Equipment can accomplish procedure iaw published procedures. If the equipment supports a ‘suspend’ autosequencing capability, suspension is annunciated. Unsuspend will resume autosequencing.	
2.2.1.3.12 Magnetic Course		I I I I	a) Magnetic variation used is value for procedure, if leg is part of terminal area procedure and specified for that procedure. b) Magnetic variation is published declination for VOR, if leg not part of procedure and the active fix is a VOR. c) Magnetic variation is defined by system, if leg not procedure and terminating fix not VOR. d) Ability to assign magnetic variation within two degrees of value given by recognized model.	Documentation verifies use of magnetic variation, and value within 2 degrees of recognized model.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.3.13 Dead Reckoning		D D D D D D D	a) Dead Reckoning capability is provided. b) DR is active when no position can be obtained from GPS/WAAS. c) If automatic input of TAS or heading not available, DR projects last known GPS/WAAS position by last known groundspeed and desired track. d) DR capability continues to navigate relative to the active flight plan. e) DR capability changes assumed track in accordance with flight plan. f) Equip. can determine bearing to airport, based upopn DR position. g) If TAS and heading is provided, DR projects last known GPS/WAAS position using TAS and headind, corrected for last known wind.		
2.2.1.3.15 Geodesic Path Computation Accuracy		A	The cross-track path deviation error between the computed path used to determine cross-track deviations and the true geodesic will be less than 10% of the horizontal alert limit of the navigation mode applicable to the leg containing the path.		
2.2.1.4.1 Primary Nav Display	2.5.11.1.1., (-).2 2.5.11.1.1.1, (-).2 2.5.11.2.1	D D D	a) Nonnumeric cross-track deviation is continuously displayed. b) Nav. parameters are continuously displayed or available on a selectable page. c) Distance, bearing, desired track, actual track and track angle error are distinguishable.	Nonnumeric cross-track deviation is continuously displayed. Nav. parameters are continuously displayed or available on a selectable page. Each Nav. display parameter is distinguishable from each other.	2.2.1.1.3.6 2.2.3.4.1 2.2.4.4.1
2.2.1.4.2.1 Electrical Output		T	a) Electrical outputs to drive displays meet characteristics in table.	Test is conducted with data showing electrical characteristics for resolution, accuracy, linearity are satisfied.	2.2.2.4.2

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.4.2.2 Display	2.5.11.1.5	D	a) Display characteristics meet requirements in Table 2-6.	Characteristics for nonnumeric display of cross track resolution, accuracy, linearity min. discernible movement are met with bench test. Mfgr must show Readability is met.	2.2.2.4.2 2.2.2.4.4 2.2.2.4.5 2.2.3.4.5 2.2.3.4.7 2.2.3.4.8
2.2.1.4.3 Active WPT Distance Display	2.5.11.1.1.1 2.5.11.1.2 2.5.11.1.2	D D D	a) Distance to WPT displayed in TO operation and from WPT in FROM operations. b) WPT distance display resolution of 0.1 nm for ranges up to 99.9 nm. c) Display resolution 1. nm at ranges between 100. and 9999. nm.	WPT distance available within resolution (NM) appropriate to distance TO or FROM WPT.	2.2.2.4.3
2.2.1.4.4 Active WPT Bearing Display	2.5.11.1.1.1 2.5.11.1.3 2.5.11.1.1.1 2.5.11.1.1., (-).11.1.3	D D D D D	a) Bearing to active WPT displayed in TO operation. b) Bearing from active WPT displayed in FROM Operation. c) In FROM operation, indicate bearing to or from the waypoint. d) Bearing displayed with resolution of 1 degree. e) display in true or magnetic	Bearing to/from WPT is displayed for appropriate operation (TO/FROM). In FROM operation, the display indicates whether bearing is to or from the WPT. Bearing resolution is 1 degree. Display in either true or magnetic.	
2.2.1.4.5.1 Desired Tk		D	a) Equip displays desired tk.	Equip displays desired tk.	
2.2.1.4.5.2 Track Angle		D	The track angle is displayed with 1°◦ resolution.		
2.2.1.4.5.3 Track Angle Error		D	The track angle error is displayed with 1°◦ resolution.		
2.2.1.4.6 Display of TO/ FROM	2.5.11.1.1, (-).2	D	a) Equipment continuously displays indication of TO or FROM Operation.	Equipment continuously outputs TO or FROM Operation.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.4.7 Waypoint Bearing/ Distance Display	2.5.11.1.1.1 2.5.11.1.1.1	D D	a) Equipment can display range/bearing to any WPT. b) Display estimated time to arrive.	Equipment displays range/bearing to selected WPT. Display estimated time to arrive at the WPT (e.g., ETA or ETE).	
2.2.1.4.9 Magnetic Course		I I I I	a) DTK is based on true-to-magnetic conversion at user location, using magnetic model. b) BRG to/from WPT, other than a VOR is based on true-to-magnetic conversion at user location, using magnetic model. c) BRG to/from a VOR is based on true-to-magnetic conversion at WPT location, uses magnetic conversion used to define path. d) CRS is based on true-to-magnetic conversion at WPT location, uses magnetic conversion used to define path.	Documentation verifies conventions for DTK, BRG, and CRS.	
2.2.1.4.10 Ground Speed		D	a) Equip. provides display of ground speed with one knot resolution.		
2.2.1.4.11 Aircraft Present Position		D	a) Equip. provides display of present Lat/Long with 0.1 minute resolution.		
2.2.1.5.1 Access		I I I & T D D	a) No manual data base updating. b) Data recalled from storage also retained in storage. c) Updating database uses high-integrity data validation technique. d) Can identify version and operating dates. e) Equipment indicates if database is not yet effective or out of date.	Database (e.g., Jeppesen data) cannot be manually updated, excludes user defined data. Data remains in storage. Updating of database includes data integrity and validation such as CRC. Can identify version and operating dates. Indicates if database is not yet effective or out of date.	2.2.1.5.2, 2.2.3.5, 2.2.4.5.1

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.5.2 Content	2.5.11.1.1.1 2.5.11.1.1.1	D D I I I D D	a) Nav. Database is updatable, containing location/path information, referenced to WGS-84, 0.01 minute Lat/Long resolution, and 0.1° course resolution. Data on Airports VORs, DMEs, etc All named WPTs and intersections shown on en route and terminal charts. RNAV departure procedures and STARS b) Departures and arrivals retrievable c) Waypoints identified as "fly-over" or "fly-by".	Nav. database will store updatable data with lat./long of 0.01 min. or better, for airports, VORs, NDBs, WPTs and intersections etc. Documentation verifies that all WPTs and intersections on charts are provided and all SIDS and STARS. SIDs and STARs retrievable as a procedure. Departures and arrivals retrievable as a procedure. Waypoints identified as appropriate.	2.2.3.5
2.2.1.5.3 Standard		I, T & A	a) Data base(s) meet RTCA documents.	Data bases meet specified rqts. in sections 3, 4 & 5 of RTCA/DO-200. Process for updating database to maintain data integrity will be evaluated.	
2.2.1.5.4.1 Incorporation of Conversion Algorithms		D D	a) If lat/long is other than WGS-84 or NAD83, annunciation displayed. b) Annunciation is designed to prevent errors or misinterpretation.	The display and data entry of lat/long in other than WGS-84 or NAD83 is annunciated.	
2.2.1.6.1 –Caution Associated with Loss of Integrity Monitoring	Installation	D D D D	a) Caution issued to indicate any loss of integrity monitoring. b) Caution in pilot's primary field. c) Indication when integrity monitoring capability is restored.	Caution issued to user of loss, and indication of restoration, of equipment's integrity monitoring capability. Caution of loss of integrity monitoring is provided by means of a separate annunciator and is distinguishable.	2.1.1.13 2.1.1.13.2 2.2.2.6 2.2.2.6.2 2.2.3.6.2 2.2.4.6.2 2.2.4.6.4 2.2.5.6.2

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.1.6.2 Annunciation - Navigation Caution	2.11.1.4 2.11.1.4 Installation	D D D	a) Continuously indicate a caution for loss of capability to provide navigation. b) Caution provided by means of unique annunciator. c) Annunicator in pilot's primary field.	Caution of loss of equipment's navigation capability. Caution of loss of navigation is provided by means of a separate annunciator and is distinguishable.	2.1.1.13.1 (note) 2.2.3.6.2 2.2.4.6.3 2.2.5.6.3
2.2.1.7 Mode Switching Requirements	2.5.11.1.1 2.5.11.1.1., (-).11.1.5 2.5.11.1.1.1 2.5.11.1.5, 2.5.11.1.6 (NPA)	D D D	a) Display nav. mode on request. (Oceanic/ remote, en route, terminal, NPA, LNAV/VNAV, APV-II and GLS). b) Automatically switch to default mode. c) Approach mode is annunciated by unique continuous indication.	Nav mode indicated on request. Optional Oceanic/remote mode verified by inspection. Modes follow Tables 2-8 and 2-9, 2-10. Mode automatically switches to default mode. Approach mode is annunciated by unique continuous indication. For modes, Auto switches are indicated.	2.2.4.5 2.2.4.7 2.2.3.7 Tables 2-8, 2-9, 2-10
2.2.2.1 General Human Factors Requirements			a) Equip. is compliant with 2.2.1.1.		2.2.1.1
2.2.2.2 Path Selection			a) Equip. is compliant with 2.2.1.2.		2.2.1.2
2.2.2.3 Path Definition			a) Equip. is compliant with 2.2.1.3.		2.2.1.3
2.2.2.4.1 Primary Navigation Displays			a) Equip. is compliant with 2.2.1.4.1.		2.2.1.4.1
2.2.2.4.2 Non-Numeric Cross-Track	 2.5.11.1.5 2.5.11.1.5	D D D	a) Full-scale deflection in oceanic/remote mode is ≤ ±5 nm. b) Full-scale deflection in en route mode is ±2 nm. c) Full-scale deflection in terminal mode is ±1 nm.	Oceanic/remote full-scale deflection is ≤ ±5 nm. En route full-scale deflection is ±2 nm. Terminal full-scale deflection is ±1 nm.	2.2.1.4.2.2

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.2.4.3 Numeric Cross-Track Deviation	2.5.11.1.5 2.5.11.1.5 2.5.11.1.5	D T T	a) Display and/or output a cross-track deviation with range ≥ 20 nm. b) Min. resolution of 0.1 nm for ranges ≤ 9.9 nm. c) Min. resolution of 1 nm for ranges > 9.9 nm.	The display or output is at least -20 nm (left) and +20 nm (right). Resolution of 0.1 nm for ranges ≤ 9.9 nm and 1.0 nm for ranges > 9.9 nm.	
2.2.2.4.4 Update Rate	2.5.11.1.3	T	a) Display update rate of 1 Hz or more.	Data presented on the display updated ≥ 1 Hz in En Route/ Terminal mode.	2.2.1.4.2.2
2.2.2.4.5 Display Up-date Latency	2.5.11.1.3	T	a) Display included in the GPS/WAAS equipment will not exceed 1 sec. latency.	The latency of data displayed ≤ 1 sec.	2.2.1.4.2.1
2.2.2.5 Database Requirements			a) Equip. is compliant with 2.2.1.5.		2.2.1.5
2.2.2.6.1 Alert Limits		I & D	The HAL for the navigation modes are: Oceanic/Remote 4 nm En Route 2 nm Terminal 1 nm		
2.2.2.6.2 Caution Associated with Loss of Integrity Monitoring		T I & D	a) Equipment provides loss of integrity monitoring caution within 30 seconds if the HPL exceeds the HAL. b) Equipment provides loss of integrity monitoring caution within 2 seconds if current HPL_{WAAS} exceeds HPL.	Test to verify that when HPL exceeds HAL there is nav. warning flag or other indication. Documentation and demonstration verifies that default values of Oceanic (4 nm), en route (2 nm), and Terminal (1 nm).	2.2.1.6.1, 2.2.1.7

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.2.6.3 Caution with Loss of Nav.	2.11.1.4 2.11.1.4 2.11.1.4	D & T A T D D	a) Caution for absence of power, equipment malfunction or failure, inadequate satellites (lasting 5 or more seconds) in position soln. within one second of condition. (see related reqts) b) Caution for fault detected and not excluded. c) Fault detection detects position failures within the time-to-alerts. d) Equipment distinguishes between types of loss of navigation capability. e) Caution returns to normal state upon termination	Caution for power loss and equipment malfunction or failure within one second. Caution for inadequate satellites in position soln. lasting for 5 or more seconds. Caution for fault detected and not excluded. Test data verifies Time-to-alerts: Oceanic (1 min.), En Route (30 secs), and Terminal (10 secs). Equipment distinguishes between cautions. Caution returns to normal state upon termination of caution condition.	
2.2.2.7.1.1 Entry Criteria			a) Equip. is compliant with 2.2.1.7.		2.2.1.7
2.2.2.7.1.2 Exit Criteria			a) Equip. is compliant with 2.2.1.7.		2.2.1.7
2.2.2.7.1.3 En Route Display Transition	2.5.11.1.5, 2.5.11.1.1.1	D	a) Transition to en route display sensitivity occurs gradually within 1 nm	Display sensitivity for automatic transition to en route mode decreases gradually until full-scale sensitivity of ±2 nm is achieved within 1 nm.	2.2.1.7 Table 2-5 2.2.4.7
2.2.2.7.2.1 Terminal Entry Criteria	2.5.11.1.1.1	D	a) Automatic mode switching to terminal mode must occur at the destination at airport.	Mode switching from en route to terminal mode does not occur at intermediate airports.	2.2.1.7 2.2.4.7
2.2.2.7.2.2 Exit Criteria			a) Equip. is compliant with 2.2.1.7.		2.2.1.7
2.2.2.7.2.3 Display Transition Rqts.	2.5.11.1.5, 2.5.11.1.1.1	D	a) En route to terminal display sensitivity increases gradually within 1 nm.	Display sensitivity for automatic transition from en route to terminal decreases gradually within 1 nm	2.2.1.7 Table 2-5

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.3.1 General Human Factors Requirements			a) Equip. is compliant with 2.2.1.1.		2.2.1.1
2.2.3.2 Path Selection			a) Equip. is compliant with 2.2.1.2.		2.2.1.2
2.2.3.2.1 Approach Selection	2.5.11.1.1.1, (-).2 2.5.11.1.1.2 2.5.11.1.1.2 2.5.11.1.1.2 2.5.11.1.7	D D D D D	a) Permit selection between multiple IAWPs. b) IAWP selection followed by automatic insertion of remaining WPTs. c) Permit manual selection of VTF approach. d) Until FAWP has sequenced, indication available that VTF has been selected.	Pilot can select between multiple IAWPs and remaining WPTs. After selecting an IAWP, the WPTs remaining in approach plan are listed in proper seqn. Manual selection of VTF approach and bypass complete approach procedure. Action required to initiate a missed approach. VTF indication until the FAWP has sequenced.	2.2.1.2.1 2.2.4.2
2.2.3.2.2 Missed Approach Sequencing	2.5.11.1.1.2 2.5.11.1.1.2 2.5.11.1.1.2	D D NA	a) Equipment provides capability to activate procedure with manual action. b) Selecting missed approach prior to MAWP initiates missed approach at the MAWP. c) Equipment should provide a capability to go Direct-TO any WPT in missed approach procedure.	Equipment provides capability to activate procedure with a manual action. Selecting a missed approach prior to MAWP executes missed approach at the MAWP. Equipment should provide a capability to go Direct-TO any WPT in missed approach procedure.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.3.3.1 Approach Path Definition	2.5.11.1.1.2, 2.5.11.1.6 2.5.11.1.7 2.5.11.1.1.2	D D D D D	a) If VTF approach is not selected deviation provided with respect to active leg of approach. b) VTF approach used guidance is relative to the inbound course to the FAF. c) Active WPT on VTF approach is initially FAWP d) Ability to account for short turns where FAWP not crossed. e) DIRECT TO FAWP, If desired track to track of final approach segment is >45 degrees indicate that the FAWP will not be sequenced. Equipment will also suspend autosequencing. f) MAWP designated as fly-over.	For non-VTF, deviation is respect to active leg. For VTF guidance is relative to inbound course of the FAF. The active waypoint in a VTF is the FAWP. If Direct-To FAWP and difference of desired track to track of final approach is >45, then indicated FAWP is not sequenced. Equipment suspends autosequencing. MAWP is fly-over WPT.	2.2.1.2.1 2.2.4.3 2.2.1.3.8
2.2.3.3.2 Missed Approach Path Definition	2.5.11.1.1.2 2.5.11.1.1.2	D D D D	a) After crossing MAWP switch to FROM if missed approach not initiated. b) If missed approach initiated by pilot, provide guidance relative to procedure. c) For missed approach initiated prior to MAWP used path defined in database. d) Equipment can use TF, CF, and Direct-To legs for procedure.	When missed approach not selected when crossing MAWP, go to FROM. Then provide procedure guidance when missed approach selected. If selected prior to MAWP, continue approach to MAWP and then automatically activate missed procedure. Demonstrated for all types of missed approaches shown in Figure 2-16. Equipment provides TF, CF, and Direct-To capability in missed approach procedure.	2.2.3.7.1.2 2.2.3.7.1.3
2.2.3.3.3 Departure Path Definition		I	a) Class 1, 2 and 3 equipment provides guidance for departure procedures.	Documentation shows the equipment provides guidance for departure procedures.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.3.3.4 Vertical Path for NPA Procedures			If equip. provides vertical path and displays vertical deviations, then: a) Vertical path is defined in Section 2.2.4.3.1. b) Vertical path is selected automatically when the lateral path is selected. c) Equip. to meet non-numeric vertical deviation display requirements in section 2.2.4.4.4. d) Equip. to meet display of vertical accuracy requirements in section 2.2.4.4.9. e) Equip. to meet LNAV/VNAV alerts requirements in section 2.2.4.6.		2.2.4.3.1 2.2.3.2.1 2.2.4.4.4 2.2.4.4.9 2.2.4.6
2.2.3.4.1 Primary Navigation Displays			a) Equip. is compliant with 2.2.1.4.1.		2.2.1.4.1
2.2.3.4.2 Non-Numeric Cross-Track Deviation	2.5.11.1.6 2.5.11.1.7	D D	a) Cross-track deviation for NPA is identical to LNAV/VNAV as defined in 2.2.4.4.2, or is compliant to specifications in 2.2.3.4.2. b) FSD changes to ± 0.3 nm when a missed approach is initiated.	Cross-track deviation is compliant with 2.2.3.4.2.	2.2.1.4.2.2 2.2.2.4.2 2.2.3.2.2 2.2.3.7.3 2.2.4.4.2 Fig. 2-14
2.2.3.4.3 Numeric Cross-Track Deviation	2.5.11.1.7 2.5.11.1.7	D D D	a) Equipment provides display or electrical output for Cross-track deviation with range of at least ± 9.99 nm. b) Resolution of 0.01 nm for deviations up to 9.99 nm. c) Resolution of 1. nm for deviations greater than 9.99 nm.	Equipment outputs on display, or electrically, the cross track deviation with a resolution of 0.01 nm. up to 9.99 nm. Outputs resolution of 1. nm for deviation greater than 9.99 nm.	2.2.2.4.3

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.3.4.4 MAWP Distance Display	2.5.11.1.1.2 2.5.11.1.1.2	D I & D	a) Distance to MAWP is available for display. b) Distance display resolutions of 0.1 nm up to range of 99.9 nm.	Prior to crossing MAWP the distance is available for displayed to the MAWP. Display resolutions are 0.1 nm up 99 nm from waypoint. Documentation verifies 1. nm resolution from 100 to 9999 nm.	2.2.3.3.2 2.2.3.7.1.2 2.2.3.7.1.3
2.2.3.4.5 MAWP Bearing Display	2.5.11.1.1.2 2.5.11.1.1.2	D D I	a) Bearing to MAWP is available for display. b) Bearing displayed with resolution of 1 degree. c) Displays bearing in true or magnetic bearing as selected.	Bearing is displayed prior to MAWP. Bearing resolution is 1 degree. Displays true or magnetic bearing as selected.	2.2.3.3.2 2.2.3.7.1.2 2.2.3.7.1.3
2.2.3.4.6 Displayed Data Update Rate			a) Equip. is compliant with 2.2.2.4.4.		2.2.2.4.4
2.2.3.4.7 Displayed Update Latency			a) Equip. is compliant with 2.2.2.4.5.		2.2.2.4.5
2.2.3.5. Database Reqts.	2.5.11.1.1.2 2.5.11.1.1.2 2.5.11.1.1.2 2.5.11.1.1.2 2.5.11.1.1.2	I & D I & D I & D I & D D D	a) Equipment stores and retrieves complete sequence of WPTs for NPA and missed approach. b) NPA procedure of database includes items listed (Runway, IAWP, etc.). c) Equipment presents all WPTs, intersections, and/or nav. aids for NPA. d) NPA sequence of items presented in the correct order. e) FAWP and MAWP are uniquely identified. f) Equipment stores and retrieves complete sequence of WPTs for departure procedure.	Verify by documentation inspection and demonstration the storage and presentation of the complete sequence of NPA and departure WPTs. Equipment stores, recalls all WPTs, intersections, nav. aids, holding patterns, procedure turns, etc. as procedures. FAWP and missed approach WPTs are uniquely identified in NPA mode.	2.2.1.5.2 2.2.4.5.2
2.2.3.6.1 Alert Limits		I & D	The horizontal alert limit for nonprecision approach mode is be 0.3 nm.	The equipment uses a HAL of 0.3 nm for nonprecision approach mode.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.3.6.2 Caution - Loss of Integrity Monitoring		T I & D	a) Equipment provide loss of integrity monitoring indication within 30 seconds if the HPL_{FD} exceeds the HAL. b) Equipment provides loss of integrity monitoring caution within 2 seconds if current HPL_{WAAS} exceeds HPL.	Test to verify that when HPL exceeds HAL there is nav. warning flag or other indication. Documentation and demonstration verifies the default values of NPA (0.3 nm).	2.2.1.6.1 2.2.1.7 2.2.2.6 2.2.4.6
2.2.3.6.3 Caution -Loss of Navigation	2.5.11.1.4 2.5.11.1.4 2.5.11.1.4 2.5.11.1.4 2.5.11.1.4 2.5.11.1.4	D D T D A T D D	a) Indication when navigation not adequate for NPA. b) Indication provided by nav. warning flag. c) Nav. flag dropped within 1 second. d) Caution for absence of power, equipment malfunction or failure, inadequate satellites in position soln. (lasting 5 seconds or more) e) Caution for fault detected and not excluded within TTA. f) In NPA, Fault detection detects position failures within 10 secs. g) Nav. warning flag when equipment does not provide integrity monitoring along FAS. i) After sequencing FAWP, indication latched until no longer in NPA.	Annunciation of equipment when navigation capability is inadequate to support NPA. Indication with nav. warning flag in 1 second. Caution for power loss and equipment malfunction or failure within one second. Caution for inadequate satellites in position soln. Caution for fault detection not excluded or available. Fault detection within 10 secs. after onset of positioning failure. After sequencing FAWP, indication latched until no longer in NPA.	2.2.1.6.2, 2.2.4.6
2.2.3.7.1.1 Entry Criteria			a) Equip. is compliant with 2.2.1.7.		2.2.1.7

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.3.7.1.2 Exit Criteria	2.5.10.1.1.2	D D D	a) Equip. automatically switches to terminal mode when missed approach is selected and 1st leg in procedure is not a TF leg within 3 degrees of final approach path. b) Equip. automatically switches to terminal mode at turn initiation point for 1st WPT in missed approach procedure, if 1st leg is TF leg aligned within 3 degrees of the final approach path. c) Equip. automatically switches to terminal mode if pilot initiates Direct-To any WPT while in NPA mode.	Equip. properly switches to terminal mode when transitioning into a missed approach or initiating Direct-To any WPT while in NPA mode.	2.2.1.8 2.2.5.8
2.2.3.7.1.3 Display Transition Requirements	2.5.11.1.6 2.5.11.1.7 2.5.11.1.1.2	D D D	a) If non-VTF, equipment does not change FSD until 2nm from FAWP. b) If VTF, immediately transition to angular/linear guidance relative to FAS. c) Sensitivity changes from $\pm$0.3 nm to $\pm$ 1 nm when equipment changes to terminal mode.	For Non-VTF display sensitivity changes over 2 nm from FAWP. If VTF, immediately switch to angular/linear guidance. Sensitivity changes when transitioning from NPA to terminal mode.	2.2.3.3.2 2.2.3.4.4 2.2.3.4.5 2.2.3.7.2.3
2.2.3.7.2.1 Departure Entry Criteria	2.5.11.1.1.1	D	a) Equipment uses NPA accuracy and integrity once departure is activated.	Equipment uses NPA accuracy and integrity on departure procedure.	
2.2.3.7.2.2 Departure Exit Criteria		D	a) Equipment reverts to terminal mode at first WPT turn initiation.	Equipment uses terminal mode sensitivities, accuracy and integrity at turn initiation for first WPT.	
2.2.3.7.2.3 Display Transition Requirements		D	a) FSD changes from $\pm$0.3 to $\pm$1 nm at turn initiation point of first WPT turn initiation.	Equipment changes from $\pm$0.3 to $\pm$1 nm at turn initiation for first WPT.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.4.1 General Human Factors Requirements			a) Equip. is compliant with 2.2.1.1.		2.2.1.1
2.2.4.2 Path Selection		D D D or I	a) Equip. supports approach path selection either through 5-digit channel number or by selecting airport, runway, approach ident and initial approach fix. b) Both methods implemented by Class Gamma equip. c) Once selected, the approach name and RPI is accessible for display.	Equip. tuning design is compliant with these requirements. When an approach is tuned, the approach name and RPI data are accessible for display.	
2.2.4.2.1 5-Digit Channel Selection		D D D	a) Database provides FAS data to navigation equip. based upon channel number. b) Subsequent selection of initial approach fix results in selection of the entire approach procedure including missed approach. c) Equip provides means for operator to differentiate duplicate channel numbers in the database.	The equip. properly responds to the input of a 5-digit channel selection.	
2.2.4.2.2 Approach Name Selection		D D	a) Equip. has capability to select approaches as specified in Section 2.2.3.2.1. b) Once selected, equip. automatically obtains FAS data.	Equipment accepts 5 digit channel input. Database provides data with approach procedure definition and FAS (if applicable). Display differentiates between duplicate channel numbers in the database.	2.2.3.2.1 2.2.4.5

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.4.2.3 Missed Approach Sequencing		D D	a) Equip. allows pilot to initiate the missed approach. b) Equip. automatically transitions to missed approach guidance if the aircraft is past the FPAP and the pilot has not already activated the missed approach.	Equip. allows pilot to initiate a missed approach. The equip. will transition to missed approach guidance when the aircraft is passed the FPAP and the pilot has not activated the missed approach.	
2.2.4.2.4 Selection of the Type of Approach with Vertical Guidance		I	Equip. provides a means to select which type of approach with vertical guidance will be conducted.	Equip. allows pilot to select type of approach that will be conducted.	
2.2.4.3.1 Approach Path Definition		I	a) Final approach path defined by FPAP, LTP/ FTP, DCH, and glidepath angle.	Inspection of documentation indicates proper definition of final approach path.	Appendix D
2.2.4.3.2 Missed Approach Path Definition			a) Equip. is compliant with 2.2.3.3.2.		2.2.3.3.2
2.2.4.3.3 Navigation Center Offset		D I	a) Equipment permits compensating for navigation center offset at installation. b) Navigation Center Offset cannot be changed during flight.	The equipment translates nav. center from antenna to another point. Documentation verifies translation is inhibited during flight. This offset may include lateral and vertical. Also requires Installation Test.	
2.2.4.4.1 Primary Nav. Displays		D	a) Nonnumeric vertical deviation continuously displayed in LNAV/VNAV mode.	Nonnumeric vertical deviation during LNAV/VNAV modes is continuously displayed.	2.2.1.4.1

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.4.4.2 Non-Numeric Lateral Cross-Track Deviation		D D D D	a) Positive lateral deviations correspond to aircraft psotions to left of lateral deviation reference pland, as observed from the LTP/FTP facing toward the FPAP. b) If VTF not selected: the deviation is either: (1) linear with FSD ± 1 nm prior to 2 nm from the FAWP and FSD gradually changes to final approach FSD during the transition from 2 nm from the FAWP and arrival at the FAWP;, or (2) is the final approch segment leteral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$. Between FAWP and the LTP/FTP, the deviation is the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$. Between the LTP/FTP and the length offset distance to the FPAP, the deviation is either the fianl approadh segment lateral deviation or linear with FSD for a cross-track error of ± (Course Width at LTP/FTP). c) If VTF selected, the deviation is either: (1) linear with FSD ± 1 nm prior $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP and FSD gradually changes to final approach FSD during the transition from $\frac{1}{\tan(\alpha_{lat,FS})}$ nm from the GARP and arrival at the LTP/FTP, or (2) FSD is the final approch segment leteral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$. Between the LTP/FTP and	FSD is managed properly during LNAV/ VNAV mode.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
			the length offset distance to the FPAP, the deviation is either the fianl approadh segment lateral deviation or linear with FSD for a cross-track error of ±(Course Width at LTP/FTP). Beyond the length offset distance to the FPAP, the deviation is linear with FSD for cross=track displacement of ±0.3 nm. d) FSD transitions to ±0.3 nm when missed approach is activated.		
2.2.4.4.3 Numeric Cross-Track Deviation			a) Equip. is compliant with 2.2.3.4.3.		2.2.3.4.3

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.4.4.4 Non-Numeric Vertical Deviation		D D D D D D	a) In LNAV/VNAV mode, continuously provide guidance. b) At a distance greater than $\frac{150m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation are linear with FSD for a vertical error of 150 m; c) Between $\frac{150m}{\tan(\alpha_{vert,FS})}$ and $\frac{45m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation are the final approach segment vertical deviation. d) Closer than $\frac{45m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation are linear with FSD for a vertical error of ±45 m. e) Vertical deviations flagged as invalid if: (a) The lateral position of the aircraft is outside of a ± 35 degree wedge with origin at the GARP, centered on the FAS; and (b) The aircraft is not on the approach side of the GPIP. f) Vertical guidance is flagged when missed approach is initiated.	Guidance is continuously provided in LNAV/VNAV mode. Demonstrate that FSD meets requirements.	2.2.1.4.2
2.2.4.4.5 Missed Approach Waypont/ LTP/ FTP Distance Display		D I	a) Distance to LTP/FTP available for display in terminal & approach modes prior to crossing LTP/FTP. b) Distance resolution of 0.1 nm up to range of 99.9 nm.	Demonstrate that range to LTP/FTP is available for display in terminal and NPA modes, when approach procedure is selected. Documentation describes display resolution and range.	2.2.1.4.3 2.2.1.4.7 2.2.3.4.4

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.4.4.6 Missed Approach Waypont/ LTP/ FTP Bearing Display		D I I	a) Bearing to LTP/FTP available for display in terminal & approach modes, prior to crossing LTP/FTP. b) Bearing resolution of 1.0 Degree. c) Bearing displayed in true or magnetic bearing as selected.	Demonstrate that bearing to LTP/FTP is available for display in terminal and approach modes, when approach procedure is selected. Documentation states bearing can be displayed in true or magnetic. Also states that local declination is used for magnetic bearing.	2.2.1.4.4 2.2.1.4.7 2.2.3.4.5
2.2.4.4.7 Update Rate		T	a) Display update rate of at least 5 Hz. b) Deviation updates based on dynamically independent position at a 1 Hz rate. c) Intervening deviation updates may be extrapolated from the velocity vectors resulting from the 1 Hz dynamically independent position is.	Data is dynamically independent and at a 1Hz rate and is presented on the display updated at <u>least 5 Hz</u> in LNAV/VNAV mode.	2.1.4.6.1
2.2.4.4.8 Displayed Update Latency		T	Latency of electrical output does not exceed 400 msec.	The latency of data displayed is measured to not exceed 400 msec.	2.3.2
2.2.4.4.9 Display of Vertical Accuracy		A	a) 95% confidence value for vertical accuracy is available for display.	Vertical accuracy is displayed for 95% confidence.	
2.2.4.5.1 Content		I & D D D	a) Equipment stores LNAV/VNAV procedures in area(s) intended in which IFR operation is intended. b) Equipment stores data necessary for stand-alone LNAV/VNAV approaches. c) Waypoints used as FAWP and LTP/FTP are uniquely identified to provide proper approach mode operation.	.	2.2.1.5.1 2.2.1.5.2 2.2.3.5

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.4.5.2 Data Integrity		I T	a) Equipment applies CRC for data validation. b) Invalid CRC check prevents activation of LNAV/VNAV for that approach.	Documentation verifies applicability of CRC to FAS data. Test verifies that an invalid CRC check of FAS data does not result in activation of LNAV/VNAV.	2.2.1.5.1
2.2.4.6.1 Alert Limits		T T or D D D I	a) Prior to FAWP HAL = 0.3 nm and no VAL. b) After sequencing FAWP, alert limits for LNAV/VNAVis managed as specified in this section. c) Equip. does not allow crew the means of changing alert limits. d) The advisory level of service does not change unless a missed approach is initiated or crew changes the desired level of service. e) Equip. uses alert limits associated with the selected level of service for monitoring.	HAL and VAL are managed properly to support LNAV/VNAV operations.	2.2.4.5.1 2.2.4.6.2 2.2.4.6.3 2.2.4.7.4
2.2.4.6.2 Caution Associated with Loss of Integrity Monitoring		T or D	a) Equip. provides a lost of integrity monitoring caution within 30 seconds if HPL_{FD} > HAL. b) Equip. provides a lost of integrity monitoring caution within 2 seconds if HPL_{WAAS} > HAL.		2.2.1.6.1 2.2.4.6.3

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.4.6.3 Caution Associated with Loss of Navigation		D T T T T	a) Class Gamma-2 equipment provides indication that nav. system cannot adequately support LNAV/VNAV approach by means of warning flag or indicator on vertical or lateral navigation display. b) Both flags or indicators displayed within 1 second of the any of the following: Power loss, equipment malfunction or failure, or FD detects position failure that cannot be excluded. c) Both flags or indicators displayed within 1 second when the reference point is between FAWP and LTP/FTP: No valid WAAS message for 4 seconds, insufficient WAAS healthy satellites, or HPL exceeds alert limit. d) Vertical flag or indicator displayed within 0.8 seconds of VPL exceeding alert limit. e) Indication latched until the equipment is no longer in LNAV/VNAV.	Equipment uses warning flag on vertical and/or lateral display to indicate nav system cannot support any approach operation. Test shows that both flags, or indicators, are measured to be displayed within 1 second for all three specified conditions. Test verifies that both flags, or indicators, are measured to be displayed within 1 second for all three specified conditions. Test verifies that the vertical flag, or indicator is displayed within 0.8 seconds of onset of VPL exceeding the alert limit.	2.1.4.2.2.2 2.2.1.6.2 2.2.2.6.2 2.2.3.6.2 2.2.4.6.1
2.2.4.6.4 Low Altitude Alert		D	When in LNAV/VNAV and before sequencing the FAWP, the equipment provides an altitude alert if the estimated position is lower than the desired FAWP height height by more than 50 M + VPL.	Equip. provides the specified low altitude alert function.	
2.2.4.6.5 Alerting Scheme		D	Under normal operations when LNAV/VNAV procedures are entered and LNAV/VNAV is active: 1) Vertical & lateral integrity flags are out of view. 2) Vertical & lateral track deviations are displayed.	Integrity flags are out view during normal operation when LNAV/VNAV procedures is entered and equipment is in LNAV/VNAV. Vertical and lateral track deviations are displayed.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.4.7.1 Entry Criteria		D D D	a) LNAV/VNAV activated only when: Valid long-term, fast, and iono WAAS corrections applied to at least 4 sv's., LNAV/VNAV procedure successfully selected, FAS data passes CRC test, and b) If activation fails: Notify pilot that selection was attempted, Selection did not succeed. c) Equip. provides an indication of the available service.	LNAV/VNAV activates only after all 4 specific conditions are satisfied. It is demonstrated that a failure of each one of these 4 conditions results in failed activation. Upon failure an indication is made to the user that selection was attempted and not successful.	2.2.4.5.2 2.2.4.7.4
2.2.4.7.2 Exit Criteria		D D D	a) If a missed approach is initiated and 1st leg is not a TF leg, equip. automatically switches to terminal mode. b) If a missed approach is initiated and 1st leg is a TF leg, equip. automatically switches to terminal mode at turn initiation point for first WPT in missed approach procedure. c) If Direct-To any WPT is initiated during a LNAV/VNAV approach, equip. automatically switches to terminal mode.	Equip. properly switches to terminal mode.	
2.2.4.7.3 Display Transition		D D D	a) When VTF not selected, FSD does not change until aircraft is 2 nm from FAWP. b) When VTF selected, LNAV/VNAV immediately transitions to angular/linear guidance. c) Sensitivity changes immediately to ±0.3 nm to ±1nm when equip. changes to terminal mode.	Display transitions are performed as specified.	2.2.3.4.2 2.2.4.4.2

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.4.7.4 Advisory of LNAV/VNAV Availability		D, I D	a) Equip. only supporting LNAV/VNAV indicates that GLS or APV-II are not available. b) Compliant with applicable requirements in Section 2.2.5.7.4.		2.2.5.7.4
2.2.5.1 General Human Factors Requirements			a) Equip. is compliant with 2.2.1.1.		2.2.1.1
2.2.5.2 Path Selection			a) Equip. is compliant with 2.2.4.2.		2.2.4.2
2.2.5.2.1 5-Digit Channel Selection			a) Equip. is compliant with 2.2.4.2.1.		2.2.4.2.1
2.2.5.2.2 Approach Name Selection			a) Equip. is compliant with 2.2.4.2.2.		2.2.4.2.2
2.2.5.2.3 Missed Approach Sequencing			a) Equip. is compliant with 2.2.4.2.3.		2.2.4.2.3
2.2.5.2.4 Selection of the Type of Approach with Vertical Guidance		I	Equip. provides a means to select which type of approach with vertical guidance will be conducted.	Equip. allows pilot to select type of approach that will be conducted.	
2.2.5.3.1 Approach Path Definition		I	a) GLS and APV-II approaches only available for procedures defined by a FAS data block. See section 2.2.4.3.1.	Inspection of documentation.	2.2.4.3.1 Appendix D
2.2.5.3.2 Missed Approach Path Definition			a) Equip. is compliant with 2.2.3.3.2.		2.2.3.3.2

Requirement Paragraph	**Test Para.**	**Test Method**	**General Requirements**	**Pass/Fail Criteria**	**Related Rqts.**
2.2.5.3.3 Navigation Center Offset			a) Equip. is compliant with 2.2.4.3.3.		2.2.4.3.3
2.2.5.4.1 Primary Nav. Displays		D	a) Nonnumeric vertical deviation continuously displayed in GLS and APV-II.	Nonnumeric vertical deviation during GLS and APV-II.is continuously displayed.	2.2.1.4.1
2.2.5.4.2 Non-Numeric Lateral Cross-Track Deviation		D D D D	a) Positive lateral deviations correspond to aircraft psotions to left of lateral deviation reference pland, as observed from the LTP/FTP facing toward the FPAP. b) If VTF not selected: the deviation is either: 1) linear with FSD ± 1 nm prior to 2 nm from the FAWP and FSD gradually changes to final approach FSD during the transition from 2 nm from the FAWP and arrival at the FAWP;, or 2) is the final approch segment leteral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$. Between FAWP and the LTP/FTP, the deviation is the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$. Between the LTP/FTP and the length offset distance to the FPAP, the deviation is either the fianl approach segment lateral deviation or linear with FSD for a cross-track error of ±(Course Width at LTP/FTP).	FSD is managed properly during GLS and APV-II.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
			c) If VTF selected, the deviation is either: (1) linear with FSD ± 1 nm prior $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP and FSD gradually changes to final approach FSD during the transition from $\frac{1}{\tan(\alpha_{lat,FS})}$ nm from the GARP and arrival at the LTP/FTP, or (2) FSD is the final approch segment leteral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$. Between the LTP/FTP and the length offset distance to the FPAP, the deviation is either the fianl approadh segment lateral deviation or linear with FSD for a cross-track error of ±(Course Width at LTP/FTP). Beyond the length offset distance to the FPAP, the deviation is linear with FSD for cross=track displacement of ±0.3 nm. d) FSD transitions to ±0.3 nm when missed approach is activated.		
2.2.5.4.3 Numeric Cross-Track Deviation			a) Equip. is compliant with 2.2.3.4.3.		2.2.3.4.3

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.5.4.4 Non-Numeric Vertical Deviation		D D D D D D D	a) In GLS or APV-II, continuously provide guidance. b) At a distance greater than $\frac{15m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation are linear with FSD for a vertical error of 150 m; c) Between $\frac{150m}{\tan(\alpha_{vert,FS})}$ and $\frac{15m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation are the final approach segment vertical deviation. d) Closer than $\frac{15m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation are linear with FSD for a vertical error of ± 15 m. e) Vertical deviations flagged as invalid if: (1) The lateral position of the aircraft is outside of a ± 35 degree wedge with origin at the GARP, centered on the FAS; and (2) The aircraft is not on the approach side of the GPIP. f) Vertical guidance is flagged when missed approach is initiated.	Guidance is continuously provided in GLS or APV-II. Demonstrate that FSD is minimum of ± 500 ft or angular measure. FSD is demonstrated to be ± 50ft constant at the runway. Documentation describes glidepath angle shape. Vertical guidance is demonstrated to activate under specified conditions.	2.2.1.4.2 2.2.4.4.4
2.2.5.4.5 Missed Approach Waypont/ LTP/ FTP Distance Display			a) Equip. is compliant with 2.2.4.4.5.		2.2.4.4.5

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.5.4.6 Missed Approach Waypont/ LTP/ FTP Bearing Display			a) Equip. is compliant with 2.2.4.4.6.		2.2.4.4.6
2.2.5.4.7 Update Rate			a) Display update rate of at least 5 Hz. b) Each deviation is dynamically independent.	Data is dynamically independent and presented on the display updated at <u>least 5 Hz</u> in GLS or APV-II.	2.1.4.8.1
2.2.5.4.8 Displayed Update Latency		T	Latency of electrical output does not exceed 400 msec.	The latency of data displayed is measured to not exceed 400 msec.	2.3.2
2.2.5.4.9 Display of Vertical Accuracy			a) Equip. is compliant with 2.2.4.4.9.		2.2.4.4.9
2.2.5.5.1 Content		I & D D D	a) Equipment stores GLS and APV-II procedures in area(s) intended in which IFR operation is intended. b) Equipment stores VAL for each GLS and APV-II approach. c) Waypoints used as FAWP and LTP/FTP are uniquely identified to provide proper approach mode operation.	.	2.2.1.5.1 2.2.1.5.2 2.2.3.5 2.2.4.5.1
2.2.5.5.2 Data Integrity		I T	a) Equipment applies CRC for data validation b) Invalid CRC check prevents activation of GLS and APV-II for that approach.	Documentation verifies applicability of CRC to FAS data. Test verifies that an invalid CRC check of FAS data does not result in activation of GLS and APV-II.	2.2.1.5.1 2.2.4.5.2

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.5.6.1 Alert Limits		T T or D D D I	a) Prior to FAWP HAL = 0.3 nm and no VAL. b) After sequencing FAWP, alert limits for LNAV/VNAV, APV-II, and GLS are managed as specified in this section. c) Equip. does not allow crew the means of changing alert limits. d) The advisory level of service does not change unless a missed approach is initiated or crew changes the desired level of service. f) Equip. uses alert limits associated with the selected level of service for monitoring.	HAL and VAL are managed properly to support APV-II, and GLS operations.	2.2.4.5.1 2.2.5.5.1 2.2.5.7.4
2.2.5.6.2 Caution Associated with Loss of Integrity Monitoring			a) The GPS/WAAS equipment provides a loss of integrity monitoring caution (see Section 2.2.1.6.1) within 30 seconds if the current HPL_{FD} exceeds the HAL. b) The equip. provides a loss of integrity moni-toirng caution within 2 seconds if the current HPLWAAS exceeds HAL.		2.2.1.6.1

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.5.6.3 Caution Associated with Loss of Navigation		D T T T T	a) Class Gamma-3 equipment provides indication that nav. system cannot adequately support GLS or APV-II approach by means of warning flag or indicator on vertical or lateral navigation display. b) Both flags or indicators displayed within 1 second of the any of the following: Power loss, equipment malfunction or failure, or FD detects position failure that cannot be excluded. c) Both flags or indicators displayed within 1 second when the reference point is between FAWP and LTP/FTP: No valid WAAS message for 4 seconds, insufficient WAAS healthy satellites, or HPL exceeds alert limit. d) Vertical flag or indicator displayed within 0.8 seconds of VPL exceeding alert limit. e) Indication latched until the equipment is no longer in the GLS or APV-II .	Equipment uses warning flag on vertical and/or lateral display to indicated nav system cannot support any approach operation. Test shows that both flags, or indicators, are measured to be displayed within 1 second for all three specified conditions. Test verifies that both flags, or indicators, are measured to be displayed within 1 second for all three specified conditions. Test verifies that the vertical flag, or indicator is displayed within 0.8 seconds of onset of VPL exceeding the alert limit.	2.1.4.2.2.2 2.2.1.6.3 2.2.2.6.3 2.2.3.6.3 2.2.4.6.3
2.2.5.6.4 Low Altitude Alert		D	When in GLS or APV-II and before sequencing the FAWP, the equipment provides an altitude alert if the estimated position is lower than the desired FAWP height by more than 20 m + VPL (APV-II), or the applicable VAL for GLS.	Equip. provides the specified low altitude alert function.	
2.2.5.6.5 Alerting Scheme		D	Under normal operations when GLS or APV-II procedures are entered and GLS or APV-II is active: 1) Vertical & lateral integrity flags are out of view. 2) Vertical & lateral track deviations are displayed.	Integrity flags are out view during normal operation when GLS or APV-II procedures is entered and equipment is in GLS or APV-II. Vertical and lateral track deviations are displayed.	

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.5.7.1 Entry Criteria		D D D	a) GLS or APV-II activated only when: Valid long-term, fast, and iono WAAS corrections applied to at least 4 sv's., GLS or APV-II procedure successfully selected, FAS data passes CRC test, and b) If activation fails: Notify pilot that selection was attempted, Selection did not succeed. c) Equip. provides an indication of the available service.	GLS or APV-II activates only after all 4 specific conditions are satisfied. It is demonstrated that a failure of each one of these 4 conditions results in failed activation. Upon failure an indication is made to the user that selection was attempted and not successful.	2.2.5.5.2 2.2.5.7.4
2.2.5.7.2 Exit Criteria		D D D	a) If a missed approach is initiated and 1^{st} leg is not a TF leg, equip. automatically switches to terminal mode. b) If a missed approach is initiated and 1^{st} leg is a TF leg, equip. automatically switches to terminal mode at turn initiation point for first WPT in missed approach procedure. c) If the pilot initiates Direct-To any waypoint while in GLS or APV-II, the equipment automatically switches to terminal mode.	Equip. properly switches to terminal mode.	
2.2.5.7.3 Display Transition		D D D	a) When VTF not selected, FSD does not change until aircraft is 2 nm from FAWP. b) When VTF selected, GLS or APV-II immediately transitions to angular/linear guidance. c) Sensitivity changes immediately to ±0.3 nm to ±1nm when equip. changes to terminal mode.	Display transitions are performed as specified.	2.2.3.4.2 2.2.4.4.2

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.2.5.7.4 Advisory of GLS or APV-II Availability		D, I D D D, I D D D	a) Equip. indicates if alert limit requirements are met for the manually selected approach. b) Indication that alert limit requirements are met are displayed continuously. c) For automatically selected approaches, the equip. displays the level of service available with entering approach mode. d) The level of service is most accurate level for which both vert. and horz. alert limits are below those required for the published procedure. e) If the most accurate level of service for which a minimum is published is available, the equipment indicates that it is available. f) If the most accurate level of service for which a minimum is published is not available, the equipment indicates that it is not available. g) In the case of (f) above, the equipment indicates the level of service that is available.	Inspection of Documentation verifies appropriate calculations used for VPL_{WAAS} and HPL_{WAAS}. Demonstrate that VPL_{WAAS} and HPL_{WAAS} are predicted for the LTP/FTP for both: 30nm within LTP/FTP and GLS or APV-II selection. Inspection of documentation verifies formulas used for the four types of service levels. Specific situation when VPL and HPL correspond to different service levels, least capable service is used. The equipment indicates the level of service that is available and displays the appropriate message to the user.	
2.3 Class Delta-4 Requirements for Precision Approach Operations			a) Equip. is compliant with 2.2.1 and 2.1.4, except for specific cases described in section 2.3.		2.1.1 2.1.4
2.3.1 General Human Factors Requirements			Equipment is compliant with 2.2.1.1		2.2.1.1
2.3.3 Path Definition		I	a) Equip. output deviations relative to the FAS.		2.2.4.3 Appendix D

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.3.4.1 Non-Numeric Cross-Track Deviation		D D	a) Equip. output is compliant with 2.2.1.4.2. b) FSD is minimum of FSD of ±1 nm or the final approach segment.		2.2.1.4.2 2.2.4.4.2
2.3.4.2 Non-Numeric Vertical Deviation		D D	a) Equip. output is compliant with 2.2.1.4.2. b) Equip. is compliant with 2.2.5.4.4.		2.2.1.4.2 2.2.4.4.4
2.3.4.3 Landing Threshold Point/Fictitious Threshold Point Distance Display		D D	a) Output or display distance to LTP/FTP prior to crossing LTP/FTP. b) Distance output or displayed with range of up to 99.9 nm with a resolution of 0.1 nm.		

Requirement Paragraph	Test Para.	Test Method	General Requirements	Pass/Fail Criteria	Related Rqts.
2.3.4.4 Displayed Data Update Rate			a) Equip. is compliant with 2.2.5.4.7.		2.2.4.4.7
2.3.4.5 Displayed Data Update Latency		D	a) Overall latency not to exceed 400 msec.		2.1.3.5
2.3.5 Database Requirements		D D	a) Equip. to verify CRC b) Equip. indicates loss of navigation if CRC cannot be verified. c) HAL and VAL for GLS approches are transferred to equip.		
2.3.6 Alerts		D D	a) Equip. is compliant with 2.2.4.6 applicable to GLS Equip. accommodates horizontal and vertical alert limits. If equipment provides LNAV/VNAV and APV-II, it must also meet requirements of Sections 2.2.4.7.4 and 2.2.5.7.4.		2.2.4.6

2.5.2 WAAS Message Loss Rate Test

2.5.2.1 Evaluation of Message Loss Rate During the Measurement Accuracy Test

2.5.2.2 Test Procedure

The data to verify the WAAS message loss rate in the presence of interference shall be collected in conjunction with the Measurement Accuracy tests using the test cases where the WAAS satellite is at minimum power level. During this test, the total number of messages that are lost (CRC does not check) shall be recorded and used as the test statistic. The test statistic may be collected over messages received from more than one WAAS satellite and from more than one test scenario.

A minimum of 22,500 messages shall be collected and processed.

2.5.2.3 Pass/Fail Determination

The total number of WAAS messages lost shall be less than or equal to 34 messages.

Note: *Using this criterion, 99% of the equipment designed to meet a 10^{-3} message loss rate will pass this test. Similarly, less than 5% of the equipment designed to a message loss rate of 2.0 x 10^{-3} will pass this test. When more than the minimum number of messages are collected, the maximum number of messages lost can be increased as long as the 5% probability of passing equipment with a message loss rate of 2.0 x 10^{-3} is not exceeded.*

2.5.2.4 Evaluation of Message Loss Rate During the 24-Hour System Accuracy Test

2.5.2.4.1 Test Procedure

The data to verify the WAAS message loss rate using the signal from a live WAAS satellite shall also be collected in conjunction with the 24-Hour System Accuracy Test. During this test, the total number of messages that are lost (CRC does not check) shall be recorded and used as the test statistic. The test statistic may be collected over messages received from more than one WAAS satellite.

86,400 messages shall be collected and processed if one WAAS satellite is in view, or 172,800 messages shall be evaluated if two WAAS satellites are in view.

2.5.2.4.2 Pass/Fail Criteria

The total number of WAAS messages lost shall be less than or equal to total of 133 or 251 messages if tracking one or two WAAS satellites, respectively.

Note: *Using this criterion, 99% of the equipment designed to meet a 1.25 x 10^{-3} message loss rate will pass this test. Similarly, only 5% of the equipment designed to a message loss rate of 2 x 10^{-3} will pass this test. The thresholds for this test were inflated to 1.25 x 10^{-3} to allow margin for a static, ground-based test. For a 10^{-3} message loss rate, these thresholds would be 109 and 204, respectively.*

2.5.3 Step Detector Test

The step detector is tested under four scenarios. If the manufacturer can show by inspection that its equipment's step detection mechanism is insensitive to the type of step (a change in navigation data or a sudden change in code phase), only one type of step need be tested. Typical satellite signal power may be used during these tests. Selective Availability shall be simulated.

2.5.3.1 Verification of Step Detector Operation Without Exclusion Capability

For all classes of equipment, simulate a satellite scenario as follows:

a. Only five satellites in view and used in the positioning solution.

After the equipment reaches steady-state operation (i.e., navigates with integrity using all of the applied satellite signals), simulate a 750 meter step error on the hardest-to-detect satellite being used in the position solution by changing the navigation message. Repeat the test with a step change in code phase to simulate the 750 meter step error.

In order to pass, the equipment must do the following:

b. The satellite with the step error should be removed from the positioning solution within 10 seconds of introducing the pseudorange step; and

c. The positioning error is not to exceed 200 meters throughout the entire test;

d. The HPL will be unavailable and the loss of integrity monitoring will be indicated.

Note: *When a step is introduced by changing the broadcast ephemeris data, the pseudorange step does not occur until after receipt of a second set of the broadcast ephemeris (per Section 2.1.1.2).*

2.5.3.2 Verification of No Interference with Fault Detection Algorithm

For Class 2, 3 and 4 equipment, simulate a satellite scenario as follows:

a. Only five satellites in view and used in the positioning solution;

b. HPL less than 0.3 nm

After the equipment reaches steady-state operation, simulate a ramp error in the hardest-to-detect satellite being used in the position solution (10 meters/second).

In order to pass, the equipment must do the following:

c. At no time is there to be an exclusion of any satellite;

d. The FD algorithm shall indicate a positioning failure within the time-to-alert after the onset of the positioning failure;

For Class 1 equipment, the same test shall be conducted with an HPL less than 1 nm.

2.5.3.3 Verification of Step Detector Operation with Exclusion Capability

For Class 2, 3 and 4 equipment, simulate a satellite scenario as follows:

a. Six or more satellites in view and used in the positioning solution;

b. Detection and exclusion capability are available for an alert limit of 0.3 nm.

After the equipment reaches steady-state operation (i.e., navigates with integrity using all of the applied satellite signals), simulate a 750 meter step error on the hardest-to-detect satellite being used in the position solution by changing the navigation message. Repeat the test with a step change in code phase to simulate the 750 meter step error.

In order to pass, the equipment must do the following:

c. The satellite with the step error shall be removed from the position solution within 10 seconds of introducing the step error;

d. The positioning error is not to exceed 200 meters throughout the entire test, before and after the introduction of the step error; and

e. HPL will change.

For Class 1 equipment, the same test shall be conducted with detection and exclusion capability available for an alert limit of 1 nm and a pseudorange step of 3000 m.

Note: *When a step is introduced by changing the broadcast ephemeris data, the pseudorange step does not occur until after receipt of a second set of the broadcast ephemeris (per Section 2.1.1.2).*

2.5.3.4 Verification of No Interference with Exclusion of the FDE Algorithm

For Class 2, 3, and 4, simulate a satellite scenario as follows:

a. Six or more satellites in view and used in the positioning solution;

b. Detection and exclusion capability are available for an alert limit of 0.3 nm.

After the equipment reaches steady-state operation, simulate a ramp error in the hardest-to-detect satellite being used in the position solution (10 meters/second).

In order to pass, the equipment must do the following:

c. The exclusion function should operate normally, eliminating the error as a positioning failure develops.

For Class 1 equipment, the same test shall be conducted with detection and exclusion capability available for an alert limit of 1 nm.

2.5.4 Initial Acquisition Test Procedures

2.5.4.1 Simulator and Interference Conditions

The tests to verify initial acquisition performance shall be run for each of the GPS/WAAS signal generator (simulator) scenarios described below:

Scenario #1: Initial Acquisition Time Test (GPS Only)

- Exactly 5 GPS satellites.
- One satellite at maximum power (including maximum antenna gain), one satellite at minimum power (including minimum antenna gain), and other satellites 3 dB above minimum signal and representative antenna gain.
- Selective Availability disabled.
- Platform dynamics: Constant velocity of 800 kt beginning at 5,000 ft (MSL) and performing a 3° climb.

Scenario #2: Initial Acquisition Time Test (GPS & WAAS)

- Exactly 4 GPS satellites and 1 WAAS satellite.
- One satellite at maximum power (including maximum antenna gain), one WAAS satellite at minimum power (including minimum antenna gain), and other satellites 3 dB above minimum signal and representative antenna gain.
- Selective Availability disabled.
- Platform dynamics: Constant velocity of 800 kt beginning at 5,000 ft (MSL) and performing a 3° climb.

The interference conditions to be tested are shown in Table 2-20. These are all broadband noise values centered at 1575.42 MHz. In all cases, the interference is to be applied to the receiver before it is powered on or the simulator is engaged.

TABLE 2-20 INITIAL ACQUISITION TIME TEST INTERFERENCE CONDITIONS

Noise Bandwidth	Total Power (dBm)
100 kHz	-116.5
20 MHz	-103.5

Combining Simulator Scenarios 1 and 2 with Table 2-20 show that the entire initial acquisition test consists of a total of four (4) situations to be tested: Simulator Scenario 1 with the two interference conditions listed in Table 2-20 and Simulator Scenario 2 again with the same two noise conditions.

2.5.4.2 Test Procedures

1. The interference to be applied, as specified in Table 2-20, shall be turned on and connected to the sensor.
2. The simulator scenario shall be engaged and the satellites RF shall be turned on.

3. The airborne equipment shall be powered and initialized to a position with total radial error equal to 60 nautical miles, and one minute (60 seconds) of error in time with respect to the starting position and time reference in the simulator. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting these tests.
4. The time to first valid position fix (TTFF), defined as the time from when the equipment is powered on until the first valid position (with integrity, i.e., HPL is available) is output, shall be observed. For simulator scenario 1 (5 GPS satellites), integrity shall be provided by the sensors FDE algorithm. For simulator scenario 2 (4 GPS satellites and 1 WAAS satellite), integrity shall be provided by WAAS. Along with the TTFF, at least the next 60 seconds of continuous position fixes (a minimum of 60 data points) after the initial fix shall also be recorded in order to verify the accuracy requirement.
5. Precise ephemeris shall be purged or rendered invalid at the end of each acquisition attempt.
6. Go to Step 2 and repeat as required.

2.5.4.3 Pass/Fail Determination

The accuracy statistic, which will be compared with the 15 m (95%) horizontal accuracy requirement stated in section 2.1.2.1 shall be computed using the 2drms formula shown below.

$$2drms = 2\sqrt{\frac{\sum_{i=1}^{N}\left(\frac{1.5(d_i)}{HDOP_i}\right)^2}{N}}$$

where:

2drms	=	Twice the distance, root-mean-square
d_i	=	Instantaneous 2-D horizontal position error (meters)
N	=	Number of points considered
HDOP	=	Instantaneous Horizontal Dilution of Precision

The use of the 2drms formula provides a conservative estimate of the 95% error and effectively weights large position errors which may be caused by unwanted interference. A failure by the sensor to produce a position output after 5 minutes indicates a failure mode, and results in declaring the test a failure.

Scaling the instantaneous 2-dimensional position error (d_i) by 1.5/$HDOP_i$ provides a means of normalizing the tests to a constant HDOP = 1.5 and accounts for fluctuations in the satellite coverage due to changing geometries. $HDOP_i$ may be obtained from the receiver under test or calculated separately. Only those satellites used in the position solution shall be included in the $HDOP_i$ calculation. The manufacturer shall demonstrate the validity of the values chosen for $HDOP_i$.

To determine the initial acquisition pass/fail criteria, consider a single trial where the sensor under test provides a valid position fix within the required time (5 minutes) and maintains the required accuracy (15 m, 95%) for at least the next 60 seconds. This sensor is considered to have passed one (1) trial. Table 2-21 shows the total test disposition and represents a quit-while-ahead testing approach designed to keep testing times at a reasonable length.

TABLE 2-21 GRADUATED SAMPLING PASS/FAIL CRITERIA

Trials	Cumulative Failures within Specified Time	Test Disposition
First Ten (10)Trials	Zero (0) One (1) Two (2) or More	Pass Run Ten (10) More Fail
Second Ten (10) Trials	Zero (0) One (1) or Two (2) Three (3) or More	Pass Run Ten (10) More Fail
Third Ten (10) Trials	Zero (0) One (1) or More	Pass Fail

For example, if no failures occur in the first ten trials, success for that simulator and interference case would be declared and the current test terminated. A single failure in the first set of ten trials necessitates running the next set of ten trials. Two or more failures during the first ten trials indicates that the sensor has failed that particular test, and so on. Justification for the above-stated criteria is shown in Appendix M.

2.5.5 Reserved

2.5.6 Satellite Reacquisition Time Test

2.5.6.1 Simulator and Interference Conditions

The tests to verify reacquisition performance shall be run for each of the GPS/WAAS signal generator (simulator) scenarios described below:

Scenario #1: Steady-State Reacquisition Time Test (GPS Only)

- Selective Availability disabled.
- Platform dynamics: Constant velocity of 800 kt beginning at 5,000 ft (MSL) and performing a 3° climb.
- Any number of GPS satellites until the sensor reaches steady state navigation.
- Then, exactly 4 GPS satellites, preparing to reacquire the lost GPS satellite, which is just above the mask angle at minimum signal power (ref. 2.5 c. (2)) and whose RF state (on or off) shall be controlled by the simulator. One satellite is minimum power + 18.5 dB and the others at a power representative of their elevation.
- Finally, the signal from the fifth GPS satellite to be acquired shall be provided.

Scenario #2: Steady-State Reacquisition Time Test (GPS & WAAS)

- Selective Availability disabled.
- Platform dynamics: Constant velocity of 800 kt beginning at 5,000 ft (MSL) and performing a 3° climb.
- Any number of GPS satellites and one WAAS satellite until the sensor reaches steady state navigation.
- Then, exactly 4 GPS and no WAAS satellite, preparing to reacquire the lost WAAS satellite which is just above the mask angle at the minimum signal power (ref. 2.5 c. (2)) and whose RF state (on or off) shall be controlled by the simulator. One GPS sat-

ellite is minimum power + 18.5 dB and the others at a power representative of their elevation.

- Finally, the signal from the WAAS satellite to be acquired shall be provided.

The interference conditions to be tested are shown in Table 2-22. These are all broadband noise values whose center is at 1575.42 MHz. In all cases, the interference is to be applied to the receiver before the simulator is engaged.

The power levels indicated in Table 2-22 are for the steady-state portion of the test and correspond to precision approach equipment. The interference power shall be 6 dB lower than those listed until sensor reaches steady state navigation. If the equipment is intended for installations without SATCOM, power levels for enroute/terminal area equipment and non-precision approach equipment steady-state operations shall be 6 and 3 dB lower than those listed in the table, respectively.

TABLE 2-22 REACQUISITION TEST INTERFERENCE CONDITIONS

Noise Bandwidth	Total Power (dBm)
100 kHz	-110.5
20 MHz	-97.5

Combining Simulator Scenarios 1 and 2 with Table 2-22 show that the entire reacquisition test consists of a total of four (4) situations to be tested: Simulator Scenario 1 with the two interference conditions listed in Table 2-22 and Simulator Scenario 2 again with the same two interference conditions.

2.5.6.2 Test Procedures

1. The interference to be applied shall be turned on and connected to the sensor. The power shall be set to the appropriate initial acquisition level shown in Table 2-22.
2. The simulator scenario shall be engaged and the satellites RF shall be turned on.
3. The airborne equipment shall be powered. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting these tests.
4. The sensor shall be allowed to reach steady state accuracy before the satellite to be reacquired is cycled off and on. Once in steady state navigation, the interference power shall be increased to the appropriate steady state level.
5. The satellite whose reacquisition is being tested shall be removed from the sensor, at least until the sensor has lost lock on the satellite and removed the satellite from the position solution, and then reapplied to the sensor within 30 seconds.
6. The reacquisition time, or time to satellite inclusion, defined as the time from when the satellite under test is reapplied to the sensor until the first valid position which includes that satellite is output, shall be observed. In addition, at least the next 60 seconds of position fixes (sampled at the minimum of once per second) after the inclusion of the reacquired satellite, shall also be recorded in order to verify the 15 m (95%) requirement. Note that for Simulator Scenario 1, the satellite to be reacquired shall be a GPS satellite, and for Scenario 2, the reacquired satellite shall be a WAAS Satellite.
7. Reset the scenario and go to Step 2 and repeat as required.

2.5.6.3 Pass/Fail Determination

The accuracy statistic shall be computed using the 2drms formula as shown in Section 2.5.4.3.

To determine the reacquisition time pass/fail criteria, the graduated sampling pass/fail criteria of Table 2-21 shall be used. A single trial success occurs when the sensor under test includes the reacquired satellite into the position solution within the required time (10 seconds) and maintains the required accuracy, 15 m (95%), for the following 60 seconds.

The statistical justification for the reacquisition time test follows that for initial acquisition and can be found in Appendix M.

2.5.7 Interference Rejection Test

2.5.7.1 Simulator and Interference Conditions

These tests are intended to verify the performance of the sensor in the presence of in-band continuous-wave interference conditions at and above the levels of Appendix C. Tests shall be run for each of the GPS/WAAS signal generator (simulator) scenarios described below:

The simulation and interference conditions shall conform to the following two requirements:

1. Simulated GPS RF for PRN 6 shall be at the minimum power level for the equipment (as described in Section 2.1.1.10). Other satellites shall be at a high power level to minimize the effect of interference on their pseudorange.
2. The CWI frequency tested shall be 20 Hz ±5 Hz offset below the 3rd spectral line below the received carrier frequency of PRN 6 (i.e., 3020 Hz offset from the carrier frequency). The initial power shall be -120.5 dBm (may be reduced during initial acquisition). The I/S ratio will be varied according to the test procedures. The exact frequency relationship must be maintained throughout the test. The scenario shall include PRN 6 because it is used in the definition of the CWI frequency.

Note: *This evaluation method is based on the assumption that a least-squares position algorithm is implemented, and that the baseline integrity algorithms are used. If a different form of positioning or integrity method is used, this evaluation method may not be appropriate.*

2.5.7.2 Test Procedures

1. The interference to be applied shall be turned on and connected to the sensor. Note that the power of the interference during initial acquisition is lower than that for steady-state operation.
2. The simulator scenario shall be engaged and the satellites RF shall be turned on.
3. The airborne equipment shall be powered and initialized. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting these tests.
4. The sensor shall be allowed to reach steady state. When the sensor has reached steady state, the power of the interference shall be adjusted to -120.5 dBm.
5. The interference power shall be maintained until the accuracy has reached steady-state. Pseudorange measurements and pseudorange validity indications (e.g., isolation bit) for all satellites shall be recorded during this interval.
6. The power of the interfering signal shall be increased by 1 dB and maintained for 200 seconds.
7. Go to Step 5 and repeat until PRN 6 has been excluded from the navigation solution. Increase the interfering signal another 3 dB and verify that PRN 6 is still excluded.

2.5.7.3 Pass/Fail Determination

For each sample when the PRN 6 pseudorange is declared valid, the following error criterion shall be evaluated:

$$Z_j \leq 5.33\left[\frac{N_j - 1}{N_j}\right]\sigma_{noise,PRN\,6,j}$$

where:

$$Z_j \equiv PR_{PRN\,6,j} - R_{PRN\,6,j} - (c\Delta t)_j$$

$$(c\Delta t)_j \equiv \frac{1}{N_j}\sum_{i=1}^{N_j}\left(PR_{ij} - R_{ij}\right)$$

PR_{ij} = smoothed pseudo-range, channel i, time j

R_{ij} = true range, satellite i, time j (includes extrapolation)

N_j = number of satellites at time j

$\sigma_{noise,ij}$ = receiver output or equivalent, satellite i, time j (refer to Appendix J.2.4)

If the error criterion is exceeded for more than the appropriate time to alert, the test fails.

2.5.8 Accuracy Tests

2.5.8.1 Measurement Accuracy Test

The purpose of the Accuracy Test is to validate that the equipment meets the accuracy requirements of Section 2.1.2.1, 2.1.3.1, and 2.1.4.1.3 under the specified interference conditions. It is also intended to verify that the σ_{noise} and σ_{divg} used in the protection level equations are appropriate bounds on the residual errors allocated to the receiver tracking performance. Data may be collected concurrently during these tests to validate the WAAS Message Loss Rate requirements in Section 2.1.1.3.2.

Note: *This evaluation method is based on the assumption that a least-squares position algorithm (per Section 2.1.4.1.4) is implemented. If a different form of positioning is used, this evaluation method may not be appropriate.*

2.5.8.2 Simulator and Interference Conditions

The simulation and interference conditions shall conform to the following requirements:

1. Interference conditions including broadband noise centered at 1575.42 MHz (Table 2-23), Continuous Wave Interference (CWI – Table 2-24), and pulsed interference (Table 2-25) shall be simulated. For the pulsed interference tests, a pulse modulated carrier with a signal bandwidth of at least 100 kHz, with peak carrier level of +20 dBm and duty cycle of 10% shall be used. This corresponds to an I/S ratio of +154.5 dB for GPS satellites. The broadband noise power levels indicated in the table are for precision approach equipment or Class 1 equipment with SATCOM. If the equipment is intended for installations without SATCOM, power levels for Class 1 (enroute/terminal/non-precision approach) equipment steady-state operations shall be 3 dB lower than those listed in the table.

Note 1: *The indicated power levels are for the steady-state portion of the tests. The interference power during the initial phase of each test may be reduced by 6 dB to facilitate initial acquisition.*

2. Simulated GPS RF shall be at the minimum power level for the equipment, except for the two broad-band interference cases which shall be tested at the maximum power level as well as the minimum power level. For test cases that require the minimum power level, one satellite shall be set to the maximum power level (including maximum transmit power and maximum antenna gain) to include the effects of C/A self-interference. For these cases the pseudorange samples of the satellite at maximum power are not used in the evaluation. Power levels may be increased if necessary to account for differences between the simulator noise temperature and the background thermal noise density (100°K). The scenario shall include PRN 6 because it is used in the definition of the CWI frequency.

3. Equipment capable of WAAS ranging shall comply with the following: for all conditions except the GPS-only scenario STEADY-STATE ACCURACY TEST PULSED INTERFERENCE VALUES, during the portion of the test where accuracy is evaluated at least two WAAS satellites shall be used. For the evaluation of GPS-only scenario conditions of STEADY-STATE ACCURACY TEST PULSED INTERFERENCE VALUES, during the portion of the test where accuracy is evaluated no WAAS satellites shall be simulated.

Note 2: *For equipment using only GPS ranging sources, the steady-state accuracy test will include a total of eleven cases (twelve when installed on aircraft with SATCOM), including minimum GPS RF power level with the nine interference conditions listed in STEADY-STATE ACCURACY TEST BROADBAND INTERFERENCE VALUES, STEADY STATE ACCURACY TEST CWI VALUES, and STEADY-STATE ACCURACY TEST PULSED INTERFERENCE VALUES (ten when installed on aircraft with SATCOM) and maximum GPS RF power level with the two broadband interference conditions listed in STEADY-STATE ACCURACY TEST BROADBAND INTERFERENCE VALUES*

Note 3: *For equipment capable of using GPS and WAAS ranging sources, the entire steady-state accuracy test will include a total of twelve cases to be tested (thirteen for equipment installed on aircraft with SATCOM): a GPS-only case with minimum GPS RF power and pulsed-interference conditions of STEADY-STATE ACCURACY TEST PULSED INTERFERENCE VALUES, nine GPS/WAAS cases (ten for equipment installed on aircraft with SATCOM) with minimum RF power and with the interference conditions listed in STEADY-STATE ACCURACY TEST BROADBAND INTERFERENCE VALUES, STEADY STATE ACCURACY TEST CWI VALUES, and STEADY-STATE ACCURACY TEST PULSED INTERFERENCE VALUES, and two GPS/WAAS cases with maximum RF power and with the broadband interference conditions listed in STEADY-STATE ACCURACY TEST BROADBAND INTERFERENCE VALUES*

4. The total duration of each test case test shall be based upon sampling intervals required to obtain samples that are statistically independent. Independent samples collected during the initial acquisition and before steady-state operation are used for the validation of σ_{noise} overbounding. The samples collected prior to steady-state operation should not be used for the steady-state RMS accuracy evaluation and the steady-state evaluation of $\left(\sigma_{noise}^2[i]+\sigma_{divg}^2[i]\right)^{1/2}$. It may be advantageous to extend the duration of this test so the data can be used to support evaluation of WAAS Message Loss Rate.

TABLE 2-23 **STEADY-STATE ACCURACY TEST BROADBAND INTERFERENCE VALUES**

Noise Bandwidth	Total Power (dBm)
100 kHz	-110.5
20 MHz	-97.5

TABLE 2-24 **STEADY STATE ACCURACY TEST CWI VALUES**

Frequency (MHz)	Power (dBm)	I/S (dB)
1525.0	-12.0	122.5
1555.42	-89.5	45.0
1575.42*	-120.5	14.0
1595.42	-89.5	45.0
1610.0	-30.0	104.5
1618.0	-12.0	122.5
1626.0**	+8.0	142.5

* The CWI frequency tested shall be 20 Hz ± 5 Hz offset below the 3rd spectral line below the carrier frequency of PRN 6 (i.e., 3020 Hz offset from the carrier frequency). The CWI must be synchronized to the satellite signal provided. The exact frequency relationship must be maintained throughout the test.

** Only Required for Aircraft with SATCOM

Note: *Care should be taken when applying non-L1 CW frequencies so that the L1 CW and broadband specifications are not exceeded.*

TABLE 2-25 **STEADY-STATE ACCURACY TEST PULSED INTERFERENCE VALUES**

Frequency (MHz)	GPS Only Scenario Pulse-Width (msec)	GPS& WAAS Scenario Pulse-Width (μsec)
1575.42	1	125.0

2.5.8.2.1 **Test Procedures**

1. The test unit is connected to the RF signal and interference source.
2. The simulator scenario shall be engaged and the satellites RF shall be turned on.
3. The equipment under test shall be powered and initialized. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting these tests.
4. When the unit is navigating, the interference to be applied shall be applied to the equipment under test, and the power of the interference shall be adjusted to the required level. Sampling should begin for each satellite immediately after it is included in the navigation solution for the σ_{noise} overbounding evaluation described in paragraph 7) below.
5. When steady-state accuracy is reached, data are recorded as follows:
   a. Initially, 50 independent samples of pseudorange data are recorded at the required sampling interval (see note below).

Note 1: *The sampling interval will be two times the integration interval used for carrier phase smoothing of pseudoranges. For example, if the integration interval used for carrier smoothing of the pseudoranges is 100 second, the sampling interval* *will be 200 seconds. If ten pseudoranges are collected per sampling interval (nine independent measurements), the duration of the initial data collection period will be 20 minutes.*

6. The normalized RMS range error statistic, RMS_PR, is computed according to the following formula, using all collected samples (including those prior to steady-state operation):

$$\mathrm{RMS\_PR}(M) \equiv \sqrt{\frac{\sum_{j=1}^{M}\left\{\sum_{i=1}^{N_j}\left[\frac{Z_{ij}^2}{\sigma_{norm,ij}^2 N_j}\right]\right\}}{M}}$$

where:

$$Z_{ij} \equiv PR_{ij} - R_{ij} - (c\Delta t)_j$$

$$(c\Delta t)_j \equiv \frac{1}{N_j}\sum_{i=1}^{N_j}\left(PR_{ij} - R_{ij}\right)$$

$$\sigma_{norm,ij}^2 = \frac{\left[\left(N_j - 1\right)^2 \sigma_{noise,ij}^2 + \sum_{\substack{k=1 \\ k\neq i}}^{N_j} \sigma_{noise,kj}^2\right]}{N_j^2}$$

where:

PR_{ij} = smoothed pseudo-range, channel i, time j

R_{ij} = true range, satellite i, time j (includes extrapolation)

N_j = number of satellites at time j

M = number of sampling intervals

$\sigma_{noise,ij}$ = satellite i, time j (refer to Appendix J.2.4)

Note 2: *Interchannel biases on the simulator may impede the accuracy test specified herein. It may be necessary to determine this bias and inflate the test threshold based upon equipment calibration. If two receivers are used to remove this bias (via double-differencing), the test must account for potential interchannel biases in the receivers themselves and cannot simply remove all bias components.*

Note 3: *Since code-carrier divergence is not simulated in this test, the σ_{divg} term is not used in this normalization. Validation of σ_{divg} should be accomplished by analysis.*

7. Verification of σ_{noise} overbounding: The error statistic is compared to the Pass Threshold of <u>Table 2-26</u> based on the Number of Independent Samples (NIS), where NIS is given by:

$$NIS(M) \equiv \sum_{j=1}^{M}\left(N_j - 1\right)$$

If RMS_PR is below the pass threshold, the result is a pass. If the RMS_PR is not below the pass threshold, additional data may be collected. In this case, the RMS_PR shall include the initial independent samples plus all additional data, and the formulas and pass criteria of this section (which apply for an arbitrary number of samples) shall be used.

Note 4: *It is expected that the pass criteria will not be met with the initial data collection (only the initial acquisition and 50 steady-state operation independent samples due to the limited sample size. Development of the test criteria, and the associated pass probabilities are described in Appendix M.*

8. Steady-state value of $\left(\sigma^2_{noise}[i] + \sigma^2_{divg}[i]\right)^{1/2}$: Using only those samples collected during steady-state, the average $\left(\sigma^2_{noise}[i] + \sigma^2_{divg}[i]\right)^{1/2}$ output values for each satellite are compared to the requirements of J.2.4. The output values must be less than or equal to the required accuracy values for the designator of the equipment.
9. Verification of RMS accuracy: The steps defined in paragraph 6 and 7 are repeated using only those samples collected during steady-state operation and using the required RMS accuracy (sections 2.1.4.1.3.1 and 2.1.4.1.3.2) (minus any steady-state value of σ_{divg}) instead of the output $\sigma_{noise,i,j}$ in the computation of $\sigma_{norm,i,j}$. The pass criteria defined in section 7 applies.

TABLE 2-26 PASS THRESHOLD TABLE

NIS	Pass Threshold
50-75	0.955
75-100	0.982
100-150	0.998
150-200	1.017
200-300	1.028
300-400	1.042
400-500	1.050
500-750	1.055
750-1000	1.063
1000-1250	1.068
1250-1500	1.072
1500-2000	1.074
> 2000	1.078

TABLE 2-27 RESERVED

2.5.8.3 24-Hour Actual Satellite Accuracy Test

2.5.8.3.1 Test Procedure

The GPS/WAAS equipment shall be tested over a 24-hour period using actual (live) GPS and WAAS satellites. The horizontal and vertical position errors shall be normalized by $1.1d_{major}$ and $1.1\ d_u$ (Class 2, 3 and 4) as defined in Appendix J, except where the multipath term (σ_{mp}) is replaced by a term representative of the ground test environment. The RMS of the normalized errors is compared to the pass threshold in Table 2-26. For Class 2, 3 and 4 equipment, this RMS should be determined over the set of data points when all data is applied (fast, long term, range rate, ionospheric corrections and degradation data). The equipment shall operate at the highest mode attainable for its declared Operational Class, limited only by the availability afforded by a fault-free GPS/WAAS signal-in-space.

For Class 2, 3 and 4 equipment, this test shall be performed at a location which provides at least 90% availability of ionospheric corrections.

2.5.8.3.2 Pass/Fail Criteria

Equipment shall be considered pass if accuracy and integrity requirements are maintained throughout the 24-hour test (i.e., the RMS condition is met and the error never exceeds the HPL or VPL).

2.5.9 Integrity Monitoring Test Procedures

The verification of the FDE algorithm for the GPS/WAAS equipment shall consist of four tests. The first test (Section 2.5.9.2) shall demonstrate that the FDE algorithm provides proper fault detection and fault exclusion availability, and will be performed off-line. The second test (Section 2.5.9.3) is an off-line test to verify that the missed alert and failed exclusion requirements are satisfied. The third test (Section 2.5.9.4) is an off-line test to verify the false alert rate. The final test (Section 2.5.9.5) is an on-line test to verify that the algorithm that is implemented in the equipment is identical to the algorithm used during the off-line tests. Note that the on-line test specifies several additional off-line scenarios for comparison to on-line results.

2.5.9.1 General Test Conditions

2.5.9.1.1 Test Philosophy

These tests specify the procedures and pass/fail criteria for equipment demonstrating compliance with the FDE requirements in Section 2.1.2.2.2.2 and 2.1.3.2.2.2. With the exception of the first test for availability, the test is independent of the navigation mode and does not have to be repeated for different modes.

2.5.9.1.2 GPS Constellation

The GPS satellite constellation to be used in the simulations shall be the 24 satellite constellation defined in Appendix B. In all tests, the satellite selection algorithm and number of channels shall be the same as that used by the equipment. The mask angle shall be 5 degrees, regardless of the mask angle of the particular equipment under test.

2.5.9.1.3 Applicability of RTCA/DO-178B

The off-line FDE software used for testing compliance with the FDE requirements shall at least be compliant to RTCA/DO-178B Level D or equivalent. The software shall be designed such that the implementations of the position solution, FDE, and satellite selection algorithms are functionally identical in both the GPS/WAAS equipment and the off-line software.

The proof of equivalence to RTCA/DO-178B and functional identity depends upon the methods, platforms, code, and tools used. In the simplest case, the platforms, code, and tools are identical. It is recognized that these elements are variable. The proof of equivalence and identity lies on the developer and is dependent upon circumstance. The RTCA/DO-178B level will also vary dependent upon the criticality of the equipment. The particular method to be used must be negotiated with the relevant regulatory agencies. RTCA/DO-178B Level D has been determined to be acceptable for the off-line tests.

2.5.9.1.4 Test Repetition

If the equipment fails two successive tests defined in Section 2.5.9.3 or 2.5.9.4 with different sets of numbers for the random processes, the integrity algorithm must be modified to correct the problem before re-testing. Re-testing must be done for all FDE tests.

2.5.9.1.5 Protection Level/Alert Limit

In order to reduce the amount of test time, these tests are based upon the HPL_{FD} used internal to the equipment. By predicating these tests upon the HPL_{FD}, the navigation mode is irrelevant and the tests can be conducted only once. In addition, the satellite geometry should not be a dominant factor since the equipment is tested to the worst-case satellite. The off-line HPL_{FD} used for this test shall not include any additional margin which is a function of the navigation mode. For example, if the HPL_{FD} is 0.2 nm, but the equipment inflates this value to the NPA HAL of 0.3 nm in order to improve the false alert rate, the equipment must be tested to a HPL_{FD} = 0.2 nm. Therefore, for the purposes of these tests a positioning failure is referenced to the HPL_{FD}, not the HAL. Similarly, the tests conducted when exclusion is available are referenced to the HEL_{FD}, not the HAL.

2.5.9.1.6 Time-to-Alert

These tests shall use the appropriate time-to-alert for the equipment under test. Recall that the total time-to-alert for Class Beta is 8 seconds, regardless of the value of HPL_{FD}. For Class Gamma, the time-to-alert is 10, 10, 30, and 60 seconds for the NPA, terminal, en route, and oceanic modes respectively. When applied to this test, the total time-to-alert for Class Gamma is:

for all HPL_{FD}'s $\leq$ 1.0 nm, TTA = 10 seconds;

for HPL_{FD}'s > 1.0 nm and < 4.0 nm, TTA = 30 seconds; and

for HPL_{FD}'s $\geq$ 4.0 nm, TTA = 60 seconds.

The time-to-alert used in these tests shall accommodate the equipment latencies after fault detection. For example, if a Class Beta sensor has a 200 ms delay in issuing a navigation alert due to a positioning failure, then the time-to-alert for these tests would be (8 seconds - 0.2 seconds) = 7.8 seconds.

2.5.9.2 Availability Tests

The off-line test described in this paragraph shall be used to demonstrate compliance with the availability requirements of Section 2.1.2.2.2.2.5 and 2.1.3.2.2.2.5. Availability of fault detection and fault exclusion shall be determined for each of the space-time points in the following analysis grid sampled every 5 minutes for 12 hours from 00:00:00 to 12:00:00 UTC (144 time points). Since it is anticipated that SA eventually will be turned off, the availability of FDE with and without SA shall be determined:

Case 1: In the presence of SA, the effect on the User Equivalent Range Error (UERE) shall be modeled as specified in Appendix B.

Case 2: In the absence of SA, a one-sigma UERE of 12.5 m shall be assumed.

Analysis grid: Points are sampled every three degrees in latitude from zero to ninety degrees north. Each latitude circle will have points separated evenly in longitude, defined as:

$$long.step = \frac{360}{ROUND\left(\frac{360}{MIN(3 \quad \deg rees / \cos(latitude), 360)}\right)}$$

This grid yields 2353 points.

Note that the total number of space-time points is 2353*144 = 338,832 points.

The availability of fault detection for each space-time point shall be determined as defined in Section 1.7.3. The availability of detection shall be determined for the terminal (Class 1, 2 and 3) and nonprecision HALs (Class 1, 2 and 3).

Similarly, the availability of exclusion shall be calculated for each space-time point as defined in Section 1.7.3. The availability of exclusion shall be determined for the terminal (Class 1, 2 and 3) and nonprecision HALs (Class 1, 2 and 3).

The availability calculations for each space-time point shall be based upon the same set of satellites that would be used by the GPS/WAAS equipment. This requires that the satellite selection algorithm be used to select the satellites for use in the FDE algorithm. In addition, the mask angle shall be 5 degrees.

The total number of space-time points for which the detection function is available shall be determined (N_d). The total number of space-time points for which the exclusion function is available shall be determined (N_a). The availability is then determined as:

$$\textit{Availability of Detection} = \frac{N_d}{338832} \qquad \textit{Availability of Exclusion} = \frac{N_a}{338832}$$

If additional augmentations are used to improve system availability, the effects of those augmentations must be completely simulated. In particular, equipment logic which affects when the augmentation is applied shall be simulated. For augmentations which do not result in predictable HPL_{FD}'s for a given geometry, location, and time, the statistical nature of the HPL_{FD} must be taken into consideration and the total number of samples taken increased accordingly.

FDE algorithms which use other navigation signals external to the aircraft, such as Loran or VOR/DME, must satisfy the availability requirement without the use of the other navigation signals. The manufacturer must provide the means to test and analyze alternate FDE algorithms to demonstrate compliance. Note that these algorithms must also be demonstrated to satisfy the missed alert, false alert, and failed exclusion requirements when the external navigation signals are used.

2.5.9.3 Off-Line FDE Tests

2.5.9.3.1 Off-Line Test Setup

For GPS signals, the effect of SA shall be simulated as specified in Appendix B. The effect of equipment tracking-loop noise shall be modeled with a single white noise term with an RMS value representative of the equipment under test at the minimum signal-to-noise ratio (C/N_0). Such noise shall be generated as Gaussian white sequence with samples that are uncorrelated in time. The sampling interval used in the simulation tests shall not exceed 1 second. A GPS satellite malfunction shall be simulated as a ramp error in measured pseudorange with a slope of 5 m/s.

Different noise samples shall be used for each satellite being used in the FDE algorithm, and new sets of noise samples are to be generated and used for each run.

During all runs in the off-line simulation tests, satellite velocities are to be set to zero, and the satellite positions are to be frozen at the values for the selected geometry. This ensures that HPL will not change during the run.

While all tests in this section are based upon the assumption that all satellite range measurements have identical error characteristics (dominated by SA), the equipment may deweight each range measurement based upon the expected error residual. In this case, the equipment must demonstrate that it satisfies all FDE requirements with a combination of expected error characteristics. It is acceptable to demonstrate compliance by mathematical extension of the basic algorithm, if a justification for the alternative error distributions is provided. Appendix J discusses the performance bounds on the measurement residuals for a variety of correction scenarios.

2.5.9.3.2 Selection of Geometries

The space-time points analyzed under Section 2.5.9.2 shall be reviewed to yield the following sets of points. If the geometries cannot be found for any set, deselect satellites in order to find acceptable geometries.

Set 1: Twenty geometries shall be selected to provide an approximately uniform range of HPL_{FD} from 0.1 nm to the maximum HAL supported by the equipment (e.g., 4 nm). Note that only the missed alert and false alert probabilities are required to be satisfied under this condition.

Set 2: Twenty geometries shall be selected to provide an approximately uniform range of HEL_{FD} from 0.1 nm to the maximum HAL supported by the equipment (e.g., 4 nm). Note that all requirements (missed alert, false alert, failed exclusion) are required to be satisfied for this set.

2.5.9.3.3 Test Procedure

One of the most difficult issues to test is the integration of the exclusion and detection functions. In particular, the exclusion requirements state that the equipment must exclude the failure prior to the radial error becoming unacceptable and without alerting the user. In Class Gamma equipment, this can be performed by taking advantage of the knowledge of the HAL. For example, once a failure is detected relative to the HPL_{FD}, the HUL may be used to bound the error until it exceeds the HAL. This provides the most time for the exclusion algorithm to exclude the failure without increasing the probability of a missed alert.

For Class Beta equipment which does not know the HAL, the decision of when to indicate a failure to the user can in this situation be made by the navigation management unit (typically a flight management system). Therefore, it is acceptable for Class Beta equipment to indicate an alert as soon as a detection occurs together with an output of the HUL. In this case, the navigation management unit must decide when the error becomes unacceptable and must be annunciated.

In order to properly test the equipment, separate outcomes are required for Class Gamma equipment and Class Beta equipment. Class Beta equipment which does know the HAL (by accepting it as an input) may comply with either test. Regardless of the Class Beta design, the integrated system would be expected to withhold indication of the failure until it becomes unacceptable if exclusion is available.

In addition to the data recorded specifically for this test, the position trace and alert status shall be recorded for several runs in support of the on-line test procedures. See Section 2.5.9.5 for a discussion of which runs should be retained.

Note: *Manufacturers may choose to use elevated SA levels to reduce the number of samples required to yield the desired statistical confidence. If manufacturers choose to do so, they must demonstrate that their test method yields at least equivalent statistical confidence to the test described above.*

2.5.9.3.3.1 Class Gamma Equipment

For each of the 40 geometries selected above, a ramp-type failure with a velocity of 5 m/s shall be introduced. For Set 1, the failure shall be introduced in the most-difficult to detect satellite. The HAL for each run in Set 1 shall be set equal to the HPL_{FD} in order to obtain the proper alerting. For Set 2, the failure shall be introduced in the most-difficult to exclude satellite. The HAL for each run in Set 2 shall be set equal to the HEL_{FD} in order to obtain proper alerting. A Monte-Carlo (random) trial run shall then be made with the ramp initiated at the time of the chosen geometry (defined as t=0).

The run is to be continued until one of the following three events occurs (a-c):

a. Correct Exclusion: The right satellite is excluded (the wrong satellite may initially be excluded provided the position error does not exceed the HEL_{FD} for longer than the time-to-alert);

b. Failed Exclusion: A navigation alert is output due to detected positioning failure; or

c. Missed Alert: The position error exceeds the HPL_{FD} (Set 1) or HEL_{FD} (Set 2) for longer than the time-to-alert without a navigation alert (this could be due to missed detection or wrong exclusion).

A total of 1650 trials shall be run for each of the 20 geometries in Set 1 and the 20 geometries in Set 2. The number of occurrences of each outcome shall be recorded for each geometry set defined in Section 2.5.9.3.2.

2.5.9.3.3.2 Class Beta Equipment

For each of the 40 geometries selected above, a ramp-type failure with a velocity of 5 m/s shall be introduced. For Set 1, the failure shall be introduced in the most-difficult to detect satellite. For Set 2, the failure shall be introduced in the most difficult to exclude satellite. A Monte-Carlo (random) trial run shall then be made with the ramp initiated at the time of the chosen geometry (defined as t=0).

For Set 1, the run is to be continued until one of the following three events occurs (a-c):

a. Correct Exclusion: The right satellite is excluded before the position error exceeds the HAL (HPL_{FD} in this test) for longer than the time to alert;

b. Failed Exclusion: A navigation alert is output due to detected positioning failure; or

c. Missed Alert: The position error exceeds the HAL (HPL_{FD} in this test) for longer than the time-to-alert without a navigation alert (this could be due to missed detection or wrong exclusion).

For Set 2, the run is to be continued until one of the following three events occurs (d-f):

d. Correct Exclusion: The right satellite is excluded before the position error exceeds the HAL (HEL_{FD} in this test) for longer than the time to alert;

e. Failed Exclusion: A navigation alert is output when the position error exceeds the HEL_{FD} for longer than the time to alert; or

f. Missed Alert: The position error exceeds the HAL (HEL_{FD} in this test) for longer than the time-to-alert without a navigation alert (this could be due to missed detection or wrong exclusion).

Since Class Beta equipment may not be aware of the HAL, it is acceptable for a navigation alert to be output prior to exclusion. The run should be continued until the occurrence of one of the three outcomes listed above (d-f).

A total of 1650 trials shall be run for each of the 20 geometries in Set 1 and the 20 geometries in Set 2. The number of occurrences of each outcome shall be recorded for each geometry set defined in Section 2.5.9.3.2.

2.5.9.3.4 Pass/Fail Criteria

In order for the GPS/WAAS equipment to pass, the total number of events for each satellite set shall be less than or equal to the numbers shown in Table 2-28.

TABLE 2-28 MAXIMUM NUMBER OF OUTCOMES TO OFF-LINE FDE TEST

Outcome	**SET 1**	**SET 2**
a. Failed Exclusion (True alert)	N/A	47
b. Missed Alert (Missed Detection or Wrong Exclusion)	47	47

Note: *The number of test runs is designed to ensure a high probability of passing the test properly, and a low probability of falsely passing the test. The probability that properly designed equipment passes the missed alert and failed exclusion tests is 99%, while the probability that equipment with a missed alert or wrong exclusion probability of 0.002 is only 1% likely to pass the test.*

2.5.9.4 False Alert Rate Test

The false alert rate is the rate with which the equipment flags the outside world that its position is outside the HPL, with the actual position still being inside the HPL (no positioning failure occurred). The false alert rate does not depend on the geometry of the visible satellites, but is mainly driven by SA. If SA is turned off, false alerts will be driven either by ionospheric error or receiver noise. These tests use the same 40 geometries that are used in Section 2.5.9.3.

The tests are classified in two categories, depending upon the algorithm implementation. The test for snapshot algorithms takes advantage of the fact that single samples of SA, ionospheric error, or receiver noise can be modeled as a simple Gaussian distribution. The test for non-snapshot algorithms must model the correlated effect of the error source over the correlation time.

Note: *Manufacturers may choose to use elevated SA levels to reduce the number of samples required to yield the desired statistical confidence. If manufacturers choose to do so, they must demonstrate that their test method yields at least equivalent statistical confidence to the tests described below.*

2.5.9.4.1 False Alert Rate Simulations for Snapshot Algorithms

For each of the geometries defined in Section 2.5.9.3, a total of N=2,475,000 samples are simulated. The number N is determined by dividing the required total number of samples (99,000,000) by 40 geometries, yielding 2,475,000 sample points per geometry. For each sample, the satellites used for positioning are selected, the pseudoranges to the selected satellites are calculated, the FDE algorithm is executed and the result is logged. The number of geometries must be higher if the alert threshold is not set based upon the geometry. In this case, the number of geometries should be selected such that an algorithm with a true false alert rate of $2x10^{-5}$/hr has a 0.01 chance of passing.

For each geometry, the number of false alerts is counted. In order to pass the false alert test, the following criteria shall be met:

1. The total number of alerts over all admissible geometries shall be equal to or less than 47.
2. For each geometry, there shall be no more than 3 alerts.

The first criterion ensures compliance with the overall false alert rate requirement. The second criterion assures that there will be no unusual bunching of alerts at any position.

Note: *The false alert rate requirement for snapshot algorithms is converted into a false alert probability per independent sample, by assuming an SA correlation time of 2 minutes. With a false alert rate of 10^{-5}/hour, this translates into a false alert probability per independent sample of $3.333x10^{-7}$. In order to test this probability with statistical confidence, a total number of 99,000,000 statistically independent samples have to be taken. Of these, a maximum of 47 samples may be allowed to have a false alert.*

2.5.9.4.2 False Alert Rate Simulations for Non-Snapshot Algorithms

For each of the geometries defined in Section 2.5.9.3, a total of N=82,500 hours of operation is to be simulated. The number N is determined by dividing the required total number of simulation hours (3,300,000) by 40 geometries, yielding 82,500 hours per geometry. During each simulation run of 82,500 hours, the satellite velocities are to be set to zero, and the satellite positions are to be frozen at the values for the selected marginal geometry. This ensures that the HAL/HPL will not change during the run.

For the purpose of this test, a false alert is defined as the occurrence of an alert indication in the absence of a real positioning failure, regardless of how long the alert indication is provided. The total number of alerts shall be counted. Only the number of occurrences of an indication are to be counted, not the duration of the indication. In order to pass the false alert test, the following criteria shall be met:

1. The total number of alerts over all admissible geometries shall be less than or equal to 47.
2. For each admissible geometry, there shall be no more than 3 alerts.

The first criterion ensures compliance with the overall false alert rate requirement. The second criterion assures that there will be no unusual clustering of alerts at any one position.

Note: *The false alert rate for non-snapshot algorithms cannot be easily converted into a false alert probability. For these algorithms, a total number of 3,300,000 hours of operation has to be simulated to gain statistical confidence. During this simulation, no more than 47 false alerts can be allowed for the equipment to pass the test.*

2.5.9.5 On-Line Verification Test

The purpose of the on-line verification tests is to ensure that the off-line algorithms and the on-line implemented algorithms are identical in function, performance, and computational (logical and arithmetic) results. This requirement is derived from the fact that all statistical performance results are determined by the off-lines tests.

Because the off-line and on-line tests use fundamentally different data generators, it is not possible to assure that any off-line and on-line tests, under identical scenarios, will produce identical results. Therefore, there shall be two separate tests: an on-target computational test; and an on-line behavioral test. An additional test is specified for precision approach fault detection.

2.5.9.5.1 On-Target Computational Test

The purpose of the on-target test is to ensure that software on the target processor (in the GPS/WAAS equipment) produces equivalent output data as the off-line algorithm, for identical input data. This test does not have to be conducted if the off-line tests described in Sections 2.5.9.3 and 2.5.9.4 are performed on the target processor using the same FDE software used in the GPS/WAAS equipment.

For the purpose of this test, equivalent means that arithmetic variables are within 0.1 meter of the off-line values and all logical variables are strictly identical (including logical counters, etc.).

The on-target test requires that the target software be exercised by forty satellite scenarios, one from each constellation in Set 1 and Set 2 as defined in Section 2.5.9.3.2. A ramp failure shall be generated as defined in Section 2.5.9.3.2 in each case.

a. For each satellite static scenario, the input data to the off-line navigation/FDE algorithm shall be recorded with its computational results. At a minimum, the computational results shall include the HPL_{FD}, horizontal radial position error, alert flag, and loss of integrity flag. Any additional variables internal to the navigation/FDE algorithm may also be recorded.

b. This input data will be duplicated in the on-target software and the input data will exercise the on-target navigation/FDE software. The computational results of the on-target software will be recorded and compared to the off-line results. The strict meaning of equivalent is defined above. The computational results for the on-line and on-target implementations are required to be equivalent.

2.5.9.5.2 On-Line Behavioral Test

Two groups of behavioral tests will be conducted: SA turned off and SA turned on. The purpose of the SA-off test is to ensure that the behavior of the GPS/WAAS equipment and the off-line tests are functionally and computationally similar. The purpose of the SA-on tests is to ensure that the GPS/WAAS equipment can properly function in a noise environment.

The SA-on and SA-off cases shall each be run using five constellations selected from the forty used under Section 2.5.9.5.1 that have a relatively constant HPL_{FD} and HEL_{FD} for the duration of the test. A ramp failure shall be generated as defined in Section 2.5.9.3.3 in each case. All test scenarios will be conducted with the GPS/WAAS equipment stationary (non-dynamic).

In order to pass the SA-off behavioral test:

1. The equipment position fixing difference shall only exceed 5 meters for periods of 2 seconds or less.
2. The equipment HPL_{FD} difference shall only exceed 50 meters for periods of 10 seconds or less.

If these thresholds are exceeded, the cause of the difference shall be identified and that cause must be within the expected characteristics of the algorithm.

In order to pass the SA-on behavioral test, each SA-on failure shall be matched with a corresponding SA-off failure for the same geometry.

2.5.10 Precision Approach Fault Detection

The verification of the RAIM algorithm for the GPS/WAAS equipment in a PA mode shall consist of four tests. The first test (Section 2.5.10.2) shall demonstrate that the RAIM algorithm provides proper fault detection availability, and will be performed off-line. The second test (Section 2.5.10.3) is an off-line test to verify that the missed alert requirement is satisfied. (Note that fault detection availability and missed alert requirements are only for test purposes. In real operations, RAIM will be executed regardless of the geometry and the missed alert probability that can be guaranteed by the geometry). The third test (Section 2.5.10.4) is an off-line test to verify the false alert rate. The final test (Section 2.5.10.5) is an on-line test to verify that the algorithm that is implemented in the equipment is identical to the algorithm used during the off-line tests. (Note that the on-line test specifies several additional off-line scenarios for comparison to on-line results.)

2.5.10.1 General Test Conditions

2.5.10.1.1 Test Philosophy

These tests specify the procedures and pass/fail criteria for equipment demonstrating compliance with the PA RAIM requirements in Section 2.1.5.2.2.2.

2.5.10.1.2 GPS Constellation

See Section 2.5.9.1.2

2.5.10.1.3 Applicability of RTCA/DO-178B

See Section 2.5.9.1.3 (fault detection only instead of FDE)

2.5.10.1.4 Test Repetition

If the equipment fails two successive tests defined in Section 2.5.10.3 or 2.5.10.4 with different sets of numbers for random processes, the integrity algorithm must be modified to correct the problem before re-testing. Re-testing must be done for all fault detection tests.

2.5.10.1.5 Protection Level/Alert Limit

The fault detection performance tests for PA are based upon the $VPLT_{FD}$. As was defined earlier in Section 2.1.5.2.2.2.2, $VPLT_{FD}$ is similar to VPL_{FD} except that the missed alert probability guaranteed by RAIM is 0.1, instead of 0.001. $VPLT_{FD}$, missed alert probability, and availabilities are used only for the purpose of testing for PA RAIM. The availability test is based on vertical alert limit of 15 m.

2.5.10.1.6 Time-to-Alert

The time-to-alert requirement is as specified in section 2.1.2.2.2.2.1, 2.1.3.2.2.2.1, and it is 6 seconds for precision approach operations.

2.5.10.2 Availability Tests

The off-line tests described in this paragraph shall be used to demonstrate compliance with the availability requirements of Section 2.1.5.2.2.2. Availability of fault detection shall be determined for each of the space-time points in the analysis grid defined in Section 2.5.9.2 sampled every 5 min for 12 hr from 00:00:00 to 12:00:00 UTC (144 time points).

The availability of fault detection for each space-time point shall be determined as defined in Section 1.7.3, except that missed alert probability requirement is 0.1 instead of 0.001 and therefore it is based on $VPLT_{FD}$ defined in Section 2.1.5.2.2.2.2.

The availability calculations for each space-time point shall be based upon the same set of satellites that would be used by the GPS/WAAS equipment. This requires that the satellite selection algorithm be used to select the satellites for use in the fault detection algorithm. In addition, the mask angle shall be 5 deg.

2.5.10.3 Off-Line Missed Alert Tests

2.5.10.3.1 Off-Line Test Setup

The residual errors for post-WAAS correction pseudorange measurements for non-failed satellites shall be modeled by RSSing the error components as follows:

Ionospheric delay estimation error: a second-order Gauss-Markov process with an auto-correlation time of 75 sec and a standard deviation of F_j x 0.432 m (F_j: ionospheric obliquity factor).

UDRE: a random constant with a standard deviation of σ_{UDRE} = 0.562 m.

Tropospheric delay estimation error: a random constant with a standard deviation of σ_{tropo} as specified in Appendix A.4.2.4.

Multipath and receiver noise: a Gaussian white sequence with samples that are uncorrelated in time and a standard deviation of σ_{air} as specified in Appendix J.

The sampling interval used in the simulation tests shall not exceed 1 sec. It shall be assumed that only one anomalous post-correction pseudorange measurement occurs at a time, and it shall be simulated as a ramp error in pseudorange measurement with a slope of 0.2 m/sec.

Different noise samples shall be used for each satellite being used in the fault detection algorithm, and new sets of noise samples are to be generated and used for each run.

During all runs in the off-line simulation tests, satellite velocities are to be set to zero, and the satellite positions are to be frozen at the values for the selected geometry.

The equipment shall deweight each range measurement based upon the expected error residual.

2.5.10.3.2 Selection of Geometries

The space-time points analyzed under Section 2.5.10.2 shall be reviewed to yield a set of twenty geometries that provide an approximately uniform range of VPL from 5 m to 100 m. If the geometries cannot be found for any set, deselect satellites in order to find acceptable geometries.

2.5.10.3.3 Test Procedures and Pass/Fail Criteria

In addition to the data recorded specifically for the off-line test, the position trace and alert status shall be recorded for several runs in support of the on-line test procedures.

For each of the 20 geometries selected in Section 2.5.10.3.2, a ramp-type failure with a velocity of 0.2 m/sec shall be introduced in the most-difficult to detect satellite. The VAL for each run shall be set equal to the $VPLT_{FD}$ in order to obtain the proper alerting. A Monte-Carlo (random) trial run shall then be made with the ramp initiated at the time of the chosen geometry (defined as t = 0). The run is to be continued until one of the following three events occurs (a - c).

a. The alert is triggered without the vertical position error exceeding $VPLT_{FD}$. This is called a “false detection”.

b. The vertical position error exceeds $VPLT_{FD}$ and the alert is also triggered within the allowable time-to-alert. This is called a “timely detection”.

c. The vertical position error exceeds $VPLT_{FD}$ but the alert is not triggered within the specified time-to-alert. This is called a “miss”.

A total of 14 trials shall be run for each of the 20 geometries. The number of occurrences of each outcome shall be recorded for each of the 20 geometries.

In order for the GPS/WAAS equipment to pass, the total number of misses shall be less than or equal to 40.

Note: *The number of test runs is designed to ensure a high probability of passing the test properly, and a low probability of falsely passing the test. The probability that properly designed equipment passes the missed alert tests is 99 percent, while the probability that equipment with a missed alert probability greater than or equal to twice the requirement (i.e., 0.2) will pass the test is less than 1 percent.*

2.5.10.3.4 False Alert Rate Test

The false alert rate shall not depend on the geometry of the visible satellites, but is mainly driven by the values of the statistical parameters characterizing post-WAAS correction pseudorange measurements. The false alert rate test uses the same 20 geometries that are used in Section 2.5.10.3. Because there is only one or two independent samples for the duration of a typical precision approach, the following test may be used for both the snapshot and non-snapshot algorithm implementations.

Note 1: *Manufacturers may choose to use an elevated statistical distribution for the post-correction pseudorange measurement errors to reduce the number of samples required to yield the desired statistical confidence. If manufacturers choose to do so, they must demonstrate that their test method yields at least equivalent statistical confidence to the tests described below.*

For each of the geometries defined in Section 2.5.10.3, a total of N = 165,000 samples are simulated. The number N is determined by dividing the required total number of samples 3,300,000 by 20 geometries, yielding 165,000 sample points per geometry. For each sample, the satellites used for positioning are selected, the post-correction pseudoranges to the selected satellites are calculated, the fault detection algorithm is executed, and the result is logged.

For each geometry, the number of false alerts is counted. In order to pass the false alert test, the following criteria shall be met:

1. The total number of alerts over all admissible geometries shall be equal to or less than 47.
2. For each geometry, there shall be no more than 3 alerts.

The first criterion ensures compliance with the overall false alert rate requirement. The second criterion ensures that there will be no unusual bunching of alerts at any position.

Note 2: *The false alert rate requirement of 2 x 10^{-5} per approach is converted into a false alert probability per independent sample, by assuming a correlation time of 75 sec for post-correction pseudorange measurements. In an approach of a typical duration of 150 sec, the false alert rate requirement of 2 x 10^{-5} per approach translates into a false alert probability per independent sample of 10^{-5}. In order to test this probability with statistical confidence, a total number of 3,300,000 statistically independent samples have to be taken. Of these, a maximum of 47 samples may be allowed to have a false alert.*

2.5.10.4 On-Line Verification Test

The purpose of the on-line verification tests is as described in Section 2.5.9.5. Because the off-line and on-line tests use fundamentally different data generators, it is not possible to assure that any off-line and on-line tests, under identical scenarios, will produce identical results. Therefore, there shall be two separate tests: an on-target computation test; and an on-line behavioral test.

2.5.10.4.1 On-Target Computational Test

Refer to Section 2.5.9.5.1 with the following exceptions.

For the purpose of this test, equivalent means that arithmetic variables are within 0.01 m of the off-line values and all logical variables are strictly identical.

The on-target test requires that the target software be exercised by twenty satellite scenarios defined in Section 2.5.10.3.2. A ramp failure shall be generated as defined in Section 2.5.10.3.3.

2.5.10.4.2 On-Line Behavioral Test

The behavioral tests will be conducted on the GPS/WAAS equipment using a satellite simulator. This test shall be performed using five geometries out of 20 defined in Section 2.5.10.3.2 that have a relatively constant VPL for the duration of the test. A ramp failure shall be generated as defined in Section 2.5.10.3.3. All test scenarios will be conducted with the GPS/WAAS equipment stationary.

In order to pass the behavioral test:

1. The equipment position fixing difference shall be less than 1 meter, but may exceed 1m for a period of 400 ms or less.
2. The equipment VPL difference shall be less than 1.5 meters, but may exceed 1.5 meters for a period of 400 ms or less.

If these thresholds are exceeded, the cause of the difference shall be identified and that cause must be within the expected characteristics of the algorithm.

2.5.11 Test Procedures for Class Gamma Equipment

This section describes specific Gamma equipment tests. The equipment required to perform these tests shall be defined by the equipment manufacturer as a function of the specific sensor configuration of the equipment. Since these tests may be accomplished more than one way, alternative test equipment setups, test conditions, or simulated flight scenarios may be used where equivalent evaluation of the GPS/WAAS equipment can be accomplished. Combinations of tests may be used whenever appropriate.

The test equipment signal sources shall provide the appropriate signal format to the specific system under test without contributing to the error values being measured. When used, the simulator(s) shall follow the same protocols (i.e., message types, message contents, frequency of messages) described in Appendix A, the WAAS Signal Specification.

2.5.11.1 General Gamma Bench Test Procedures

The bench test procedures described below require the use of simulators to assume the role of the other components of the total system. Therefore, a manufacturer can use an airborne system and test it to the bench tests described in this section. However, in order to have Gamma equipment certified, flight tests shall also be conducted.

Bench tests can be conducted with a test equipment configuration similar to Figures 2-19 and 2-20. [Generic Bench Test Configuration] The configuration includes entering flight plan information into the Gamma equipment under test. Information corresponding to the flight plan, such as waypoints and aircraft speed, is entered into the GPS/WAAS simulator. The simulator uses this information to provide RF signals to the Gamma equipment. These signals simulate aircraft flight for various patterns and paths corresponding to the processed flight plan. In addition to the flight plan derived information (e.g., waypoints), the GPS/WAAS simulator processes the appropriate satellite constellation from Appendix B.

Unless otherwise noted, the ground speed of the simulated aircraft should be compatible with the ground speed of an aircraft, for which the equipment is being tested for each mode (e.g., en route/remote, terminal, non-precision approach, and precision approach). Bench tests that successfully pass the criteria only need to be performed once unless otherwise indicated.

2.5.11.1.1 Simulated Flight Bench Test Procedures

The approach for bench testing Gamma equipment requirements includes the use of multiple flight plans to create different operational test conditions. This test methodology maximizes the use of GPS/WAAS simulators for dynamic bench testing. This approach is effective in evaluating GPS/WAAS equipment performance and functional capabilities in a cost effective manner.

The first simulated flight plan is a flight departure from JFK International Airport [KJFK], New York, NY, and arrival at Los Angeles International Airport [KLAX], Los Angeles, CA. However, only a portion of this flight is tested. The second simulated flight is for a departure from, a GPS approach to and a missed approach at William R. Pogue Municipal Airport (airport identifier: 0F8, zero foxtrot eight), Sand Springs, OK. Executing these flight plans along with additional manual inputs and/or observations during the simulated flights will verify several requirements. The flight plans can be conducted in their entirety, or by conducting portions of each flight plan at a time.

When these two flight plans were developed it was realized that the waypoints and airways used in the flight plans would most likely change in the future. For example, in flight plan number 1 the standard instrument arrival at KLAX named REEDR.3 might be changed in the future to REEDR.4. For this reason, the manufacturer has the option of adjusting the flight plan, or using another flight plan provided that the individual requirements referenced in Tables 2-32 and 2-33 are still verified. The flight profiles in Figures 2-21 and 2-22 must be duplicated with any new flight plan.

2.5.11.1.1.1 Simulated Flight Plan Test 1

This test includes entering two flight plans and simulating a flight departure from KJFK and arrival at KLAX. The test uses a 20 waypoint flight plan but is executed for only a portion of the flight. The manufacturer has the option to select aircraft type and aircraft speeds, but they should be appropriate for the intended equipment's market and application.

Note that the first eight waypoints in this flight plan are identified by latitude/longitude positions. The waypoints in the remainder of the flight plan include references to current navaids, intersection positions or names. These waypoints and approaches may be adjusted to accommodate changes in the navigation database. The waypoints and their characteristics (e.g., lat/long, bearing and range to each other) are identified in the following tables. These waypoints are also referred to in Figure 2-21, Flight Profile for Flight Plan 1.

Figure 2-21 illustrates the flight plan and deviations to the flight plan during the bench test. The table below (Table 2-29) characterizes the waypoints used in this test. They describe the latitude/longitude positions, bearing and range between waypoints and the magnetic variations at each waypoint. The current names of Flight Plan No. 1 Waypoints 1 to 8 are provided for information purposes.

1. Setup the test equipment according to Figure 2-19 or 2-20, as appropriate. Configure the GPS/WAAS simulator with the satellite constellation in Appendix B and the equivalent simulated flight information from Table 2-29, Simulated Flight Plan Test Number 1.
2. Conduct the test in the sequence of steps provided in the table. Note any flight plan deviations or test anomalies that occur during the test. Verify that the success criteria for each step is satisfactory.

TABLE 2-29 WAYPOINT INFORMATION FOR FIRST FLIGHT PLAN FOR SIMULATED FLIGHT PLAN TEST 1

FP WPT No.	WPT Name	LATITUDE	LONG	Distance between WPTs (NM)	True Heading (Degrees)	Mag Variation
	KJFK	N40° 38' 23.10"	W072° 46' 44.13"			W13
1	CRI	N40° 36' 44.90"	W 073° 53' 40.00"	KJFK to WPT1 5.53	252.82 º	W11
2	RBV	N40° 12' 08.6"	W074° 29' 42.05"	WPT 1 to 2 36.91	228.42 º	W11-W10
				KJFK to WPT2 82.89	252.16 º	W10
3	LOBES	N40° 11' 24.30"	W74° 38' 47.07"	WPT 2 to 3 6.99	263.99 º	W10-W12
4	COPES	N40° 07' 50.58"	W75° 22' 36.37"	WPT 3 to 4 33.79	264.19 º	W12-W11
5	SIELE	N40° 05' 31.93"	W75° 49' 07.29"	WPT 4 to 5 20.47	263.67 º	W11
6	J6/J230	N40° 01' 00.47"	W76° 30' 53.22"	WPT 5 to 6 32.39	262.20 º	W11
7	FLIRT	N39° 55' 43.89"	W76° 42' 14.41"	WPT 6 to 7 10.20	238.93 º	W11
8	MRB	N39° 23' 08.06"	W77° 50' 54.18"	WPT 7 to 8 62.23	238.81 º	W10-W7

TABLE 2-30 NOT USED

2.5.11.1.1.2 Simulated Flight Plan Test 2

This bench test includes a simulated flight for departure from, GPS approach to, and missed approach at William R. Pogue Municipal Airport (0F8). This simulated flight verifies requirements associated with terminal airspace and involves a missed approach and holding pattern. The manufacturer has the option to select aircraft type and aircraft speeds but they should be appropriate for the intended equipment's market and application. Figure 2-22 illustrates the flight plan and deviations to the flight plan during the bench test. Table 2-31 contains the latitude and longitude positions of the waypoints used in the flight plan. If the tester elects to change the waypoints or procedures, the flight profile in Table 2-32 must remain the same.

<u>TABLE 2-31</u> WAYPOINT INFORMATION FOR SIMULATED FLIGHT PLAN TEST 2

WPT Name	LATITUDE	LONG	Distance between WPTs (NM)	True Heading (Degrees)	Mag Variation
DARRO	N35° 59' 39.05"	W96° 14'12.43"	DARRO TO ACERT 4.99	85.3	E8
ACERT	N36° 00' 03.51"	W96° 08' 03.94"	ACERT TO CENTO 4.99	85.3	E8
CENTO	N36° 00' 27.66"	W96° 01' 55.39"	NA	NA	E8
FANCY	N36° 05' 02.96"	W96° 08' 33.84"	ACERT TO FANCY 4.99	355.37	E8
WILUM	N36° 10' 02.41"	W96° 09' 03.77"	FANCY TO WILUM 5.00	355.37	E8
ABCUX	N36° 15' 59.02"	W96° 09' 39.48"	WILUM TO ABCUX 5.95	355.36	E8

1. Setup the test equipment according to Figure 2-19 or 2-20, as appropriate. Configure the GPS/WAAS simulator with the satellite constellation in Appendix B and the equivalent simulated flight information for Table 2-33 Simulated Flight Plan Test Number 2.
2. Conduct the test in Table 2-33. The flight profile is illustrated in Figure 2-22. Note any flight plan deviations or test anomalies that occur during the test. Verify that the success criteria for each step is satisfactory.

TABLE 2-32 SIMULATED FLIGHT PLAN TEST NUMBER 1

Step	Action	Success Criteria	Phase of	Requirement
1.	Enter departure airport (KJFK) and arrival airport (KLAX).	Verify that both airports are accepted.	Preflight	2.2.1.5.2
2.	Enter the following flight plan as a stored or alternate flight plan (the intent is that this flight plan is activated later in this test) Waypoints 2 through 5 from Table 2-29,Waypoint 6 from Table 2-29 (enter as 274° radial from RBV and 248° radial from LRP), Waypoints 7 through 8 from Table 2-29. Complete creation of a flight plan to the arrival airport (KLAX) with a maximum of 18 waypoints. The additional waypoints must include a user waypoint at N40 49.3 W088 43.9 and an arrival route (e.g., REEDR 3) into KLAX.	Verify that the flight plan data is accepted.	Preflight	2.2.1.2.1
3.		Verify that the user defined waypoint (Waypoint 6; J6/J230) was accepted as entered. Verify that the entry of the two radials defining this intersection was accepted as a waypoint and that the resolution was at least one degree.	Preflight	2.2.1.2.5
4.		Verify that the latitude and longitude (N 40 49.3 W 088 43.9) entry was displayed as latitude and longitude before the data was entered into the flight plan and that the resolution was at least 0.1 minute.	Preflight	2.2.1.2.5
5.		Verify that the arrival route (e.g., REEDR.3) was in the data base including the appropriate transitions for the arrival (e.g., three transitions associated with REEDR.3). Verify that by entering selected arrival and transition(s) that all the appropriate waypoints were accepted into the flight plan.	Preflight	2.2.1.2.1, 2.2.3.2, 2.2.3.3.1

Step	Action	Success Criteria	Phase of	Requirement
6.		Verify following waypoints are accepted: KJFK, RBV, LOBES, SIELE, user defined intersection (Waypoint 6; J6/J230), FLIRT, MRB, and the remaining waypoints added to the flight plan.	Preflight	2.2.1.3, 2.2.1.2.1
7.		Verify that each leg is accepted with its course and distance.	Preflight	2.2.1.2.1, 2.2.1.2.2
8.		Verify that the flight plan entered is not the active flight plan.	Preflight	2.2.1.2.2
9.	Enter vertical path information, such as flight level altitude (FL350), if required.	Verify that any vertical path information (flight level) is accepted.	Preflight	
10.	Enter the departing runway (31L) if required.	Verify the departing runway is accepted.	Preflight	
11.	Enter second flight plan for a flight from Philadelphia airport (KPHL) to Tampa airport (KTPA): KPHL, OOD, LAL (e.g., DIRECT LAL), KTPA	Verify the second flight plan can be activated. Verify that the first flight plan entered remains in the equipment and is not active.	Preflight	2.2.1.2.2
11A.	Enter vertical path information, such as flight level (FL 160), if required.	Verify that any vertical path information (flight level) is accepted.	Preflight	
12.		Verify that the following waypoints are accepted: KPHL, OOD, LAL, KTPA.	Preflight	2.2.1.3
13.	Select & Activate the first flight plan	Verify first flight plan entered (KJFK to KLAX) is now the active flight plan.	Preflight	2.2.1.3, 2.2.1.2.3
14.		Review the entire flight plan verifying that each leg is identified including the arrival route (e.g., REEDR.3).	Preflight	2.2.1.2.1
15.	Insert CRI (Waypoint 1 from Table 2-29) into the active flight plan prior to RBV	Verify that waypoint CRI is entered and is a part of the active flight plan.	Preflight	2.2.1.2.1
15A.	Enter the following user defined waypoint after WPT CRI: CRI 220R/30.1 DME	Verify that the waypoint is accepted. Verify the resolution of 220 degrees and 30.1 nm.	Preflight	2.2.1.2.1

Step	Action	Success Criteria	Phase of	Requirement
16.	Delete the following from the flight plan: CRI 220R/30.1 DME	Verify the user-defined waypoint is deleted from the flight plan.	Preflight	2.2.1.2.1
17.	Enter the following route change after WPT CRI: CRI 221R/30.2 DME	Verify that the waypoint is accepted. Verify that the range is 30.2 nm and that the bearing resolution is 221 degrees.	Preflight	2.2.1.2.1, 2.2.1.2.2
18.	Execute the route change in the previous step. ***Note:*** *Some equipment may have already accepted the route change and do not need to "execute" in order to perform the verification for this step.*	Verify that the route change is accepted. Verify that the flight plan is still active.	Preflight	2.2.1.2.1, 2.2.1.2.2
19.		Verify that resolutions of 1 degree in the 221R and 0.1 nm in the 30.2 distance was accepted.	Preflight	2.2.1.2.5
20.	Bench test begins simulated flight –Take off	Verify that during departure the display sensitivity change from 0.3 nm FSD at departure end of runway to 1.0 nm FSD over a distance of 2 nm. Verify that automatic mode switching is annunciated. Verify that terminal mode is indicated after Take-off. ***Note:*** *The sensitivity changes will stop after 2 nm.*	Depart to Terminal	2.2.2.7.2.3, Table 2-5, 2.2.1.7
21.	After take off, execute: "DIRECT RBV".	Verify that "DIRECT RBV" is accepted. Verify that the access to the "DIRECT TO" feature was by means of a single manual action.	Terminal	2.2.1.2.2, 2.2.1.2.4
22.		Verify the "DIRECT TO" RBV leg was accepted and that the flight plan is intact with no discontinuity between RBV and WPT LOPES.	Terminal	2.2.1.2.4, 2.2.1.3, 2.2.1.3.4
23.		Verify that the numeric cross-track deviation is displayed, or that a electrical output is continuously provided during terminal mode.	Terminal	2.2.1.4.2.2
24.	Intentionally left blank.			
25.	Intentionally left blank.			

Step	Action	Success Criteria	Phase of	Requirement
26.		Verify automatic annunciation when the default mode switches to en route mode. ***Note:*** *During transition to en route mode the display sensitivity decreases (full scale sensitivity ± 5 nm).*	Terminal to En Rte	2.2.1.7
27.	Manually request current navigation mode.	Verify that the current mode indicated is en route.	En Route	2.2.1.7
28.		Verify that an indication is provided that RBV is the active "TO" WPT.	En Route	2.2.1.2.4
29.		Verify that an annunciation is issued prior to WPT RBV and again at the WPT crossing.	En Route	2.2.1.3.7, 2.2.1.3.10
30.	Proceed 4-5 nm on J230 past WPT RBV.	Verify that when passing WPT RBV the next WPT LOBES is automatically sequenced and becomes the active "TO" WPT.	En Route	2.2.1.2.4
31.	Recall WPT RBV on the display.	Verify that RBV can be recalled.	En Route	2.2.1.2.2
32.	Proceed on a 90 degree heading change to the right. ***Note:*** *This is intended to position the aircraft for a flyover of RBV from the north.*	The simulated aircraft should now proceed north of the airway.	En Route	2.2.1.2.2
33.	Turn right DIRECT TO RBV	Verify that equipment executes the Direct TO.	En Route	2.2.1.3.4
34.	Select a course of 181 degree to RBV. Set up equipment to not sequence the next waypoint in the flight plan. Execute. . ***Note:*** *Some equipment may have already accepted the route change and do not need to "execute" in order to perform the verification for this step.*	Verify that the current waypoint is RBV and then the RBV 181 degree radial (Flight will continue for 20.0 nm from the RBV). Verify that the flight plan waypoint sequencing is suspended (e.g., a flight plan discontinuity) and that the original flight plan is active.	En Route	2.2.1.2.4, 2.2.1.2.3.2
35.	Pass over WPT RBV and proceed out on the 181 degree radial.	Verify that an annunciation is issued prior to RBV. Verify that an annunciation is issued at the WPT crossing. Verify that the equipment shows "FROM" while proceeding out the RBV 181 degree radial. Verify the display resolution of 1. degrees (181).	En Route	2.2.1.2.4, 2.2.1.3.9

Step	Action	Success Criteria	Phase of	Requirement
36.	Scroll through the entire flight plan.	Verify the equipment permits scrolling through the flight plan.	En Route	2.2.1.2.1
37.	Enter and accept a WPT 20 nm from RBV on the 181 radial (WPT name is user defined)	Verify the equipment permits data entry of user defined WPT. Verify that the equipment shows a "TO".	En Route	2.2.1.2.4.1, 2.2.1.2.4
38.	Near the WPT 20 nm from RBV, leave the RBV 181 radial and proceed on a heading of 270 degrees.			
39.	Insert the 350 degree course inbound to WPT COPES.	Verify equipment permits data entry and provides information for accomplishing inbound course to COPES (CF).	En Route	2.2.1.2.1, 2.2.1.3.5
40.	Proceed inbound to COPES on the 350 degree course.	Verify that the active WPT is COPES and/or the active leg is the COPES 170 degree radial to COPES. Verify that the bearing is in 1. degree resolution.	En Route	2.2.1.2.4.1, 2.2.1.4.4
41.	Intentionally left blank.			
42.		Verify that the aircraft proceeds inbound on the COPES 170 degree radial.	En Route	2.2.1.3.5
43.		Verify that a turn anticipation annunciation is issued prior to a fly-by of WPT COPES. Verify that an annunciation is issued for turn initiation. Verify that an annunciation is issued for the bisector to COPES and that the next waypoint (SIELE) is sequenced.	En Route	2.2.1.3.9, 2.2.1.3.10.1
44.		Verify that when passing WPT COPES the next WPT SIELE is automatically sequenced and becomes the active WPT and/or COPES to SIELE becomes the active leg. ***Note:*** *This path is defined by a TF leg. WPT LOBES may be dropped from the flight plan.*	En Route	2.2.1.2.4.1

Step	Action	Success Criteria	Phase of	Requirement
45.	Set up the equipment to accomplish a holding pattern in the northeast quadrant of WPT SIELE with the following characteristics: "HOLD EAST OF SIELE ON J230, RIGHT TURNS, 10 MILE LEGS".	Verify that an annunciation is issued prior to WPT SIELE. Verify that an annunciation is issued at the WPT crossing. If automatic sequencing has been suspended, verify that the equipment indicates the condition. Verify that a holding pattern can be accomplished. ***Note:*** *Manually accomplishing a holding pattern may require additional equipment entries.*	En Route	2.2.1.3.11
46.		Verify that the equipment allows the selection of the inbound course of J230 (274 degrees) to the holding fix.	En Route	2.2.1.3.11
47.	Scroll through the entire flight plan while in the holding pattern.	After entering the holding pattern, verify that the remainder of the flight plan is retained.	En Route	2.2.1.2.2, 2.2.1.3.11
48.	After entering a second holding pattern and heading west on the inbound leg of the holding pattern, discontinue the holding pattern and continue on to SIELE.	Verify that the flight plan to LAX still exists as the active flight plan. ***Note:*** *A "DIRECT TO" or other commands may be necessary to reestablish flight plan sequencing.* Verify that an annunciation is issued prior to WPT SIELE. Verify that an annunciation is issued at the WPT crossing.	En Route	2.2.1.3.7, 2.2.1.3.9, 2.2.1.3.11
49.		Verify that the equipment has readily returned to automatic WPT sequencing prior to crossing SIELE and that the aircraft continues on the active flight plan.	En Route	2.2.1.2.4.1, 2.2.1.3
50.		Verify that the equipment recognizes the user defined intersection (Waypoint 6; J6/J230) and provides information to continue on the flight plan to WPT FLIRT.	En Route	2.2.1.3
51.		Verify that a turn anticipation annunciation is issued prior to a fly-by of intersection J230/J6. Verify that an annunciation is issued for turn initiation. Verify that an annunciation is issued for the bisector to Intersection J230/J6 and that the next flight plan wpt (FLIRT) is sequenced. Verify a “TO” indication is provided and bearing to WPT FLIRT.	En Route	2.2.1.3.6, 2.2.1.3.9, 2.2.1.3.10.1, 2.2.1.4.5, 2.2.1.4.4
52.		Verify that an annunciation is issued prior to WPT FLIRT and again at the WPT crossing.	En Route	2.2.1.3.7, 2.2.1.3.9

Step	Action	Success Criteria	Phase of	Requirement
53.		Verify that the numeric cross-track deviation is displayed, or that a electrical output is continuously provided during the en route mode.	En Route	2.2.2.4.3
54.	After passing WPT FLIRT enter a user defined WPT at current position.	Verify a user defined WPT can be created at the current position on the flight path. After passing WPT FLIRT verify that flight plan guidance continues on a straight line path.	En Route	2.2.1.2.6
55.	Initiate insertion of Martinsburg (KMRB) airport in the flight plan prior to WPT MRB when within 10 nm of approaching WPT MRB, but do not cause KMRB to become part of the active flight plan.	Verify that there is no mode switch from en route mode into terminal mode. ***Note:*** *MRB airport is about 5.9 nm from WPT MRB.*	En Route	2.2.2.7.2.1
56.	Test Completion	Verify that the equipment still recognizes MRB as the next WPT. This test is completed.	En Route	

TABLE 2-33 SIMULATED FLIGHT PLAN TEST NUMBER 2

Step	Action	Success Criteria	Phase of	Requirement
1.	Enter William R. Pogue Municipal Airport (airport identifier: 0F8, zero foxtrot eight,), Sand Springs, OK, as the departure and arrival airport.	Verify that the departure and arrival airport was accepted. Verify that the equipment accesses ICAO compliant airport nomenclature.	Preflight	2.2.1.2.1
2.	Enter vertical path information, such as altitude (2400 ft.), if required.	If applicable, verify that any vertical path information (altitude) is accepted.	Preflight	
3.	Bench test begins simulated flight -Take off Runway 35.		Terminal	
4.	Execute a turn left and proceed on a heading of 260^{o}.		Terminal	
5.	Retrieve GPS Approach to 0F8, runway 35	Verify that all IAWP's are available for selection (ACERT, CENTO, DARRO,).	Terminal	2.2.3.2.1 2.2.3.5
6.	Select DARRO as the IAWP and activate the approach. If applicable select 'Direct To' DARRO	Verify that DARRO is the IAWP. Verify that the NPA procedure consists of the following: a) Runway number and label, b) FAWP, MAWP and MAHWP	Terminal	2.2.3.2.1 2.2.3.5
7.		Verify that the approach waypoints ACERT, FANCY, and WILUM were automatically inserted in the active flight plan. Verify that the MAHWP ABCUX was automatically inserted in the active flight plan. Verify that the bearing and distance to the missed approach waypoint is available for display.	Terminal	2.2.3.2.1 2.2.1.4.7 2.2.3.4.4 2.2.3.4.5
8.		Verify that the direct to DARRO course was accepted. Verify that DARRO is the active waypoint. Verify that the equipment provides guidance to DARRO. Verify that a continuous indication is provided that the equipment is in 'TO' operation.	Terminal	2.2.1.2.5.2 2.2.1.2.5.3 2.2.1.4.6

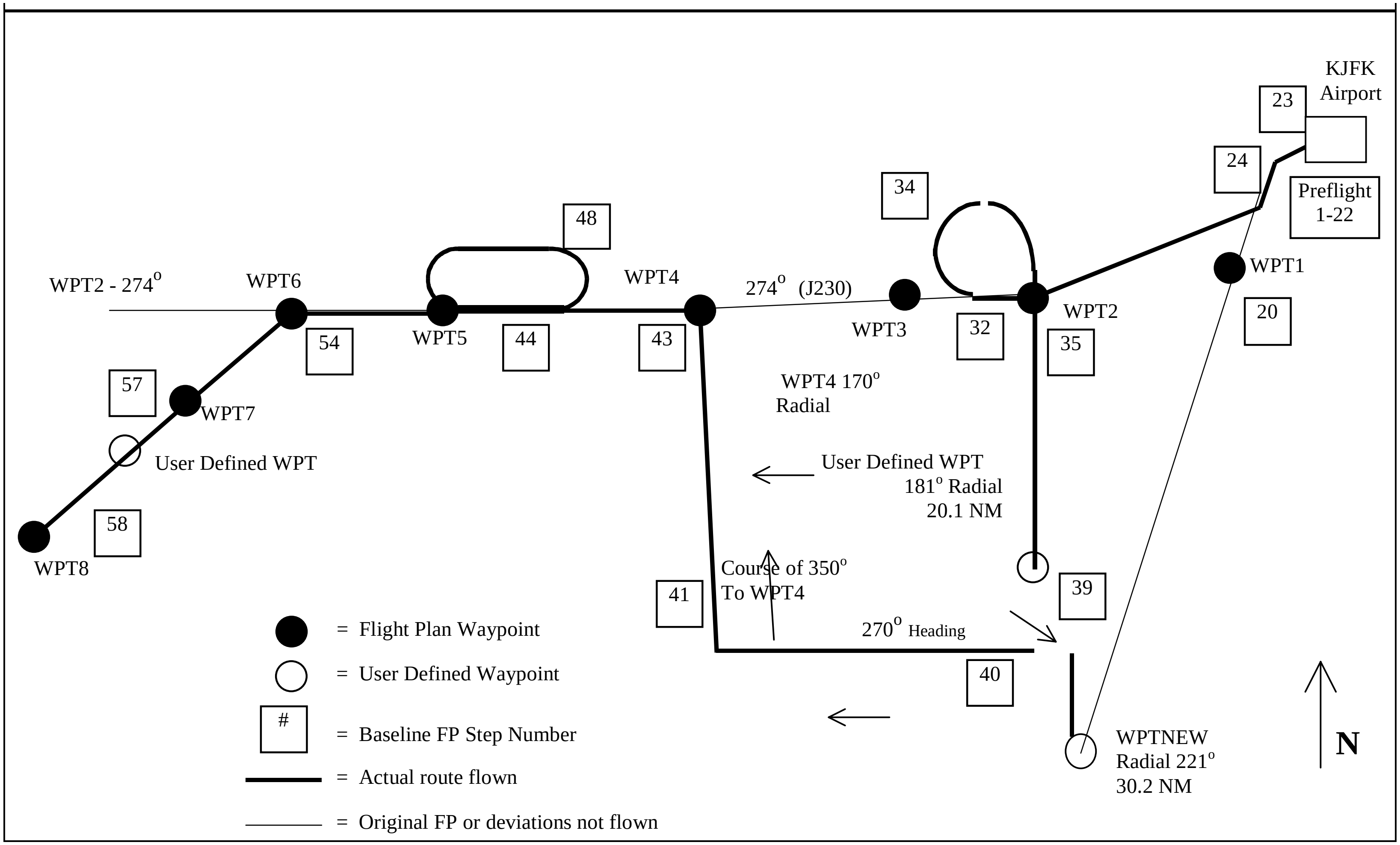
Step	Action	Success Criteria	Phase of	Requirement
9.		Verify that the following navigation parameters are displayed either continuously or on a selectable page: Active WPT distance or estimated time to WPT Active WPT name Active WPT bearing Desired track Actual track or track angle error	Terminal	2.2.1.4.1
10.		Verify that a turn anticipation annunciation is issued prior to a fly-by turn of WPT DARRO. Verify that an annunciation is issued for turn initiation. Verify that an annunciation is issued for sequencing (crossing) the WPT. Verify the waypoints are sequenced when the position is at the bisector of the angle formed by the leg to and from DARRO. Verify that the next waypoint ACERT is sequenced. ***Note:*** *The equipment should provide positive course guidance through the turn.*	Terminal	2.2.1.3.10 2.2.1.3.7 2.2.1.3.7.1
11.		After fly-by of DARRO request current navigation mode and verify that equipment has remained in Terminal mode. Verify that the equipment provides guidance for the fly-by turn by computing and displaying deviation commands to accomplish the turn.	Terminal	2.2.1.7
12.		Verify that the equipment provides an indication of the desired track of the next active leg prior to the onset of the turn anticipation indication. Verify that a turn anticipation annunciation occurs prior to the start of a fly-by turn of WPT ACERT. Verify that an annunciation is issued for turn initiation. Verify that an annunciation is issued for sequencing the WPT (e.g., at the bisector of the angle formed by the leg to and from ACERT). Verify that WPT FANCY (FAWP) is sequenced. Verify that the equipment provides guidance for a fly-by turn.	Terminal/ NPA	2.2.1.3.7.1 2.2.1.3.10 2.2.1.3.7

Step	Action	Success Criteria	Phase of	Requirement
13.		Verify automatic mode switch to NPA when the FAWP (WPT FANCY) is the active waypoint. Verify that WPT FANCY is uniquely identified as the FAWP.	NPA	2.2.1.7 Table 2-9 2.2.3.5
14.		Verify that an annunciation is issued prior to crossing WPT FANCY. Verify that an annunciation is issued at WPT FANCY. Verify that the next WPT, WILUM, is sequenced. Verify that WPT WILUM is uniquely identified as the MAWP.	NPA	2.2.1.3.10 2.2.3.5
15.		Verify that prior to crossing the MAWP the distance to the MAWP is displayed to a resolution of 0.1 nm. Verify that prior to crossing the MAWP the bearing to the MAWP is displayed to a resolution of 1 degree. Verify that the bearing can be display in true or magnetic.	NPA	2.2.3.4.5 2.2.1.2.5.2 2.2.3.4.4
16.	At WILUM (GPS RWY 35 missed approach waypoint) execute the missed approach.	Verify the missed approach can be executed with a manual action. Verify the display sensitivity changes immediately to $\pm$ 0.3 nm.	NPA/ Terminal	2.2.3.2.2 2.2.3.7.1.3
17.		Verify equipment automatically switches to terminal mode when the missed approach is initiated. Verify that at crossing the MAWP the sequenced waypoint is ABCUX. Verify the equipment provides guidance to the MAHWP. Verify that a 'TO' indication is displayed.	Terminal	Table 2-9 2.2.3.7.1.2 2.2.3.2.2 2.2.3.3.2 2.2.1.2.4
18.		Verify that at the first fix of the missed approach procedure (WPT WAHPT) the display sensitivity immediately changes to $\pm$ 1.0 nm.	Terminal	2.2.3.7.1.3
19.	Enter the holding pattern.	Verify that the equipment provides the capability for accomplishment of the holding pattern (hold NW of ABCUX on the ABCUX 349^o R, with right turns). ***Note:*** *A tear drop entry may be used to accomplish the published holding pattern.*	Terminal	2.2.1.3.11

Step	Action	Success Criteria	Phase of	Requirement
20.	Discontinuity in Test. Using the same flight plan information place the equipment prior to FAWP FANCY and continue test.	Restart test as necessary to place equipment in position prior to FAWP FANCY. A different set of requirements are verified by this second missed approach.	NPA	
21.		Verify that WPT FANCY is sequenced. After crossing the FAWP, verify that WILUM is sequenced.	NPA	2.2.1.3.10
22.	PRIOR to MAWP WILUM, execute a missed approach.	Verify the missed approach can be executed with a manual action. Verify equipment automatically switches to terminal mode with initiation of the missed approach. Verify that WILUM is a flyover waypoint. Verify the equipment sequences to ABCUX after crossing WILUM.	NPA/ Terminal	2.2.1.7 2.2.1.3.8 2.2.3.2.2 2.2.3.3.2
23.		Verify the display sensitivity immediately changes to $\pm$0.3 nm. Verify guidance is provided to the MAHWP.	Terminal	2.2.3.7.1.3
24.	Discontinuity in Test. Using the same flight plan information place the equipment prior to FAWP FANCY and continue test.	Restart test as necessary to place equipment in position prior to FAWP FANCY. A different set of requirements are verified by this third missed approach.	NPA	
25.		Verify that WPT FANCY is sequenced. Verify that an annunciation is issued prior to crossing WPT FANCY. Verify that an annunciation is issued at WPT FANCY.	NPA	2.2.1.3.7.1 2.2.1.3.10
26.		After crossing the FAWP, verify that the next WPT, WILUM, is sequenced. Verify the equipment crosses the MAWP (WPT WILUM).	NPA	2.2.1.3.10

Step	Action	Success Criteria	Phase of	Requirement
27.	After passing MAWP WILUM, do not select the missed approach.	Verify that the equipment automatically changes at the MAWP (WPT WILUM) from a 'TO' waypoint to a 'FROM' waypoint. Verify that after crossing the MAWP a prompt is provided to execute a missed approach. Verify the same course that existed prior to WILUM (349^o) is followed after WPT WILUM. ***Note:*** *Some equipment may not provide the prompt to execute the missed approach.*	NPA	2.2.3.2.2 2.2.3.3.2 2.2.1.3.6
28.	Proceed on a heading of 040^o		NPA	
29.	Execute the missed approach.	Verify the missed approach can be executed with a manual action. Verify that the equipment shows guidance to the MAHWP (WPT ABCUX). Verify that the mode automatically switches to Terminal.	NPA/ Terminal	2.2.1.7 2.2.3.2.2 2.2.3.3.2 2.2.1.3.11
30.	This test is complete.			

<u>FIGURE 2-21</u> FLIGHT PROFILE FOR FLIGHT PLAN 1



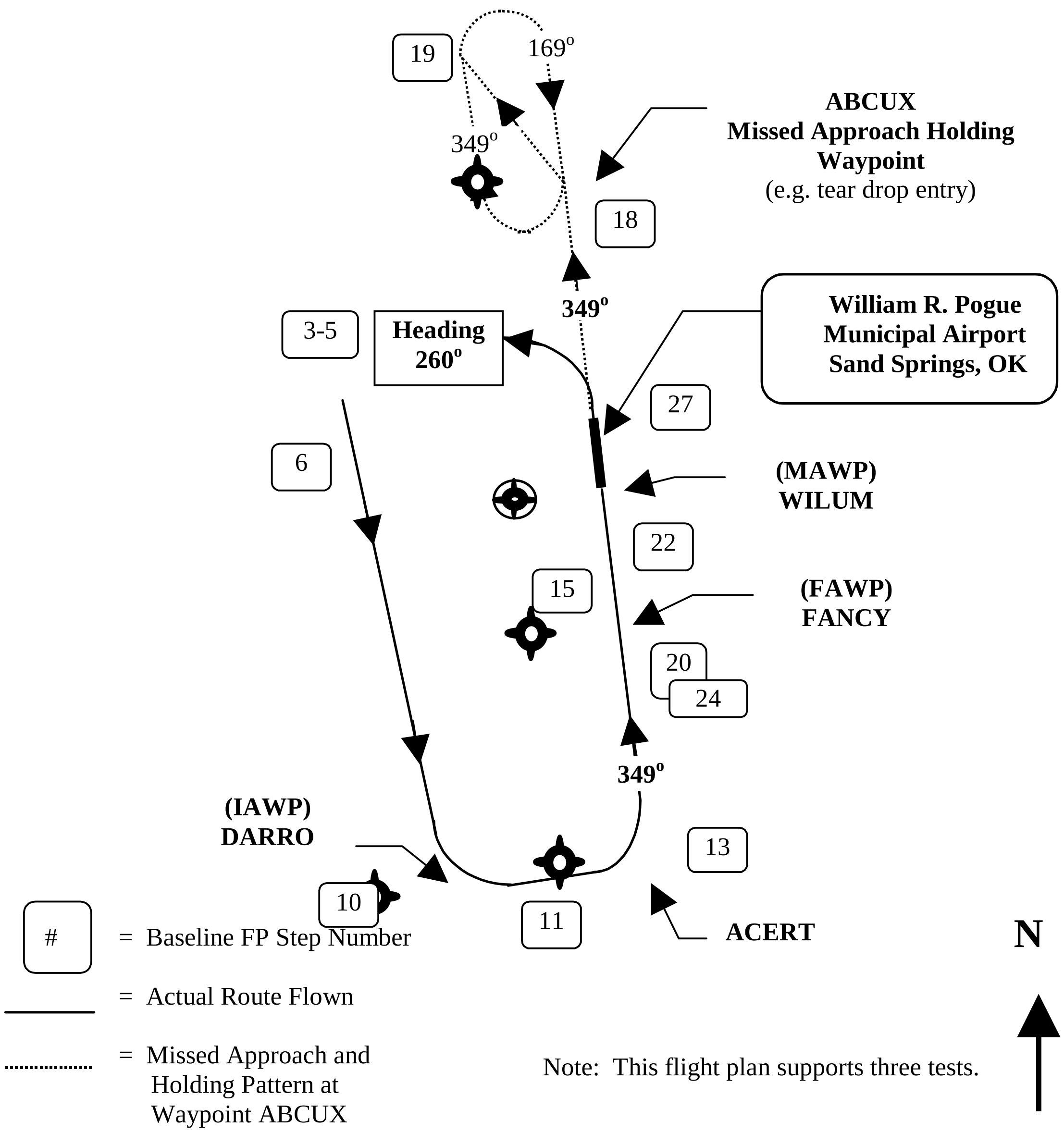


FIGURE 2-22 FLIGHT PROFILE FOR FLIGHT PLAN 2

2.5.11.1.2 **Waypoint Distance Display**

This bench test includes verifying requirements associated with the display of waypoint distances. The test involves simulating an active waypoint at various distances from the GPS/WAAS Gamma equipment and verifying the display readouts and resolutions.

1. Configure the equipment for bench tests as shown in Figure 2-19 or 2-20, as appropriate. Configure the GPS/WAAS simulator with the satellite constellation in Appendix B.
2. Position the active waypoint 102.3 nm from the aircraft and verify the distance readout is 102 nm. Step the aircraft position towards the waypoint in 0.1 nm increments from 102.3 to 99.7 nm. Verify the display resolution switches from 102 to 101, 100, 99.9, 99.8 and 99.7 nm.
3. Position the active waypoint 1002.3 nm from the aircraft and verify the distance readout is 1002 nm. Step the aircraft position towards the waypoint in 0.1 nm increments

from 1002.3 to 998.3 nm. Confirm the display resolution from 1002.3 to 998.3 is 1. nm and switches from 1002 to 1001, 1000, 999, and 998.

4. Position the active waypoint 9999 nm from the aircraft and verify the distance readout is 9999 nm. Step the aircraft position towards the waypoint in 1. nm increments from 9999 to 9995 nm. Confirm the display resolution from 9999 to 9995 is 1. nm and switches from 9999 to 9998, 9997, 9996, and 9995.

2.5.11.1.3 Equipment Response Time Test

This bench test verifies equipment response times. It includes measuring display latency, display update rates, and time to provide flight guidance during nominal and heavy processing conditions. The test objective is to verify that response times are meet under both normal and high usage conditions. The test requires the equipment to process two waypoint flight plans, activate a simulated flight, perform manual entries, exercise equipment functionality such as fault detection, and measuring equipment responses. The manufacturer has the option to select aircraft type and aircraft speeds but they should be appropriate for the intended equipment's market and application.

1. Setup the test equipment according to Figure 2-19 or 2-20, as appropriate. Configure the GPS/WAAS simulator with the satellite constellation in Appendix B and the equivalent simulated flight information from Table 2-32, Simulated Flight Plan Test Number 1. This test includes entering two flight plans and simulating a flight departure from New York (KJFK).
2. During this test measure equipment responses and verify that display latency does not exceed 1 second and the display update rate in en route and terminal mode is at least 1 Hz. Verify that guidance derived from flying this course is provided in at least five seconds. Verify that the time between accepting changes to active flight plan and outputing navigation guidance does not exceed five seconds.
3. Make the following changes to Table 2-32.
    a. At step 31 add the following:

       ACTION: Reduce the number of satellites simulated in the satellite constellation in Appendix B until a navigation alert is annunciated. Restore all satellites in the constellation.

       SUCCESS CRITERIA: Verify that a caution is annunciated for loss of navigation capabilities. Verify the caution is annunciated within 6 seconds. Verify that the navigation data (e.g., distance to waypoint) is flagged or removed.
    b. At step 39 add the following:

       ACTION: Execute the function(s) necessary to identify the nearest [NRST] nine (9) airports to the current position.

       SUCCESS CRITERIA: Verify that the nine airports presented are the closest airports to the position according to the database. Verify equipment responses (e.g., display update rate) are within required times.
4. Conduct the test steps 1 to 41 provided in Table 2-32. Note any test anomalies that occur during the test. Verify that the success criteria for each step is satisfactory. Verify the equipment response times meet requirements during the entire test.

2.5.11.1.4 Loss of Power and Navigation Cautions and Annunciations

The following test verifies the indication of loss of navigation capability for specific situations. This test is not inclusive of all causes for the annunciation of a loss of navigation. This test can be used to verify loss of both General Loss of Navigation Caution (2.2.1.6.2), En Route/Terminal (2.2.2.6.2) and NPA Navigation Caution (2.2.3.6.2). The manufacturer must still verify by inspection of documentation the applicable requirements.

1. Setup the test equipment according to Figure 2-19 or 2-20, as appropriate. Configure the GPS/WAAS simulator with the satellite constellation in Appendix B. Conduct the following test procedures and verify that an indication is provided for loss of navigation with each step.
2. Remove the electrical power to the equipment. Verify that a caution is annunciated for loss of navigation capabilities within one second. Verify the caution is a unique, independent annunciator. Verify that for NPA qualified equipment that a loss of navigation indication is provided by means of a dropped navigation flag. Restore the power. Verify that the equipment returns to its normal state. If the Gamma equipment uses multiple or separate power inputs (power for separate components such as a display and receiver), repeat this step by removing power for each component. Verify a loss of navigation caution is annunciated, restore the power and verify a return to normal state for each instance.
3. Reduce the number of satellites simulated in the satellite constellation in Appendix B until a navigation alert is annunciated. Verify that a caution is annunciated for loss of navigation capabilities within the time-to-alert period plus one second (en route is 6 seconds). Verify that the navigation data (e.g., distance to waypoint) is flagged or removed. Verify that for NPA qualified equipment that a loss of navigation indication is provided by means of a dropped navigation flag. Restore all satellites in the constellation. Verify that the equipment returns to its normal operating state.
4. Create a condition were the Gamma equipment will determine that an equipment malfunction or failure has occurred (e.g., disconnect antenna, Gamma equipment software failure). Verify that a caution is annunciated for loss of navigation capabilities within one second. Verify that for NPA qualified equipment that a loss of navigation indication is provided by means of a dropped navigation flag. Correct the malfunction or induced failure and verify that the equipment returns to its normal operating state.
5. Verify that the equipment distinguishes between the different causes of loss of navigation created in steps 2 to 4.

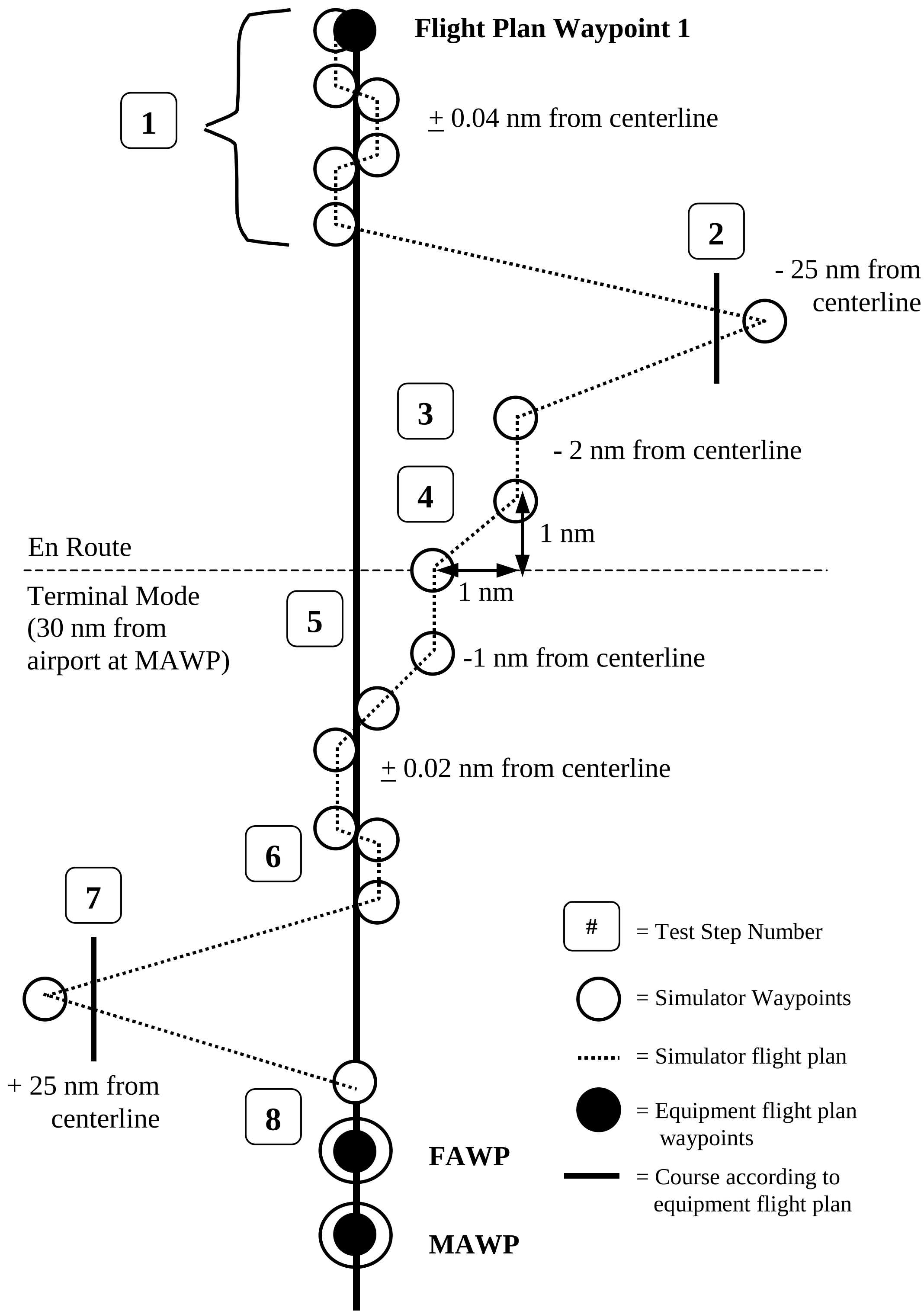
2.5.11.1.5 Cross-Track Deviation Display Bench Test for En Route and Terminal

Bench testing of some requirements necessitate test conditions where the simulated aircraft position (RF signals output from the simulator) differs from the active Gamma equipment flight plan. For example, to test nonnumeric display deviations of aircraft position, the simulated output positions from the GPS/WAAS simulator deviate from the processed flight plan. This difference will provide an aircraft course deviation from the flight plan and permit verification of appropriate display requirements. This bench test uses this test condition. This bench test also verifies some manual mode switching requirements.

1. Configure the equipment as shown in Figure 2-19 or 2-20, as appropriate. Configure the GPS/WAAS simulator with the satellite constellation in Appendix B. Turn off the Selective Availability (SA).
2. Program the simulator to the waypoints shown in Figure 2-23 (Cross Track Deviation for En Route and Terminal) and Table 2-34 (Waypoints for Cross Track Deviation). Table 2-34 includes the latitudes and longitudes for the simulator waypoints and flight plan waypoints for an approach to Atlantic City International airport (ACY). The table also includes additional information to assist in test preparations and execution. This includes deviation distances from the flight path centerline and range along

the centerline from runway threshold. The table includes the Geodesic coordinates for a direct flight. These Geodesic points are flight points on the flight centerline to the simulator waypoints. Comments are also provided for each test step in Table 2-35.

3. Enter the flight plan information into the Gamma equipment for a direct flight from waypoint 1 to ACY runway 13 as shown in the figure. The airport forces the mode switch from En route to terminal at 30 nm from the airport. Conduct the test and verify the steps in Table 2-35.



<u>FIGURE 2-23</u> CROSS-TRACK DEVIATION FOR EN ROUTE AND TERMINAL

TABLE 2-34 WAYPOINTS FOR CROSS TRACK DEVIATION BENCH TEST FOR EN ROUTE AND TERMINAL

Test Step No.	Flight Plan Wypt	Sim. Wypt No.	**Simulator Waypoints** Latitude	Longitude	FP Range to airport (nm)	Cross-Track Dev. (nm)	**Geodesic- Flight points on Great Circle path** Latitude	Longitude	Comments
1	1				64.0	0	N 39 58 30.67003	W 075 48 44.86552	FP wypt No.1 64nm, bearing 117.9875
		1	N 39 58 28.54907	W 075 48 46.33055	64.0	0.04			First Simulator wypt offset from FP.
		2	N 39 58 0.36510	W 075 47 37.41888	63.0	0.04	N 39 58 2.48582	W 075 47 35.9542	These waypoints are used to show a minimum discernible movement on the non-numeric display. The simulator outputs position information that shows deviations from the flight plan centerline of "0.04 nm.
		3	N 39 57 36.41067	W 075 46 25.59114	62.0	-0.04	N 39 57 34.29019	W 075 46 27.05705	
		4	N 39 57 8.20339	W 075 45 16.71007	61.0	-0.04	N 39 57 6.08315	W 075 45 18.17640	
		5	N 39 56 35.74471	W 075 44 10.77819	60.0	0.04	N 39 56 37.86471	W 075 44 9.31146	
		6	N 39 56 7.51511	W 075 43 19.92940	59.0	0.04	N 39 56 9.63487	W 075 43 0.46225	
2		7	N 40 13 29.00575	W 075 16 8.28826	49.0	-25.00	N 39 51 26.71086	W 075 31 32.83425	The equipment must show a numeric cross track deviation of -20 nm. This is shown by having the simulator output positions -25 nm from the flight plan centerline.
3		8	N 39 46 34.40862	W 075 14 18.90203	35.0	-2.00	N 39 44 48.71420	W 075 15 32.79225	In the en route mode the full scale deflection is 2.0 nm from centerline.
		9	N 39 46 5.88373	W 075 13 10.42463	34.0	-2.00	N 39 44 20.20127	W 075 14 24.33544	

Test Step No.	Flight Plan Wypt	Sim. Wypt No.	Simulator Waypoints Latitude	Simulator Waypoints Longitude	FP Range to airport (nm)	Cross-Track Dev. (nm)	Geodesic- Flight points on Great Circle path Latitude	Geodesic- Flight points on Great Circle path Longitude	Comments
4		10	N 39 43 18.85611	W 075 09 13.67629	30.0	-1.00	N 39 42 26.03709	W 075 09 50.66493	Transition of full scale deflection from en route to terminal mode is from 2 to 1 nm. Terminal full scale deflecion is 1 nm.
5		11	N 39 42 50.28100	W 075 08 5.28759	29.0	-1.00	N 39 41 57.46796	W 075 08 42.28647	Waypts 10 & 11 are 1 nm from centerline
		12	N 39 41 29.94379	W 075 07 33.18365	28.0	-0.02	N 39 41 28.88761	W 075 07 33.92368	Minimum discernible movement on non-numeric display in terminal mode ("0.02 nm from centerline).
		13	N 39 40 59.23999	W 075 06 26.31678	27.0	0.02	N 39 41 0.29605	W 075 06 25.57655	
		14	N 39 40 44.94027	W 075 05 52.14966	26.5	0.02	N 39 40 45.99606	W 075 05 51.40886	
		15	N 39 40 18.44356	W 075 04 42.34468	25.5	-0.02	N 39 40 17.38768	W 075 04 43.08522	
6		16	N 39 40 4.13511	W 075 04 8.18863	25.0	-0.02	N 39 40 3.07929	W 075 04 8.92927	
7		17	N 39 13 16.98428	W 075 08 11.11450	15.0	25.00	N 39 35 16.32449	W 074 52 46.63195	The equipment must show a numeric cross track deviation of +20 nm. This is shown by having the simulator output positions +25nm from the flight plan centerline.
8		18	N 39 30 28.45544	W 074 41 25.89835	5.0	0.00	N 39 30 28.4554	W 074 41 25.89835	Simulator wypts = flight centerline.
	2	19	N 39 30 14.03284	W 074 40 51.90268	4.5	0.00	N 39 30 14.03284	W 074 40 51.90268	Simulator wypt 19 = FP FAWP
	3	20	N 39 28 4.10484	W 074 35 46.11732	0.0	0.00	N 39 28 4.10484	W 074 35 46.11732	Simulator wypt 20 = FP MAWP/DP

TABLE 2-35 TEST SEQUENCE FOR EN ROUTE AND TERMINAL CROSS-TRACK DEVIATION

STEP	Success Criteria and Observations
1	Verify at step 1 in Figure 2-23 that a minimum discernible movement is apparent in the non-numeric display. This movement corresponds to a +2% (0.04 nm) and -2% (0.04 nm) of the full scale (±2 nm in the en route mode). Verify that the resolution of the electrical output is 1% of full scale.
2	Verify that at step 2 in Figure 2-23 the numeric display or electrical output for the cross-track deviation is at least -20 nm (left).
3	Verify that at step 3 in Figure 2-23 the nonnumeric display or electrical output for the full scale deflection is 2.0 nm for En Route mode.
4	Verify that prior to entering the terminal area the display sensitivity increases gradually within 1 nm.
5	Verify that an automatic mode switch from En Route to Terminal occurs. Verify that an annunication is provided to indicate a mode switch. Verify that at step 5 in Figure 2-23 the nonnumeric display or electrical output for the full scale deflection is 1.0 nm for terminal mode.
6	Verify that at step 6 in Figure 2-23 that a minimum discernible movement is apparent in the non-numeric display. This movement corresponds to a ±2% (±0.02 nm) of the full scale (1 nm in terminal mode). Verify the resolution of the electrical output is +1% of full scale.
7	Verify that at step 7 in Figure 2-23 the numeric display or electrical output for the cross-track deviation is at least +20 nm (right).
8	At step 8 in Figure 2-23 both the simulator inputs and flight plan are equal. Verify that at step 8 in Figure 2-23 the accuracy of the nonnumeric centered display is at least ± 3% of full scale.

2.5.11.1.6 Cross-Track Deviation Display Test for NPA

This bench test requires the Gamma equipment to process flight data different from the GPS/WAAS simulator in order to verify NPA display requirements. The manufacturer has the option to select aircraft type and aircraft speeds. This test is for a NPA that is not a VTF approach.

1. Configure the equipment as shown in Figure 2-19 or 2-20, as appropriate. Configure the GPS/WAAS simulator with the satellite constellation in Appendix B. Turn off the Selective Availability (SA). Program the simulator to the waypoints shown in Figure 2-24. Enter the flight plan information into the Gamma equipment for a straight NPA.
2. Conduct the test and verify the steps in Table 2-36.

TABLE 2-36 TEST SEQUENCE FOR NPA CROSS TRACK DEVIATION

STEP	Success Criteria and Observations
1	At step 1 in Figure 2-24 the equipment starts processing in Terminal mode beginning at Flight Plan WPT 1. The equipment is programmed to head directly toward the airport runway in order to conduct a NPA. This waypoint is 27.8 nm from MAWP/DP. The simulator waypoint begins at a point 1.0 nm perpendicular to FP, which is at the terminal mode full-scale deflection (negative).
2	Verify that the nonnumeric display or electrical output indicates the full scale deflection between steps 1 and 2. Verify the FSD is-1.0 nm. At step 2, the 2.0 degree wedge intercepts the 1.0 nm FSD at a distance of 26.8 nm from the MAWP, along the flight path.
3	Verify that the nonnumeric display or electrical output indicates that the full scale deflection was maintained between step 2 and step 3. The simulated inputs will now transition to a positive FSD along the 2 degree wedge beginning in step 4.
4	Verify that the nonnumeric display or electrical output indicates a positive FSD.
5	Verify that the nonnumeric display or electrical output indicates a positive full scale deflection between steps 4 and 5.
6	At this step the 2.0 degree wedge is 0.30 nm perpendicular from the flight path and a distance of 6.94 nm from the MAWP along the flight path. Verify that the display indicates a negative full scale deflection at this point.
7	Verify that the display or electrical output indicates a positive, angular full scale deflection between steps 6 and 7.
8	Verify that the nonnumeric display or electrical output indicates no deviation from the flight path. The simulator flight path and flight plan overlap from step 8 until the MAWP.
9	Verify that after crossing the MAWP the full scale deflection is 350 feet.

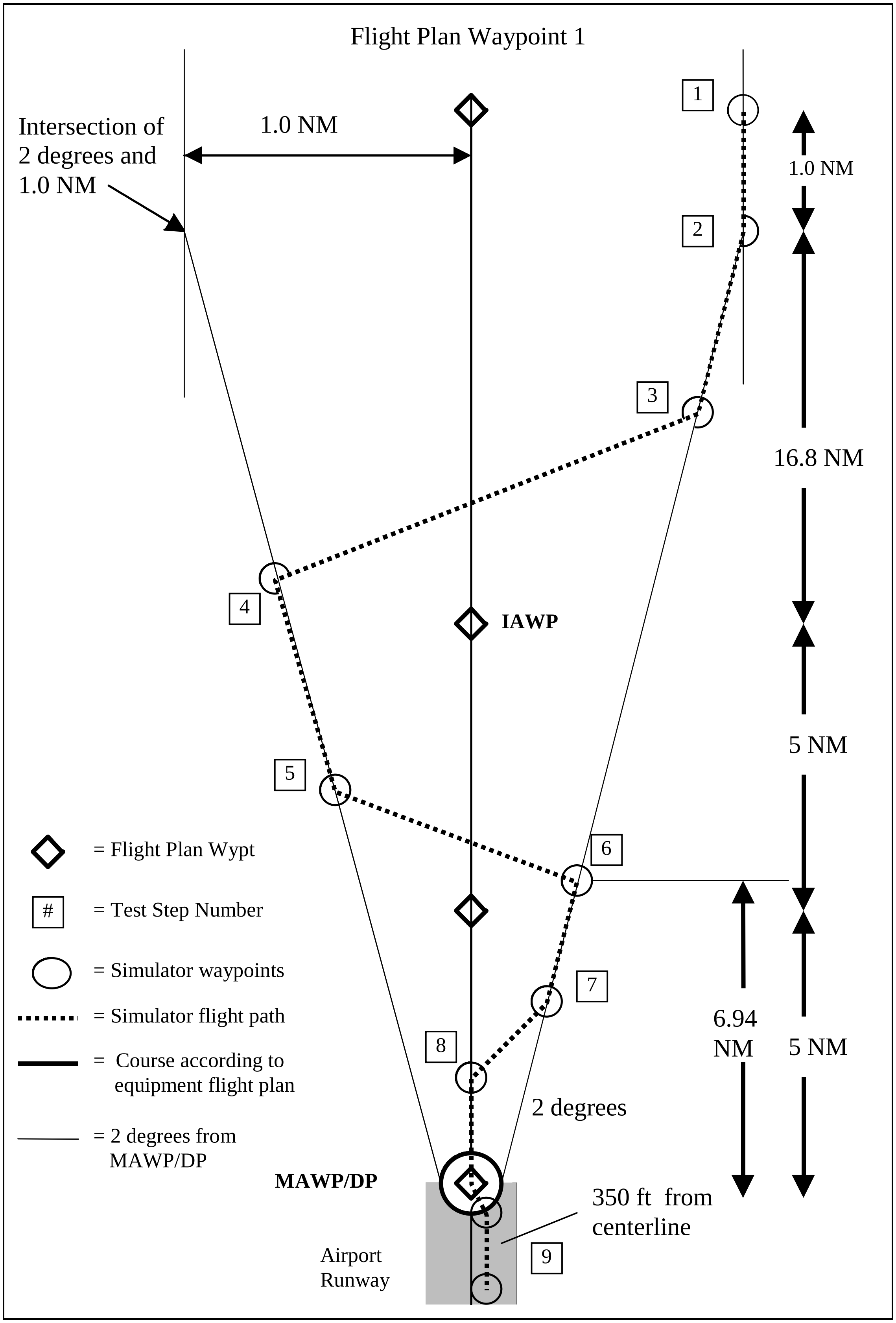


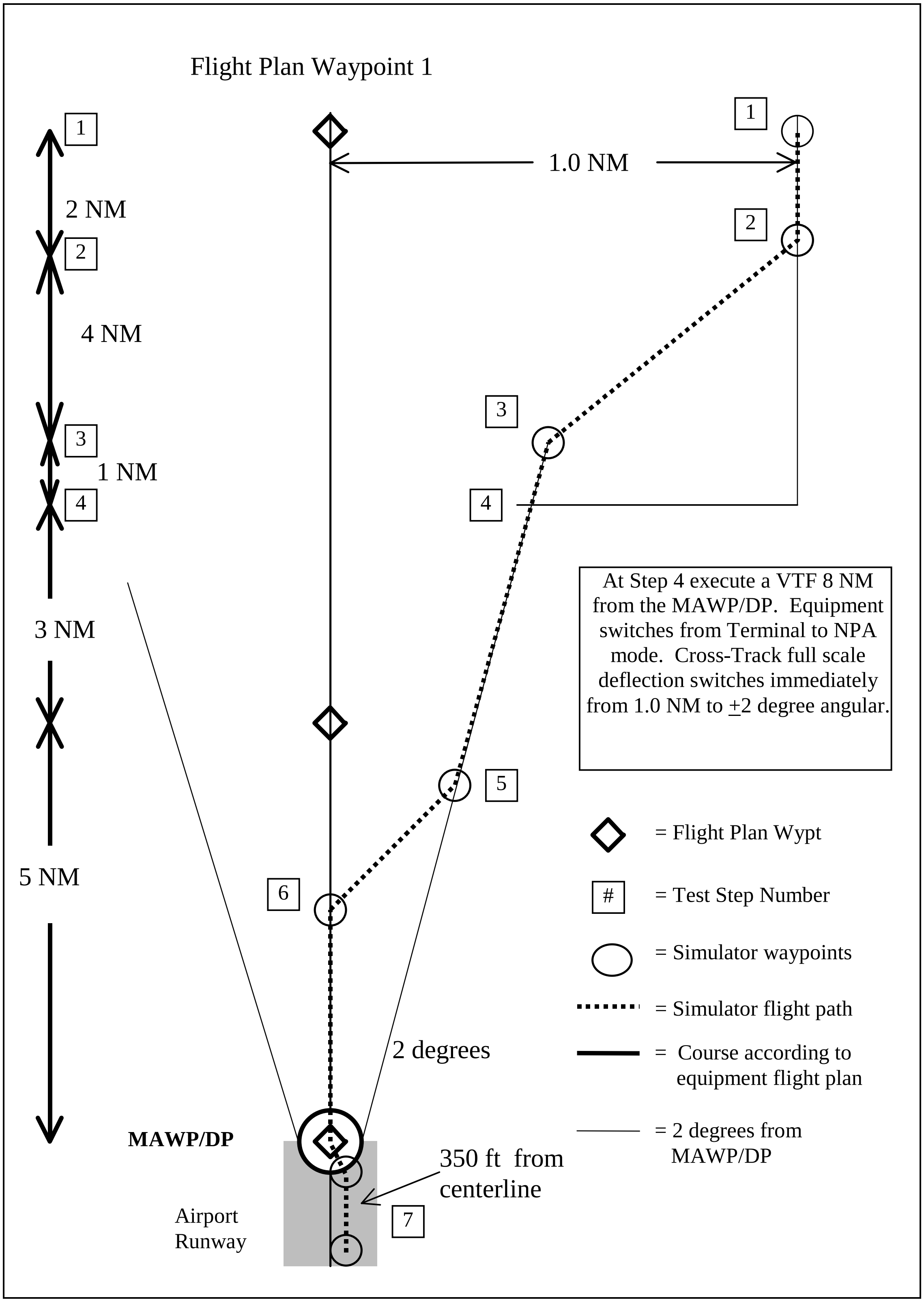
FIGURE 2-24 CROSS TRACK DEVIATION FOR NPA

This bench test requires the Gamma equipment to process flight data different from the GPS/WAAS simulator in order to verify NPA display requirements. The manufacturer has the option to select aircraft type and aircraft speeds.

1. Configure the equipment as shown in Figure 2-19 or 2-20, as appropriate. Configure the GPS/WAAS simulator with the satellite constellation in Appendix B. Turn off the Selective Availability (SA). Program the simulator to fly the simulator flight path shown in Figure 2-25. Enter the flight plan information into the Gamma equipment for a VTF NPA as shown in the figure.
2. Conduct the test and verify the steps in Table 2-37.

TABLE 2-37 TEST SEQUENCE FOR VTF NPA CROSS-TRACK DEVIATION

STEP	Success Criteria and Observations
1	At step 1 in Figure 2-25 the equipment starts processing in Terminal mode at Flight Plan WPT 1. The equipment is programmed to head directly toward the airport runway in order to conduct a VTF NPA. This waypoint is 15 nm from the MAWP/DP. The simulator waypoint begins at a point 1.0 nm perpendicular to the FP, and at the terminal mode full-scale deflection (negative).
2	Verify that the nonnumeric display or electrical output indicates FSD between steps 1 and 2. Verify the FSD is -1.0 nm.
3	Verify that the nonnumeric display or electrical output is less than the full scale deflection between steps 2 and 3.
4	Execute a VTF NPA 3 nm from the FAWP (8 nm from the MAWP/DP or 9.645 nm from the runway threshold) along the flight path. Verify the equipment switches from Terminal mode to NPA mode. At this step the FSD is along the 2.0 degree wedge and is $\pm$0.337 nm perpendicular from the flight path. Verify that the angular nonnumeric display or electrical output indicates full scale deflection.
5	Verify that the display or electrical output indicates a negative, full scale deflection is along the 2.0 degree wedge between steps 4 and 5.
6	Verify that the nonnumeric display or electrical output indicates no deviation from the flight path. The simulator flight path and the flight plan overlap from step 6 until the MAWP/DP.
7	Verify that after crossing the MAWP the full scale deflection is 350 feet.



<u>FIGURE 2-25</u> CROSS-TRACK DEVIATION FOR VECTORED NPA

2.5.11.2 Reserved

2.5.11.3 Human Factors Bench Tests

The following static bench tests verify the usability of the Gamma equipment controls and displays. They include equipment usage, display characteristics, audible alerts, and equipment controls. A series of test cases are followed by checklists that an evaluator completes to assess the equipment requirements. See Tables 2-38, 2-39, 2-40, and 2-41. The qualification of each item is based on the requirements in section 2.2.

Note: *These checklists are based on the FAA Human Factors and Operations Checklist for Standalone GPS receivers (TSO-C129 A1) dated Dec. 1994.*

2.5.11.3.1 Equipment Usability

The objective of this test is to evaluate the Gamma equipment's data entry, display information, and workload. This is accomplished by entering a flight plan (e.g., waypoints), editing the flight plan, and assessing the usability of the equipment to perform these tasks. The test procedure is to enter the two flight plans from the bench test in paragraph 2.5.11.1.1.1 (Table 2-32) into the Gamma equipment using only one hand. This task will include entering waypoints using different methods, scrolling through the flight plan, retrieving and editing waypoints, conducting flight plan entry procedures, etc. After conducting the bench test in paragraph 2.5.11.1.1.1, or an equivalent test, evaluate the capabilities of the equipment according to Checklist 1 (Table 2-38) (Equipment Usability) indicating the results as pass, pass with exception, or fail. The 'pass with exception' evaluation provides a means to note when a criteria item is satisfactory but remedial action should be considered by the manufacturer, or the capability is marginal but acceptable.

2.5.11.3.2 Display Brightness and Readability Test

The objective of this bench test is to evaluate the brightness and readability of the numeric and non-numeric displays under various lighting conditions. If applicable, this test would also be conducted for a moving map display. This test involves qualitative assessments of the displays under three ambient light conditions: Dark, Indirect lighting, and Bright. The test procedure is to conduct the test cases in Checklist 2 (Display Brightness) by viewing the Gamma equipment displays from a distance and viewing angle similar to the perspective of a pilot for installed equipment. Evaluate the equipment according the evaluation criteria in the Checklist indicating the results as pass, pass with exception, or fail.

TABLE 2-38 HUMAN FACTORS TEST: CHECKLIST 1. EQUIPMENT USABILITY

Evaluation Criteria	Pass	Pass/ exception	Fail
Data Entry Procedures 1. Feedback is provided during data entry. 2. Programming steps are simple and easy. 3. Confirmation of action is provided prior to activation.			
Display Information 1. Waypoints category information is displayed. 2. Waypoint to be edited is clearly denoted. 3. Any prompts are understandable & consistent. 4. Capability provided to verify data entry. 5. Route legs are identifiable. 6. Routes are identifiable. 7. Distance & Bearing are clearly distinquishable. 8. Desired track, Actual track, and Track angle error are clearly distinquishable from one another. 9. When multiple actions are necessary to perform a function, the equipment provides contextual information of the active subfunction or mode that is unambiguous.			
Moving Map Display (if applicable) 1. Symbology is distinct: Clear indication of individual position, Distinction between overlapping symbols, tracks from course lines, Distinction between symbols in close proximity. 2. Map motion is not distracting: Screen refresh rate is not distracting, Symbols maintain shape integrity. 3. Map characteristics are apparent: Clear indication of track-up and north-up, display of map scale.			
Workload 1. Dependence on memory to complete a task is minimal. 2. Minimum number of controls needed to complete tasks. 3. Single hand operation to complete tasks.			

TABLE 2-39 HUMAN FACTORS TEST: CHECKLIST 2. DISPLAY BRIGHTNESS

Evaluation Criteria	**Pass**	**Pass / exception**	**Fail**
Test Case 1. Dark Ambient Conditions. Equipment displays are presenting flight plan information with no ambient lighting (artificial or natural lighting). 1. Brightness adjustments are acceptable and easy to use. (If manual adjustments are available.) 2. Colors are clearly distinguishable from one another. 3. Small symbols can be discriminated from one another. 4. Small alphanumerics can be discriminated. *1 5. Characters embedded in text can be discriminated. 6. Control labels & displays are readable from 30 inches. 7. Displays are readable from up to 35 degrees in the horizontal plane normal to the display. 8. Displays are readable from up to 20 degrees in the vertical plane normal to the display. 9. Visual alerts are apparent and alert illumination is not disruptive to pilots dark adaptation.			
Test Case 2. Indirect, Reflected Ambient Conditions. Equipment displays FP information in a normal level of artificial (room) and indirect natural lighting. Test observer faces equipment & window during daylight. 1. Brightness adjustments are acceptable and easy to use. (If manual adjustments are available.) 2. Colors are clearly distinguishable from one another. 3. Small symbols can be discriminated from one another. 4. Small alphanumerics can be discriminated. *1 5. Characters embedded in text can be discriminated. 6. Control Labels & displays are readable from 30 inches. 7. Displays are readable from up to 35 degrees in the horizontal plane normal to the display. 8. Displays are readable from up to 20 degrees in the vertical plane normal to the display. 9. Visual alerts are apparent on the display.			
Test Case 3. Bright Ambient Conditions. Equipment displays FP information with a normal level of artificial (room) lighting and direct sunlight reflecting on equipment displays. 1. Brightness adjustments are acceptable. (If manual adjustments are available.) 2. Colors are clearly distinguishable from one another. 3. Small symbols can be discriminated from one another. 4. Small alphanumerics can be discriminated. *1 5. Characters embedded in text can be discriminated. 6. Control labels & displays are readable from 30 inches. 7. Displays are readable from up to 35 degrees in the horizontal plane normal to the display. 8. Displays are readable from up to 20 degrees in the vertical plane normal to the display. 9. Light reflection causes no distraction. 10. Reflection causes no interference with displayed information. 11. Visual alerts are apparent on the display.			

*1 Example is distinguishing '2' from 'Z', and '5' from 'S'.

2.5.11.3.3 Audible Alerts Test

The objective of this bench test is to evaluate the quality and discrimination between audible alerts for Gamma equipment that implements audible alerts. This test involves qualitative assessments of auditory alerts by an observer with average hearing capabilities and using a test configuration that may include using a representative pilots headset.

Test procedure includes presenting all of the auditory alerts that can be issued from the equipment to the test observer. The observer deactivates each individual alert. After hearing all the auditory alerts the observer evaluates the alerts according to Checklist 3 (Audible Alerts) indicating the results as pass, pass with exception, or fail.

TABLE 2-40 HUMAN FACTORS TEST: CHECKLIST 3. AUDIBLE ALERTS

Evaluation Criteria	Pass	Pass / exception	Fail
Audibility/Distraction Level 1. Sufficiently loud, Quality of pitch, duration of alert.			
Alert Distinction 1. Discriminate alerts by pitch, loudness, and pattern.			
Distinction between Critical and Non-Critical Alerts 1. Discriminated the critical and non-critical alerts; Loudness, pitch, duration or pattern.			
Alert Deactivation 1. Alerts are easily deactivated.			
Workload, Memory requirements 1. Dependence on memory for the alerts is minimal, Redundant Alert status indicated (display and sound).			

2.5.11.3.4 Equipment Controls Test

The objective of this bench test is to evaluate the knobs and buttons for ease of use and functionality for equipment operations. This test involves qualitative assessments of characteristics of the equipment and that the equipment's design minimizes operator errors.

Test procedure includes presenting the Gamma equipment from a distance and viewing angle similar to the perspective of a pilot for the installed equipment. The test participant exercises all the knobs and buttons according to their intended use. After operating the equipment the observer evaluates the equipment according to Checklist 4 (Equipment Controls) indicating the results as pass, pass with exception, or fail.

TABLE 2-41 HUMAN FACTORS TEST: CHECKLIST 4. EQUIPMENT CONTROLS

Evaluation Criteria	Pass	Pass / exception	Fail
Activation 1. Force required to activate knobs/buttons is acceptable. 2. Feedback is adequate, minimal risk of inadvertent activation or deactivation.			
Accessibility 1. Requires only single hand operations, identifiable, use does not obscure displays.			
Arrangement 1. Logical arrangement according to functional groups, sequence of use, and frequency of use.			
Operations 1. Minimal chance of error, Easy error recovery, usability.			
Knob Shape & Size 1. Does not interfere with use, distinguishable, aids in pilots use.			
Labels 1. Construction: Discernible and readable on equipment. 2. Placement: Unobstructed by use. 3. Terminology: Labels describe function of knob, Are consistent across equipment, abbreviations conform to aviation usage.			

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3 INSTALLED EQUIPMENT PERFORMANCE

3.1 General Requirements

This section addresses the installed equipment requirements of Class Beta, Gamma and Delta Equipment as described by Table 3-1.

TABLE 3-1 EQUIPMENT CLASSES AND ORGANIZATION OF SECTION 3

Section		Must be met for Equipment Class						
		Beta			**Gamma**			**Delta**
		1	2	3	1	2	3	4
3.1	General Requirements	X	X	X	X	X	X	X
3.2	Class Beta Equipment	X	X	X				
3.3.1	Class Gamma Equipment — General Requirements for all Navigation Modes				X	X	X	
3.3.2	Class Gamma Equipment to Support En Route, Terminal Area, and Non-Precision Approach Navigation				X	X	X	
3.3.3	Class Gamma Equipment to Support LNAV/VNAV Navigation					X	X	
3.3.4	Class Gamma Equipment to Support GLS and APV-II Navigation						X	
3.4	Class Delta Equipment to Support GLS and APV-II Navigation							X

3.1.1 Installation Requirements

3.1.1.1 Accessibility

Controls installed for in-flight operation shall be readily accessible from the pilot's seated position. Only single-hand operation should be required, the controls should be readily identifiable, and the use of the controls should not obscure pertinent displays.

3.1.1.2 Interference Effects

The equipment shall not be installed in such a manner as to be the source of objectionable conducted or radiated interference or to be adversely affected by conducted or radiated interference from other equipment or systems installed in the aircraft.

Given the relatively low signal power of GPS/WAAS, special precautions may have to be taken to prevent interference. The following factors are among those which should be considered:

- Double-shielded cabling may need to be used between the GPS/WAAS antenna and GPS/WAAS equipment.
- The GPS/WAAS antenna should be separated as much as possible from other antennas (e.g., VHF, SATCOM, and HF in particular) and the windscreen (to prevent case-to-antenna coupling).
- Installations involving multiple GPS/WAAS equipments may require special isolation techniques.

- The GPS/WAAS equipment should generally be installed as far away as feasible from any VHF transmitter boxes.
- Both DME and a faulty ELT have been known to cause interference to GPS.

3.1.1.3 Inadvertent Turnoff

There shall be a minimum risk of inadvertent turnoff.

3.1.2 Installed Equipment Performance Requirements

3.1.2.1 General Performance Requirements

The installed equipment shall meet the applicable requirements contained in Section 2.1.1 in addition to, or as adapted by, the requirements stated below. Further, the installed equipment shall meet the applicable requirements contained in Sections 2.1.2, 2.1.3, 2.1.4, and 2.1.5 depending upon the Class of equipment (Class 1 through 4), as depicted in Table 1-1 of this document.

3.1.2.2 Coverage

When the aircraft is within the nominal WAAS coverage area, the installed equipment shall meet applicable performance requirements in Section 2. This shall include bank angles of up to 30 degrees and pitch angles associated with approaches and departures.

3.1.3 Conditions of Test

Conditions stated in the following paragraphs are applicable to equipment tests specified in Sections 3.1.4, 3.3.1.3, 3.3.2.3, 3.3.3.3, 3.3.4.3, 3.3.5.3 and 3.4.3.

3.1.3.1 Test Environment

Unless otherwise specified, tests are to be conducted with the equipment installed in the aircraft type of intended use and powered by the aircraft's electrical power generating system.

3.1.3.2 Associated Equipment or Systems

Unless otherwise specified, all electrically operated aircraft equipment and systems must be operational before conducting interference tests.

3.1.3.3 Environmental Conditions

During tests, the equipment shall not be subjected to environmental conditions that exceed those specified by the manufacturer.

3.1.3.4 Adjustment of Equipment

Circuits of the equipment under test shall be properly aligned and otherwise adjusted in accordance with the manufacturer's recommended practices prior to application of the specified tests.

3.1.3.5 Warm-Up Period

Unless otherwise specified, all tests shall be conducted after the manufacturer's specified warm-up (stabilization) period. This period shall not exceed 15 minutes.

3.1.4 Test Procedures for Installed Equipment Performance

The test procedures specified in this document are intended to be suitable for first time IFR airworthiness installation approvals for GPS/WAAS equipment.

3.1.4.1 Ground Test Procedures

3.1.4.1.1 Conformity Inspection

Visually inspect the installed equipment to determine the use of acceptable workmanship and engineering practices. Verify, through review of installation drawings, wiring diagrams, descriptive wiring routing, and equipment data flow diagrams that all mechanical and electrical connections have been made properly and without creating an unsafe electrical or mechanical environment (e.g., yoke mounted equipment may require special assessment). Verify that the equipment has been located and installed in accordance with the manufacturer's recommendations and approved equipment list. Review the structural analysis of the equipment installation, including antenna, in order to ascertain whether structural mounting, dynamic, and crash load requirements are satisfied. Verify that the aircraft environment in which the GPS/WAAS equipment is installed is appropriate to the environmental categories (or criteria) in RTCA/DO-160D to which the equipment has been tested. Verify, via an electrical load analysis, that the total electrical load requirements are within the capabilities of the aircraft's electrical generating system, and determine that the supplied electrical power is consistent with applicable equipment reliability requirements.

3.1.4.1.2 Lab/Bench Tests and Equipment Data Evaluation

Evaluate manufacturer-supplied bench test data on the GPS/WAAS equipment and verify that (1) the tests are in accordance with Sections 2.4 and 2.5 of this document; (2) that the equipment has passed applicable tests; and (3) that the data provided is applicable to the installation.

3.1.4.1.3 Antenna Installation

Verify that the antenna is approved for the particular type of GPS/WAAS equipment installed (e.g., that the antenna incorporates or does not incorporate a low-noise amplifier as expected by the GPS/WAAS equipment). Verify that adequate isolation is provided between the GPS/WAAS antenna and any other transmitting antenna(s) installed on the aircraft (or between multiple GPS/WAAS antennas). Ensure that antenna installation minimizes the effects of blockage due to the wings, tail, etc. during aircraft maneuvering. Verify that the GPS/WAAS antenna is not installed just aft of the top of the windscreen (i.e., avoid case-to-antenna coupling) or in a location which may result in ice accumulation on the antenna. For precision-approach-capable equipment, ensure that the GPS/WAAS antenna is not installed in a multipath-rich location.

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.

3.1.4.1.4 Electromagnetic Compatibility

Verify electromagnetic compatibility between the GPS/WAAS equipment and other aircraft equipment. Particular attention should be given to other "L" band equipment, such as TCAS or SATCOM equipment; VHF transmissions on the frequencies listed below; high frequency (HF) communications systems; and other transmitting equipment (e.g., ACARS, AFIS, Flightfone, etc.).

Verification of adequate isolation from the interference of VHF communication transceivers is required. These tests shall be conducted on the completed GPS/WAAS installation by tuning each VHF transmitter to the frequencies listed below and transmitting for a period of 20 seconds. 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 (e.g., low pass or notch filters installed at the output of the VHF transmitter) be included in the aircraft installation. 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

3.1.4.2 Flight Test Procedures

3.1.4.2.1 Electromagnetic Compatibility

Verify while in flight the results of the ground test of Section 3.1.4.1.4.

3.2 Class Beta Equipment

Class Beta equipment will generally be installed as part of a multi-sensor navigation system, which is anticipated to provide similar functionality to an appropriate class of installed Class Gamma equipment. Guidance for installed equipment performance testing for multi-sensor navigation systems is contained in FAA Advisory Circular 20-130A. Appropriate installed equipment performance testing of the multi-sensor system after integration of the Class Beta equipment should be presumed to be required. The installed multi-sensor system is expected to provide an equivalent level of performance as specified in this document for Class Gamma equipment.

3.3 Class Gamma Equipment

3.3.1 General Requirements for All Navigation Modes

3.3.1.1 Installation Requirements

3.3.1.1.1 Display Visibility

The appropriate flight crew member(s) shall have an unobstructed view of displayed data when in the seated position. The horizontal (and vertical) deviation(s) display(s) and failure annunciation shall be located within the pilot's primary field of view (i.e., within 15 degrees of the pilot's primary line of sight), as shall any indication requiring immediate aircrew action.

Displays used for loss of integrity monitoring, waypoint sequencing, start of a turn, turn anticipation, TO/FROM indication, approach mode annunciation, and automatic mode switching shall be located within the pilot’s normal field of view. If the box is located in the center radio stack, the lateral normal field of view is from the center of the airspeed indicator to and including the box. If the box is installed to the left of the airspeed indicator, the lateral normal field of view is the center of the altimeter to and including the box. The vertical normal field of view includes the basic “T” instrument and the box.

Limitations on equipment installations to ensure display readability will be included in the installation instructions and must be verified to be consistent with the evaluation.

Note: *Visors, glareshields, or filters may be an acceptable means of obtaining daylight visibility.*

3.3.1.1.2 Control/Display Capability

A suitable interface shall be provided to allow data input, data output, and control of equipment operation. Particular attention should be placed on the controls required to perform operations that occur with a high frequency or that must be conducted under potentially stressful operating conditions. The workload associated with accessing the Direct-To function, entering a Hold mode, executing a missed approach, and initiating an approach to a different runway at the same airport (or to the alternate airport) following a missed approach should be minimized.

3.3.1.1.3 Operation of Controls

Controls intended for use in flight shall be designed to minimize errors and, when operated in all possible combinations and sequences, shall result in a condition whose presence or continuation would not be detrimental to the continued performance of the equipment. Controls shall be designed to maximize operational suitability and minimize pilot workload. The amount of force required to activate knobs/buttons shall be acceptable, feedback to the pilot should be adequate, and risk of inadvertent activation or deactivation should be minimized. Knob shape and size should not interfere with equipment use and should help distinguish controls. Reliance on pilot memory for operational procedures shall be minimized. The control/display shall be operable with the use of only one hand. A quick-reference card summarizing the user interface to the GPS/WAAS equipment should be provided. Examples of the information expected to be included on such a reference card can be found in Section 4 of this document.

3.3.1.1.4 Accessibility of Controls

Controls that are normally adjusted in flight shall be readily accessible and properly labeled as to their function. Controls that are not normally adjusted in flight shall not be readily accessible to the operator. Labels should be horizontally oriented, unobstructed by use of controls, descriptive of control function, and consistent across the equipment. Any abbreviations should conform to aviation usage (e.g., see Section 2.2.1.1.6 and 2.2.1.1.7 and Appendix O).

3.3.1.1.5 Arrangement of Controls

Controls shall be arranged logically according to functional groups, sequence of use, and frequency of use.

3.3.1.2 Installed Equipment Performance Requirements

3.3.1.2.1 Cross-Track Deviation Display

For installations where GPS/WAAS outputs can drive a display that is shared in common with other navigation equipment (e.g., VOR/DME, ILS, MLS), the annunciation of the system in use shall be clearly indicated. Deviation from the desired track shall be displayed to the range and resolution requirements as defined in Section 2 of this document for applicable navigation modes. Minimum discernible movement, accuracy of the centered display, resolution of the electrical output, linearity of the display and/or electrical output, and display latency shall be as specified in Section 2 of this document for applicable navigation modes.

Deviation display designs with display ranges and resolutions outside the bounds of the required values shall be substantiated by demonstration, by reference to appropriate empirical data, or by similarity to previous certified range/resolution displays.

3.3.1.2.2 Data Entry Capability

Appropriate feedback shall be supplied during data entry, with confirmation of input action prior to activation based upon that input. Any equipment prompts must be easily understood.

3.3.1.3 Test Procedures for Installed Equipment Performance

3.3.1.3.1 Ground Test Procedures

3.3.1.3.1.1 Cockpit Layout of Installed Equipment

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

3.3.1.3.1.2 Accuracy Test

Verify that the installed equipment configuration (including the antenna) provides position data meeting the accuracy criteria specified for the pertinent navigation modes supported. This test shall cover a continuous period of at least 2 hours with a maximum sample interval of two minutes.

Note: *The 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/WAAS equipment configuration, including antenna, must consist of the hardware to be used in the installation and be representative of the installed equipment configuration.*

3.3.1.3.1.3 Power Supply Fluctuations

Cycle the aircraft power between all power sources and verify proper operation of the equipment as specified by the equipment manufacturer. Effects of engine starting or other transients should be evaluated.

3.3.1.3.2 Flight Test Procedures

3.3.1.3.2.1 Switching and Transfer Functions

Verify/assess all switching and transfer functions, including electrical bus switching, pertaining to the GPS/WAAS installation.

3.3.1.3.2.2 Failure Modes/Annunciations

Review, and verify where appropriate through demonstration, various failure modes and associated annunciations, such as loss of electrical power, loss of signal reception, GPS/WAAS equipment failure, autopilot/flight director response to GPS/WAAS flags, etc. Verify that a warning associated with loss of navigation is accompanied by a visible indication within the pilot's normal field of view. Verify that audible alarms are sufficiently loud and of appropriate pitch quality, duration, and pattern. Verify that alarms are easily deactivated (but not easily deactivated inadvertently).

3.3.1.3.2.3 Steering Response

Verify that steering response is appropriate while autopilot and/or flight director is coupled to the GPS/WAAS equipment during a variety of different track and mode changes. This evaluation shall include, as applicable, transition from en route to terminal to approach modes and vice-versa. Additionally, all available display sensitivities shall be evaluated. Several fly-by turns should be accomplished to evaluate autopilot coupling. Section 3.3.1.3.2.8 discusses the appropriate criteria for evaluating fly-by turn performance.

3.3.1.3.2.4 Displayed GPS/WAAS Navigation Parameters

Evaluate displayed GPS/WAAS navigation parameters on interface cockpit instruments such as HSI, CDI, distance display, electronic flight instruments system (EFIS), moving maps, fuel management systems, etc. Verify that display minimum discernible movement, accuracy of the centered display, resolution of the electrical output, linearity of the display and/or electrical output, and display latency are appropriate for the navigation modes supported.

3.3.1.3.2.5 Controls Accessibility, Usability and Visibility

Evaluate the accessibility and usability of all controls pertaining to GPS/WAAS. Verify that data entry procedures are in conformance with the requirements of Sections 2.2.1.2 and 3.3.1.2.2. Assess the visibility of the controls, displays, and annunciators relating to the GPS/WAAS installation during day and night lighting conditions (to include indirect, reflected ambient conditions). No distracting cockpit glare or reflections may be introduced by the GPS/WAAS equipment and all controls must be illuminated for identification and ease of use. Colors, small symbols, and small alphanumerics must be clearly distinguishable, brightness of (non-adjustable) annunciators must be acceptable, and brightness and contrast adjustments must be acceptable. Characters embedded in text must be distinguishable. Night lighting shall be consistent with other cockpit lighting.

3.3.1.3.2.6 Crew Workload

Verify that crew workload is acceptable when operating the GPS/WAAS equipment in association with other piloting requirements.

3.3.1.3.2.7 Continuity of Navigation Data

Verify continuity of navigation data during normal aircraft maneuvering for the navigation modes to be validated.

3.3.1.3.2.8 Fly-By Turn Performance

Conduct several fly-by turns (both coupled and hand-flown). Verify that the equipment accomplishes the turn as a fly-by waypoint and discourages overshoot.

3.3.2 Class Gamma Equipment to Support En Route, Terminal Area and Nonprecision Approach Navigation

3.3.2.1 Installation Requirements

The requirements of Section 3.3.1.1 apply.

3.3.2.2 Installed Equipment Performance Requirements

3.3.2.2.1 General Performance Requirements

The installed equipment shall meet the requirements of Section 2.2.2 in addition to, or as adapted by, the following requirements.

3.3.2.2.2 Waypoint Input and Display

The equipment shall provide a means to readily display the active waypoint.

3.3.2.3 Test Procedures for Installed Equipment Performance

3.3.2.3.1 Ground Test Procedures

The requirements of Section 3.3.1.3.1 apply.

3.3.2.3.2 Flight Test Procedures

3.3.2.3.2.1 Equipment Operation

Verify the overall operation of the GPS/WAAS equipment to include at least the following: the ability to create and modify a flight plan, hold at a designated waypoint, intercept and track to or from a waypoint on a selected course (CF leg), 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.). Verify that the necessary controls are easy to access and identify, that the control use sequence requires minimal reliance on memory and promotes error-free operation, that flight critical information is accessible, that waypoints may be easily located in the equipment's database, and that the display outputs are readable (and acceptably noise free) with acceptable changes in body position and that all messages/annunciations are understandable. Display visibility should be evaluated with the aircraft flying both directly into the sun and with the sunlight shining across the display from a side window. If a moving map display is provided, verify display readability, appropriateness and clarity of map scale, and map update rate. This test is intended to confirm that the installed GPS/WAAS equipment is functioning as expected (from bench test data) and should generally involve sampling techniques as opposed to exhaustive tests.

3.3.2.3.2.2 Accuracy Test

There are no unique flight tests to evaluate the system accuracy.

3.3.2.3.2.3 Flight Technical Error

Verify that flight technical error (FTE) can be maintained at less than 1.0 nmi for en route and terminal transition operating modes. This test is required only if the GPS/WAAS equipment is coupled to an autopilot or if the navigation displays are non-standard. One acceptable way of assessing FTE is to monitor the measured cross-track deviation (see Section 2.2.2.4.3) while either flying under autopilot control or flying to the navigation display provided.

3.3.2.3.2.4 Lateral Maneuver Anticipation

Verify that the lateral maneuver anticipation supplied by the GPS/WAAS equipment is appropriate for the aircraft type. If the GPS/WAAS equipment is coupled to an autopilot, the maneuver anticipation function must be evaluated over a range of turn conditions in order to assess the proper functioning of the interface.

3.3.2.3.2.5 Automatic Lateral Change

Verify that if the GPS/WAAS equipment is coupled to an autopilot, an appropriate annunciation of impending waypoint crossing is provided.

Note: *The timing of this annunciation is dependent on operational procedures and aircraft/equipment design. If an appropriate map display is installed in the aircraft, it may be used in place of an annunciation.*

3.3.2.3.2.6 Direct-To Function

Verify that execution of an aircraft heading change to intercept a direct leg does not cause "S" turns.

3.3.3 Class Gamma Equipment to Support LNAV/VNAV Navigation

3.3.3.1 Installation Requirements

3.3.3.1.1 Display Visibility

The approach mode annunciation and distance to waypoint in the approach mode shall be clearly visible within the pilot's normal field of view.

3.3.3.2 Installed Equipment Performance Requirements

3.3.3.2.1 General Performance Requirements

The installed equipment shall meet the requirements of Section 2.2.3.

3.3.3.3 Test Procedures for Installed Equipment Performance

3.3.3.3.1 Ground Test Procedures

The requirements of Section 3.3.1.3.1 apply.

3.3.3.3.2 Flight Test Procedures

3.3.3.3.2.1 Equipment Operation

Conduct a sufficient number of approaches and transitions from en route to terminal to approach operations using the navigation database to verify proper overall operation of the GPS/WAAS navigation system in the approach environment. This verification should include at least: turn anticipation, waypoint sequencing, display sensitivity changes, annunciations, procedure turns at the FAWP, holding patterns at the missed approach holding waypoint, transitions from TO-FROM operation to TO-TO operation, VTF-style heading intercepts after the IAWP to intercept the final approach course both before and after the FAWP, and DIRECT TO operation before and after the IAWP. Verify that approach selection options are clear, that the navigation mode of the equipment is clearly discernible, that all alerts and displayed messages are readily understandable, and that operation is consistent with pilot expectations and requires an acceptable pilot workload. This test is intended to confirm that the installed GPS/WAAS equipment is functioning as expected (from bench test data) and should generally involve sampling techniques as opposed to exhaustive tests.

3.3.3.3.2.2 Flight Technical Error

Verify that flight technical error can be maintained at less than 0.25 nm for non-precision approach operating modes. This test is required only if the GPS/WAAS equipment is coupled to an autopilot or the navigation displays are non-standard.

3.3.3.3.2.3 Steering Response

The steering response evaluation of Section 3.3.1.3.2.3 shall also include transition between approach and missed approach modes.

3.3.3.3.2.4 Automatic Lateral Change

Verify that an appropriate annunciation of impending waypoint crossing is given whether the approach is coupled or uncoupled.

3.3.3.3.2.5 Missed Approach

Verify that selection of a missed approach by the pilot results in automatic selection of terminal mode and that display sensitivities change accordingly.

3.3.3.3.2.6 Horizontal Deviation Display

If the installation involves upgrading of the aircraft's horizontal deviation display to support angular display sensitivity for non-precision approach operating modes, verify proper operation of the new display.

3.3.4 Class Gamma Equipment to Support LNAV/VNAV Navigation

3.3.4.1 Installation Requirements

3.3.4.1.1 Display Visibility

The approach mode annunciation, distance-to-threshold, and horizontal and vertical deviations display(s) shall be located within the pilot's normal field of view.

3.3.4.2 Installed Equipment Performance Requirements

3.3.4.2.1 General Performance Requirements

The installed equipment shall meet the requirements of Section 2.2.4 in addition to, or as adapted by, the following requirements.

3.3.4.2.2 Vertical Path Deviation Display

Deviation from the desired vertical profile shall be displayed in accordance with the requirements defined in Section 2.2.4 of this document. Deviation display designs with displayed ranges and resolutions outside the bounds of the required values shall be substantiated by demonstration, by reference to appropriate empirical data, or by similarity to previously certified range/resolution displays. Minimum discernible movement, accuracy of the centered display, resolution of the electrical output, linearity of the display and/or electrical output, and display latency shall be as specified in Section 2.2.4 of this document.

3.3.4.3 Test Procedures for Installed Equipment Performance

3.3.4.3.1 Ground Test Procedures

3.3.4.3.1.1 Antenna to Aircraft Navigation Reference Offset

If applicable, confirm that the antenna to aircraft center of navigation offset used by the GPS/WAAS equipment is appropriate to the installation (see Section 2.2.4.3.3).

3.3.4.3.2 Flight Test Procedures

Note: *Flight evaluation of the initial implementation of a particular airborne equipment configuration may require additional flight evaluations, including tests to demonstrate overall system accuracy utilizing an acceptable ground truth system.*

3.3.4.3.2.1 Differential GPS/WAAS Operation

Validate differential GPS/WAAS operation and verify display and/or autopilot operation by conducting at least 2-3 LNAV/VNAV approaches in each mode (e.g., autopilot coupled, flight director, raw data). For each approach, record the GPS position as the aircraft crosses the runway threshold (should the GPS/WAAS equipment not have a means whereby this can be done with, e.g., a single button push, consideration should be given to recording the GPS coordinates using video or still-photo methods). The ability of the GPS/WAAS equipment to indicate whether or not LNAV/VNAV approach capability is available should be verified, particularly if a non-standard means of compliance is being proposed. (These approaches may also be used as part of the assessment in Section 3.3.4.3.2.2 below.) This test is intended to confirm that the installed GPS/WAAS equipment is operating as expected (i.e., in accordance with bench test data) and should generally involve sampling techniques as opposed to exhaustive tests.

3.3.4.3.2.2 Flight Technical Error

Verify that FTE can be maintained to meet the accuracy requirements of Section 2.2.4 without sustained aircraft oscillation or unusual flying characteristics. This test is required only for autopilot coupled approach mode or if nonstandard navigation displays are being employed. This test should be performed under varying wind conditions.

3.3.4.3.2.3 Continuity of Navigation Data

Verify continuity of navigation data during normal aircraft maneuvering. Momentary (less than approximately 3 seconds) loss of GPS/WAAS signals shall not result in loss of navigation capability or presentation of navigation flags.

3.3.5 Class Gamma Equipment to Support Precision Approach (APV-II, GLS) Navigation

3.3.5.1 Installation Requirements

3.3.5.1.1 Display Visibility

The approach mode annunciation, distance-to-threshold, and horizontal and vertical deviations display(s) shall be located within the pilot's normal field of view.

3.3.5.2 Installed Equipment Performance Requirements

3.3.5.2.1 General Performance Requirements

The installed equipment shall meet the requirements of Section 2.2.5 in addition to, or as adapted by, the following requirements.

3.3.5.2.2 Vertical Path Deviation Display

Deviation from the desired vertical profile shall be displayed in accordance with the requirements defined in Section 2.2.5 of this document. Deviation display designs with displayed ranges and resolutions outside the bounds of the required values shall be substantiated by demonstration, by reference to appropriate empirical data, or by similarity to previously certified range/resolution displays. Minimum discernible movement, accuracy of the centered display, resolution of the electrical output, linearity of the display and/or electrical output, and display latency shall be as specified in Section 2.2.5 of this document.

3.3.5.3 Test Procedures for Installed Equipment Performance

3.3.5.3.1 Ground Test Procedures

3.3.5.3.1.1 Antenna to Aircraft Navigation Reference Offset

If applicable, confirm that the antenna to aircraft center of navigation offset used by the GPS/WAAS equipment is appropriate to the installation (see Section 2.2.5.3.3).

3.3.5.3.2 Flight Test Procedures

Note: *Flight evaluation of the initial implementation of a particular airborne equipment configuration may require additional flight evaluations, including tests to demonstrate overall system accuracy utilizing an acceptable ground truth system.*

3.3.5.3.2.1 Differential GPS/WAAS Operation

Validate differential GPS/WAAS operation and verify display and/or autopilot operation by conducting at least 2-3 GLS approaches in each mode (e.g., autopilot coupled, flight director, raw data). For each approach, record the GPS position as the aircraft crosses the runway threshold (should the GPS/WAAS equipment not have a means whereby this can be done with, e.g., a single button push, consideration should be given to recording the GPS coordinates using video or still-photo methods). The ability of the GPS/WAAS equipment to indicate whether or not GLS approach capability is available should be verified, particularly if a non-standard means of compliance is being proposed. (These approaches may also be used as part of the assessment in Section 3.3.5.3.2.2 below.) This test is intended to confirm that the installed GPS/WAAS equipment is operating as expected (i.e., in accordance with bench test data) and should generally involve sampling techniques as opposed to exhaustive tests.

3.3.5.3.2.2 Flight Technical Error

Verify that FTE can be maintained to meet the accuracy requirements of Section 2.2.5 without sustained aircraft oscillation or unusual flying characteristics. This test is required only for autopilot coupled approach mode or if nonstandard navigation displays are being employed. This test should be performed under varying wind conditions.

3.3.5.3.2.3 Continuity of Navigation Data

Verify continuity of navigation data during normal aircraft maneuvering. Momentary (less than approximately 3 seconds) loss of GPS/WAAS signals shall not result in loss of navigation capability or presentation of navigation flags.

3.4 Class Delta-4 Equipment to Support Precision Approach Navigation

Class Delta equipment provides path deviation data to a flight director or flight computer, and may or may not drive a display. The Class 4 designation applies to equipment which provides an "ILS look-alike signal" only for approach and landing operations, but does not support other navigation modes. Class Delta-4 equipment receives path definition data from a flight computer. Installed Class Delta-4 equipment is required to meet the requirements of Section 2.3 and the requirements and tests of Section 3.1 as well as the requirements of this section.

3.4.1 Installation Requirements

The requirements of Section 3.1.1 apply. If the GPS/WAAS equipment drives a display, which provides deviation information to the pilot, Section 3.3.1.1.1, the display-related requirements of Section 3.3.1.1.2, and the deviation display requirements of Section 3.3.5.1.1 apply.

3.4.2 Installed Equipment Performance Requirements

The installed equipment shall meet the requirements of Section 2.3. If the GPS/WAAS equipment drives a display, which provides deviation information to the pilot, the requirements of Sections 3.3.1.2, 3.3.2.2, 3.3.3.2, 3.3.4.2 and 3.3.5.2 that are related to precision approach position determination and the display of deviation information during a precision approach apply.

3.4.3 Test Procedures for Installed Equipment Performance

3.4.3.1 Ground Test Procedures

If the GPS/WAAS equipment drives a display which provides deviation information to the pilot, Section 3.3.4.3.1 (with the exception that Class Delta-4 equipment must be able to receive and/or validate the FAS data for only a single approach) as well as the portions of Sections 3.3.1.3.1, 3.3.2.3.1, 3.3.3.3.1, and 3.3.3.4.1 which are related to precision approach position determination and the display of deviation information during a precision approach apply. If the equipment does not drive a display, Section 3.2 applies.

3.4.3.2 Flight Test Procedures

If the GPS/WAAS equipment drives a display, which provides deviation information to the pilot, Section 3.3.4.3.2 as well as the portions of Sections 3.3.1.3.2, 3.3.2.3.2, 3.3.3.3.2 and 3.3.4.3.2 which are related to the display of deviation information during a precision approach apply. If the equipment does not drive a display, Section 3.2 applies.

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4 OPERATIONAL CHARACTERISTICS

Note: *This section has been written to specifically address the operational issues typically addressed in a flight manual supplement. It is a list of what we anticipate that the pilot will do with the information provided. There are no requirements in this section.*

4.1 Preface

Pilots are the end point users of aircraft navigation equipment. The primary objectives of an aircraft MOPS, which are to establish performance criteria that ensure safe, reliable, functional and economically realizable equipment, are only met if the end point users (pilots) are able to benefit. Further, since pilots are servant to and real-time-team providers of aircraft access to the public, the national and international public benefit of operational performance is derived from benefit to pilots. In order to benefit pilots use of WAAS, a great deal of care has gone into creating a performance standard, which meets these objectives. Safety of flight is of paramount concern to pilots. Aircraft safety cannot be achieved without equipment reliability. Functionality is more than a matter of convenience to pilots. The cockpit work-load during approach to an airfield can rapidly alter the pilots perspective of functionality, from convenience to safety, especially during adverse weather conditions. Economically realizable equipment, which is at first a concern for equipment manufacturers, becomes a concern for pilots who are for the most part constrained to use equipment deemed by the equipment manufacturers to be economically realizable. Looking toward the goal of pilot benefit then, the following paragraphs are included here to detail the pilot environment during use of the WAAS.

4.2 Turn-On and Initialization of the WAAS GNSS Airborne Receiving System

Turning on the GPS/WAAS equipment will cause it to perform the necessary functions to automatically receive and process the WAAS and GNSS satellite signals for navigational use including integrity of the navigation solution. In general, initialization of position is not required.

4.3 Initial Ground Operations

Since GPS/WAAS equipment will vary substantially in capability and functional operation, familiarity with the equipment prior to initial operation is essential. Taxi guidance is not presently provided as an enhancement of WAAS GNSS equipment but when precision differential ground augmentation equipment becomes available these services may be provided. During ground checks the pilot should verify proper operation of the GPS/WAAS equipment including a check of the present position and a check to ensure that equipment warnings and annunciations are not present.

Note: *The "Situation Normal" dark panel precedent has been followed in the MOPS.*

4.4 Take Off and Departure

Take off vertical guidance is provided as advisory information (not coupled to the autopilot) in some equipment. Horizontal guidance is provided continuously during take off but with terminal area precision only (CDI sensitivity and terminal integrity). The equipment will provide guidance along departure routes. Terminal precision will prevail within 30 nm of the airport. Under IFR complete loss of navigation function during the terminal area departure may require the termination of the flight. Equipment produced in compliance with this MOPS will have an extremely low probability of complete loss of navigation. Presentation of failure indications other than the complete loss of the navigation function will still allow use of the navigation information but extreme caution is necessary. Temporary loss of integrity monitoring during departure probably implies no more than caution and preparedness in case further warnings require timely or immediate action. A loss of integrity monitoring caution indicates that the protected area of horizontal position determination cannot be ensured or that the protection radius has been penetrated. Although this event is very rare, further caution by the pilot is needed if this event occurs especially in congested airspace. Under IFR the pilot-in-command shall report to ATC, as soon as practical, any malfunctions of navigational, approach, or communications equipment in accordance with section 91.187 of the FAR.

Note: *During departure, en route, and non-precision approach, FDE is only used by the GPS/WAAS equipment if the WAAS integrity is not available. During precision approach, fault detection is always used if available. As a result, it should be very unusual to experience a loss of integrity monitoring.*

4.5 Turn Maneuvers

Turn maneuvers may be accomplished either manually or with the aid of an autopilot. Manual maneuvering in turns, including turn anticipation, is accomplished by observing the turn-annunciation prior to initiating the turn and keeping in mind the total course change angle and aircraft speed. Autopilot coupled turn anticipation and maneuvering will be coordinated by the equipment.

4.6 En Route

Committing to the en route phase of flight means that nominal function of the navigation system has been achieved during the departure phase. Complete dependence on the navigation system except for ATC flight following radar and D.R. (Dead Reckoning) is a fact of long range and oceanic flight especially during night flight operations, and IMC (Instrument Meteorological Conditions). During the en route phase of flight, warnings and annunciations need to be evaluated for their impact on the continued safety of the flight. The equipment requirements are designed to realize the dependence and ensure highly safe operation of the equipment during long flights.

4.7 Approach

Approach to an airport intensifies the pilot's work load. The WAAS GNSS equipment requirements account for the increase in pilot work load during approach in proportion to the precision needed for the approach type being conducted. The requirement accomplishes this accounting by increasing demand on the equipment during approach navigation mode. Approaches to airports that do not provide instrument approach facilities or are not instrument approach certified or using equipment that is not capable of approach can only be conducted under VFR flight rules. It is anticipated that the pilot will select the specified precision or non-precision instrument approach from the navigation database prior to arriving in the approach area. Typically the pilot will select the approach well in advance. Unless there has been a failure or degradation in service, the approach will be activated automatically when the aircraft is within 30 nm of the airport and approaching the final approach segment. Upon activation of the approach mode, the equipment will annunciate the mode change. At this point, the glide slope (may not apply to non-precision approaches) and course deviation display will be activated and providing approach guidance. In order for the pilot to continue an approach, the guidance needle(s) should be on-scale and operating. For approaches with vertical guidance, if only the vertical integrity flag drops into view, the lateral guidance is still within specification, and the pilot will be able to continue a non-precision approach (much like a localizer approach). If the horizontal or both integrity flags come into view, the pilot will abandon the approach to that runway.

4.8 Missed Approach

In the event that the pilot decides to conduct a missed approach, the equipment can provide guidance for the missed approach procedure (assuming that the reason for the missed approach is not that the GPS/WAAS equipment has failed). In order to obtain missed approach guidance, the pilot must activate the missed approach procedure, typically by hitting a button on the GPS/WAAS equipment. Once the missed approach procedure is activated, the equipment will automatically provide guidance to the missed approach holding waypoint, and then automatically enter FROM mode.

If the pilot decides to conduct a missed approach but does not activate the missed approach procedure, the equipment will continue to provide FROM guidance after passing the missed approach waypoint. This guidance may be used for maintaining runway heading. The pilot is responsible for being familiar with the missed approach procedure and changing course at the appropriate time. Caution must be taken not to forget to activate the missed approach procedure and unintentionally maintaining runway heading too long, leaving the published departure procedure. The pilot can activate the missed approach at any time on the approach or after passing the missed approach waypoint.

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Alex Joseph	Northstar Technologies
Jeff Kacirek	Honeywell International, Inc.
Rudolph Kalafus	Trimble Navigation
Elliott Kaplan	The MITRE Corporation
Robert Kelly	Kelly Systems Engineering
Charlie Kettler	Federal Aviation Admininstration
Todd Kilbourne	Trios Associates, Inc.
Taehwan Kim	The MITRE Corporation
George Kinal	Consultant
Tony King	Delta Air Lines, Inc.
Roger Kirpes	Rockwell Collins, Inc.
Paul Kline	Honeywell International, Inc.
Joseph Kolesar	The MITRE Corporation
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Vladimir Latev	Universal Avionics Systems Corp.
Steve Lazar	Aerospace Corporation
Michael Lemke	Department of Defense/JSC
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Jean-Marc Liszez	STNA
Fan Liu	Honeywell International, Inc.
Sheng Liu	Raytheon Electronic Systems
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Bruno Lobert	Alcatel Space Industries
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Frank Lorge	Federal Aviation Administration
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Appendix A

WIDE AREA AUGMENTATION SYSTEM SIGNAL SPECIFICATION

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Appendix A—WIDE AREA AUGMENTATION SYSTEM SIGNAL SPECIFICATION

A.1 Introduction

The Wide Area Augmentation System (WAAS) uses satellites (initially geostationary satellites - GEOs) to broadcast Global Navigation Satellite System (GNSS) integrity and correction data to GNSS users, and to provide a ranging signal that augments the GNSS, which is made up of the Global Positioning System (GPS) and the GLObal NAvigation Satellite System (GLONASS) systems.

This appendix defines the service to be provided by the WAAS. It provides specifications for WAAS ranging signal characteristics, and contents and format for WAAS integrity and corrections data. This appendix also defines certain user equipment functions necessary to correctly interpret and apply WAAS data.

A.2 Signal Characteristics

The signal broadcast via the WAAS GEOs to the WAAS users is designed to minimize standard GPS receiver hardware modifications. The GPS frequency and GPS-type of modulation, including a Coarse/Acquisition (C/A) PRN code, will be used. In addition, the code phase timing will be maintained close to GPS time to provide a ranging capability.

A.2.1 Carrier Frequency

The WAAS broadcast will consist of a single carrier frequency of 1575.42 MHz (GPS L1).

A.2.2 Spurious Transmissions

Spurious transmissions will be at least 40 dB below the unmodulated carrier power over all frequencies.

A.2.3 Modulation

GPS-type modulation will be used for the code and the data. Message symbols at a rate of 500 symbols per second (sps) will be added modulo-2 to a 1023-bit PN code, which will then be bi-phase shift-keyed (BPSK) modulated onto the carrier at a rate of 1.023 M-chips per second. Code/carrier coherence will be maintained as described in Section A.2.6.4. Code/data coherence will be maintained as described in [1]. The 500 sps will be synchronized with the 1 kHz C/A code epochs.

A.2.4 Carrier Phase Noise

The phase noise spectral density of the unmodulated carrier will be such that a phase locked loop of 10 Hz one-sided noise bandwidth will be able to track the carrier to an accuracy of 0.1 radians rms.

A.2.5 Signal Spectrum

The broadcast signal will be at the GPS L1 frequency of 1575.42 MHz. At least 95% of the broadcast power will be contained within a ±12 MHz band centered at the L1 frequency. The bandwidth of the signal transmitted by a WAAS satellite will be at least 2.2 MHz.

A.2.6 Signal Characteristics Modified Relative To GPS

A.2.6.1 Doppler Shift

The Doppler shift, as perceived by a stationary user, on the signal broadcast by WAAS geostationary satellites (GEOs) will be less than 40 meters per second (≈210 Hz at L1) in the worst case (at the end of life of the GEOs). The Doppler shift is due to the relative motion of the GEO.

A.2.6.2 Carrier Frequency Stability

The short-term stability of the carrier frequency (square root of the Allan Variance) at the input of the user's receiver antenna will be better than 5×10^{-11} over 1 to 10 seconds, excluding the effects of the ionosphere and Doppler.

A.2.6.3 Polarization

The broadcast signal will be right-handed circularly polarized. The ellipticity will be no worse than 2 dB for the angular range of ±9.1° from boresight.

A.2.6.4 Code/Carrier Frequency Coherence

The lack of coherence between the broadcast carrier phase and the code phase will be limited. The short term (< 10 seconds) fractional frequency difference between the code phase rate and the carrier frequency will be less than 5×10^{-11} (one sigma). That is,

$$\left| \frac{f_{code}}{1.023\ MHz} - \frac{f_{carrier}}{1575.42\ MHz} \right| < \frac{\Delta f}{f_0} \qquad \text{[A-1]}$$

where $\Delta f / f_0$ has a one-sigma value of 5×10^{-11}. Over the long term (< 100 seconds), the difference between the change in the broadcast code phase, converted to carrier cycles by multiplying the number of code chips by 1540, and the change in the broadcast carrier phase, in cycles, will be within one carrier cycle, one sigma. This does not include code/carrier divergence due to ionospheric refraction in the downlink propagation path.

A.2.6.5 User Received Signal Levels

The received radiated power level into a 0 dBi Right-Hand-Circularly-Polarized (RHCP) antenna from a WAAS GEO on or near the surface of the earth will be greater than -161 dBW at elevation angles greater than 5 degrees. The maximum received signal strength will be -155 dBW in such an antenna. The expected typical received power versus elevation angle is shown in Figure A-1.

A.2.6.6 Correlation Loss

Correlation loss is defined as the ratio of output powers from a perfect correlator for two cases: (1) the actual received WAAS signal correlated against a perfect unfiltered PN reference, or (2) a perfect unfiltered PN signal normalized to the same total power as the WAAS signal in case 1, correlated against a perfect unfiltered PN reference.

The correlation loss resulting from modulation imperfections and filtering inside the WAAS satellite payload will be less than 1 dB.

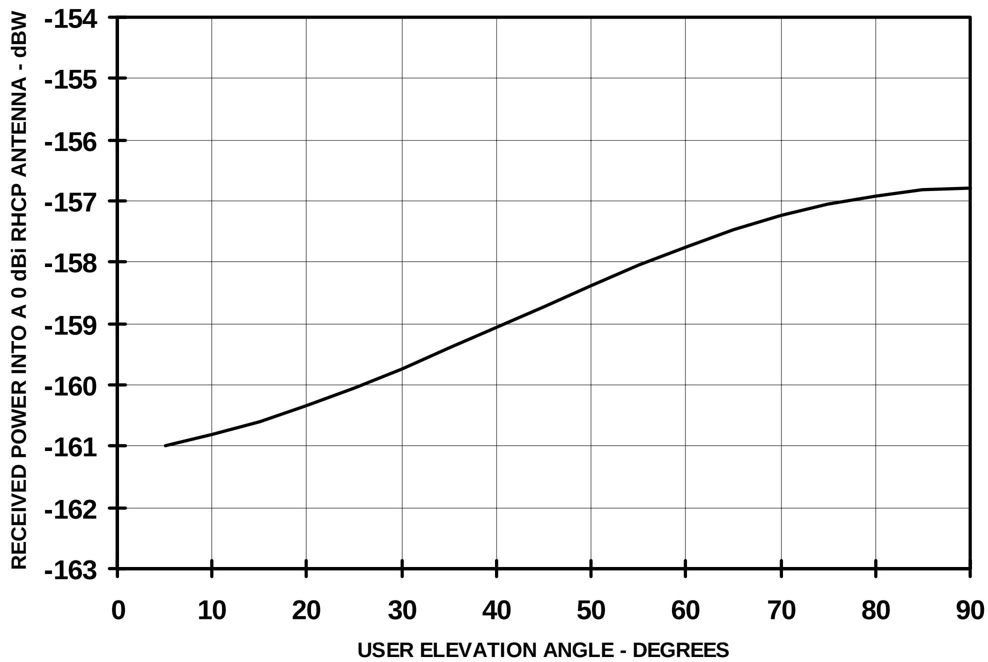


FIGURE A-1 EXPECTED TYPICAL RECEIVED POWER LEVELS

A.2.6.7 Maximum Code Phase Deviation

The maximum uncorrected code phase of the broadcast signal will not deviate from the equivalent WAAS Network Time by more than can be accommodated by the GEO time correction provided in the GEO Navigation Message ($\pm 2^{-20}$ seconds). The maximum corrected code phase deviation will be limited in accordance with the overall signal-in-space performance requirements.

A.3 WAAS C/A Codes

A.3.1 Requirements

The following is the definition of the C/A codes (herein called the WAAS codes) to be used by WAAS GEOs broadcasting a GPS look-alike signal. The requirements imposed on these selected codes are as follows:

1. They must belong to the same family of 1023-bit Gold codes as the 37 C/A codes reserved by the GPS system and specified in Section 3.2.1.3 of [1]. The first 32 are assigned to GPS satellites, while the last 5 (of which two are the same) are reserved for other uses.
2. They must not adversely interfere with GPS signals.

A.3.2 Identification of WAAS Codes

The WAAS codes are identified in three ways:

1. PRN number,
2. G2 delay in chips,
3. Initial G2 state

The definition of either the G2 delay or initial G2 setting is required for implementation of the generation of the selected codes. Arbitrary PRN numbers are assigned to the selected codes.

A.3.3 WAAS Codes

WAAS codes are a subset of the nineteen selected Satellite Based Augmentation System (SBAS) codes that are presented in the "C/A-Code Allocation" table maintained on the GPS program office web site at http://gps.losangeles.af.mil. Like the GPS C/A codes, the PRN number is arbitrary, but starting with 120 instead of 1. The actual codes are defined by either the G2 delay or the initial G2 register setting. Future GNSS satellites could also have PRN codes associated with the yet to be defined PRNs 139 – 210; receivers should be designed to acquire and track all of the defined codes (including the unallocated PRN codes).

A.3.4 Recommended WAAS/GPS Coder Implementation

The assigned codes cannot be implemented using the two-tap selection derived for the GPS C/A codes. Thus, the recommended WAAS coder implementation is either a programmable G2 shift register delay with single output (Figure A-2), or a programmable initial G2 shift register state with a single output (Figure A-3). The reserved GPS C/A codes can also be generated with either of these implementations. Table 3-I of [1] specifies the G2 shift register delay (called the Code Delay) and the First 10 Chips Octal, which is the octal inverse of the initial G2 shift register state.

TABLE A-1 SBAS RANGING C/A CODES

PRN	G2 Delay (Chips)	Initial G2 Setting (Octal)	First 10 SBAS Chips (Octal)
120	145	1106	0671
121	175	1241	0536
122	52	0267	1510
123	21	0232	1545
124	237	1617	0160
125	235	1076	0701
126	886	1764	0013
127	657	0717	1060
128	634	1532	0245
129	762	1250	0527
130	355	0341	1436
131	1012	0551	1226
132	176	0520	1257
133	603	1731	0046
134	130	0706	1071
135	359	1216	0561
136	595	0740	1037
137	68	1007	0770
138	386	0450	1327

Note: *In the octal notation for the first 10 chips of the G2 or the SBAS code as shown in these columns, the first digit on the left represents a "0" or "1" for the first chip. The last three digits are the octal representation of the remaining 9 chips. (For example, the initial G2 setting for PRN 120 is: 1 001 000 110). Note that the first 10 SBAS chips are simply the octal inverse of the initial G2 setting.*

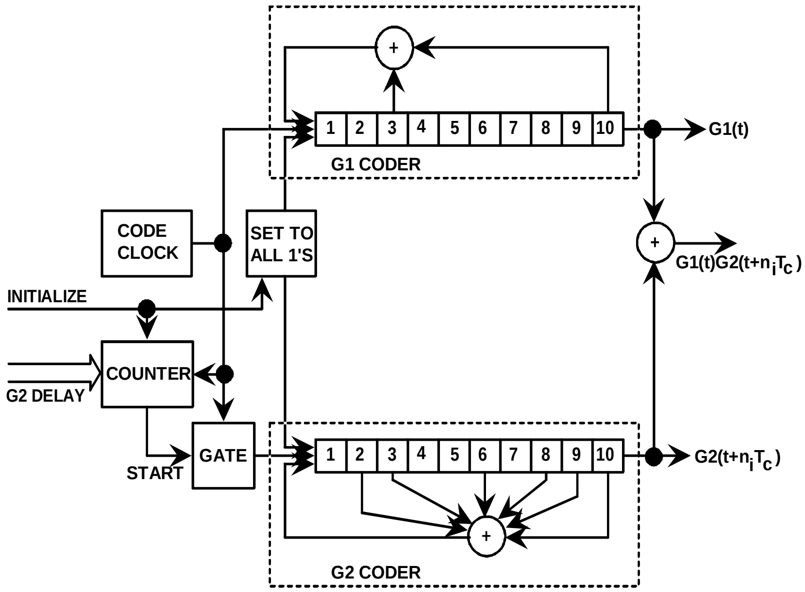


FIGURE A-2 WAAS/GPS CODER IMPLEMENTED WITH SINGLE G2 OUTPUT PLUS PROGRAMMABLE G2 DELAY

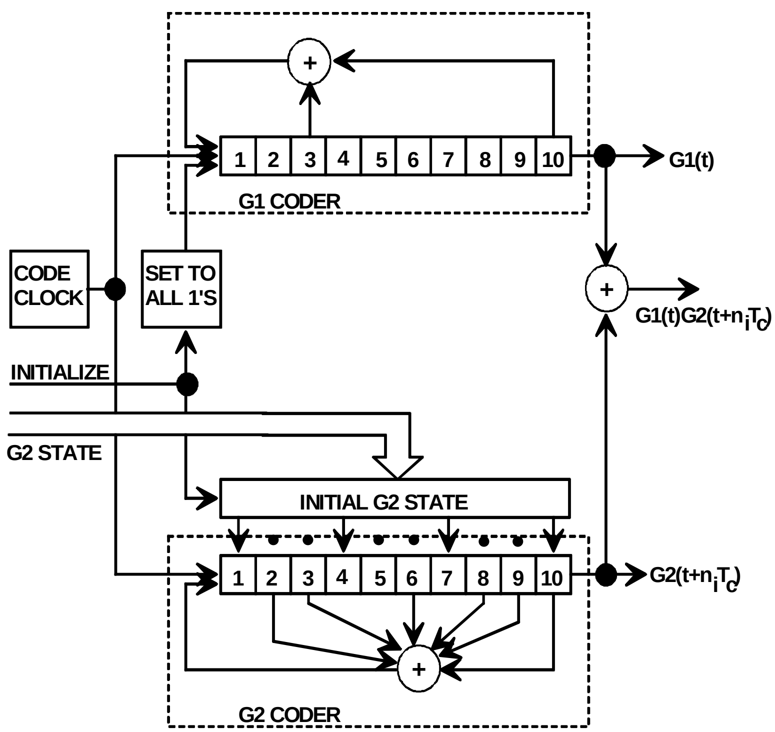


FIGURE A-3 WAAS/GPS CODER IMPLEMENTED WITH A PROGRAMMABLE INITIAL G2 STATE

A.4 WAAS Signal Data Contents and Formats

A.4.1 Introduction

A given WAAS GEO will broadcast either coarse integrity data or both such data and wide area corrections. The coarse integrity data will include use/don't-use information on all satellites in view of the applicable region, including the GEOs. Correction data include estimates of the error after application of the corrections.

The parameter, σ^2_{UDRE}, is the variance of a Normal distribution associated with the user differential range error for a satellite after application of fast corrections and long term corrections, excluding atmospheric effects. The parameter, σ^2_{GIVE}, is the variance of a Normal distribution associated with the residual ionospheric vertical error at an IGP for an L1 signal.

A.4.2 Principles and Assumptions

Certain principles and assumptions are used as a guide in the definition of the format and data contents. First of all, the signal data bandwidth should have the necessary capacity to broadcast both integrity and corrections data simultaneously for the entire service region. Next, information common to both the integrity and corrections data should not be repeated in order to minimize the required data rate. Note that the delivered level of accuracy can be controlled by adjusting the accuracy of the corrections, but integrity is always provided.

A.4.2.1 Data Rate

The baseline data rate will be 250 bits per second. The data will always be rate 1/2 convolutional encoded with a Forward Error Correction (FEC) code. Therefore, the symbol rate that the GPS receiver must process is 500 symbols per second (sps). The convolutional coding will be constraint length 7 as standard for Viterbi decoding, with a convolutional encoder logic arrangement as illustrated in Figure A-4. The G1 symbol is selected on the output as the first half of a 4 millisecond data bit period. (If soft decision decoding is used, the bit error rate (BER) performance gain of this combination of coding and decoding is 5 dB over uncoded operation.) As an example, the algorithms for the implementation of this decoding are described in George C. Clark and J. Bibb Cain, Error Correction Coding for Digital Communications, Plenum Press, New York, 1981 [2].

A.4.2.2 Timing

WAAS Network Time is defined as that which is maintained, after corrections, to GPS system time, within the overall WAAS performance requirements. Data blocks will maintain synchronism with the GPS data blocks to within the same performance requirements. It is noted that, when using corrections, the user's solution for time will be with respect to the WAAS Network Time, and not with respect to GPS system time. If corrections are not applied, then the solution will be with respect to a composite GPS/WAAS Network Time, and the resulting accuracy will be affected by the difference between the two. WAAS Network Time will be within 50 nanoseconds of GPS system time. Estimates of the time difference between WAAS Network Time and Universal Coordinated Time (UTC) and GLONASS system time will be provided in an appropriate data message (Type 12).

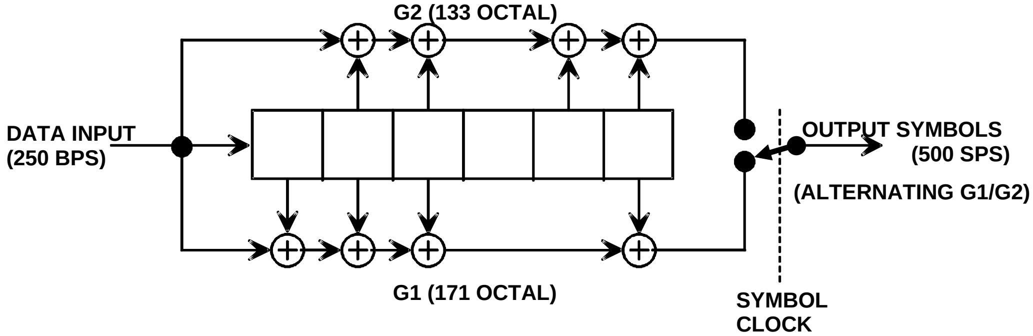


FIGURE A-4 CONVOLUTIONAL ENCODING

The leading edge of the first symbol that depends on the first bit of the current message is broadcast from the WAAS satellite synchronous with a one second epoch of WNT.

A.4.2.3 Error Corrections

There will be two types of correction data — fast and long-term. The fast corrections are intended to correct for rapidly changing errors such as GNSS clock errors, while the long-term corrections are for slower changing errors due to the atmospheric and long term satellite clock and ephemeris errors. The fast corrections are common to all users and will be broadcast as such.

For the slower corrections, the users are provided with ephemeris and clock error estimates for each satellite in view (Message Types 24 and 25). Although long term satellite clock errors are common to all regions, they are slow-varying and Issue of Data (IOD) dependent. Therefore, they are best accommodated as part of the slower corrections. Separately, users are provided with a wide-area ionospheric delay model and sufficient real-time data to evaluate the ionospheric delays for each satellite using that model (Message Types 18 and 26). Specific procedures for using the corrections are given with the definition of the relevant messages.

WAAS will ensure that discontinuities in the satellite position after application of long term corrections are minimized so that the range error is typically compensated by the σ^2_{UDRE} when range-rate corrections are calculated (see Section A.4.5).

In addition, the degradation of accuracy (see Section A.4.5) is modeled to account for the possibility that any messages are missed by the user.

A.4.2.4 Tropospheric Model

Because tropospheric refraction is a local phenomenon, all users will compute their own tropospheric delay correction.

The tropospheric delay estimate takes the form:

$$TC_i = -\left(d_{hyd} + d_{wet}\right) \cdot m(El_i) \quad \text{[A-2]}$$

[d_{hyd}, d_{wet}] are calculated from the receiver's height and estimates of five meteorological parameters: pressure [P (mbar)], temperature [T (K)], water vapor pressure [e (mbar)], temperature lapse rate [β (K/m)] and water vapor "lapse rate" [λ (dimensionless)].

Values of each of the five meteorological parameters, applicable to the receiver latitude [ϕ] and day-of-year [D] (starting with 1 January), are computed from the average and seasonal variation values given in Table A-2. Each parameter value [ξ] is computed as:

$$\xi(\phi, D) = \xi_0(\phi) - \Delta\xi(\phi) \cdot \cos\left(\frac{2\pi(D - D_{\min})}{365.25}\right) \quad \text{[A-3]}$$

where D_{min}=28 for northern latitudes, D_{min}=211 for southern latitudes, and ξ_0, $\Delta\xi$ are the average and seasonal variation values for the particular parameter at the receiver's latitude. For latitudes $|\phi| \le 15°$ and $|\phi| \ge 75°$, values for ξ_0 and $\Delta\xi$ are taken directly from Table A-2. For latitudes in the range $15° < |\phi| < 75°$, values for ξ_0 and $\Delta\xi$ at the receiver's latitude are each pre-calculated by linear interpolation between values for the two closest latitudes [ϕ_i, ϕ_{i+1}] in Table A-2:

$$\xi_0(\phi) = \xi_0(\phi_i) + \left[\xi_0(\phi_{i+1}) - \xi_0(\phi_i)\right] \cdot \frac{(\phi - \phi_i)}{(\phi_{i+1} - \phi_i)} \qquad \text{[A-4]}$$

$$\Delta\xi(\phi) = \Delta\xi(\phi_i) + \left[\Delta\xi(\phi_{i+1}) - \Delta\xi(\phi_i)\right] \cdot \frac{(\phi - \phi_i)}{(\phi_{i+1} - \phi_i)} \qquad \text{[A-5]}$$

TABLE A-2 METEOROLOGICAL PARAMETERS FOR TROPOSPHERIC DELAY

	Average				
Latitude (°)	**P_0 (mbar)**	**T_0 (K)**	**e_0 (mbar)**	**β_0 (K/m)**	**λ_0**
15° or less	1013.25	299.65	26.31	6.30e-3	2.77
30	1017.25	294.15	21.79	6.05e-3	3.15
45	1015.75	283.15	11.66	5.58e-3	2.57
60	1011.75	272.15	6.78	5.39e-3	1.81
75° or greater	1013.00	263.65	4.11	4.53e-3	1.55
	Seasonal Variation				
Latitude (°)	**ΔP (mbar)**	**ΔT (K)**	**Δe (mbar)**	**D*b* (K/m)**	**D*l***
15° or less	0.00	0.00	0.00	0.00e-3	0.00
30	-3.75	7.00	8.85	0.25e-3	0.33
45	-2.25	11.00	7.24	0.32e-3	0.46
60	-1.75	15.00	5.36	0.81e-3	0.74
75° or greater	-0.50	14.50	3.39	0.62e-3	0.30

Zero-altitude zenith delay terms [z_{hyd}, z_{wet}] are calculated as:

$$z_{hyd} = \frac{10^{-6} k_1 R_d P}{g_m} \qquad \text{[A-6]}$$

$$z_{wet} = \frac{10^{-6} k_2 R_d}{g_m(\lambda + 1) - \beta R_d} \cdot \frac{e}{T} \qquad \text{[A-7]}$$

where k_1 = 77.604 K/mbar, k_2 = 382000 K^2/mbar, R_d = 287.054 J/kg/K, and g_m = 9.784 m/s^2.

[d_{hyd}, d_{wet}] are calculated as:

$$d_{hyd} = \left(1 - \frac{\beta H}{T}\right)^{\frac{g}{R_d \beta}} \cdot z_{hyd} \quad \text{[A-8]}$$

$$d_{wet} = \left(1 - \frac{\beta H}{T}\right)^{\frac{(\lambda+1)g}{R_d \beta} - 1} \cdot z_{wet} \quad \text{[A-9]}$$

where g = 9.80665 m/s^2 and the receiver's height, [H] is expressed in units of meters above mean-sea-level.

The tropospheric correction mapping function for satellite elevation, $m(E_i)$, is calculated as:

$$m(El_i) = \frac{1.001}{\sqrt{0.002001 + \sin^2(El_i)}} \quad \text{[A-10]}$$

This mapping function is valid for satellite elevation angles of not less than 5°.

A.4.2.5 Residual Tropospheric Error

The model for the residual error for the tropospheric delay estimate for satellite *i* is:

$$\sigma^2_{j,tropo} = (0.12 \cdot m(E))^2 \quad \text{[A-11]}$$

where the tropospheric vertical error is σ_{TVE} = 0.12 m

A.4.2.6 PRN Masks

Masks will be used to designate which *PRN* belongs to which correction *slot*. For example, GPS satellites are assigned the first PRNs (1-37). These masks improve the efficiency of the broadcast by preventing the continual inclusion of PRNs for fast corrections and σ^2_{UDRE} parameters. In the case of GLONASS satellites, the PRN indicates the GLONASS constellation slot number.

A.4.2.7 Number of Satellites

The WAAS will provide data for a maximum of 51 satellites.

A.4.2.8 Issue of Data

The fast correction data for each satellite supported will be accompanied by a Fast Correction Issue of Data (IODF) to prevent erroneous application of σ^2_{UDRE}. The long term satellite correction data for each satellite supported will be accompanied by Issue of Data (IOD) information to prevent erroneous application of correction data. The WAAS issue of long term satellite correction data will be identical to the GPS IOD Ephemeris defined in [1] for the GPS satellites, and identical to a similar term for the GLONASS satellites when defined. Various other WAAS issues of data defined below will also be applied to prevent erroneous use of the PRN and Ionospheric Grid Point (IGP) masks.

A.4.2.9 Acquisition Information

Preambles will be provided in the messages for data acquisition.

A.4.3 Format Summary

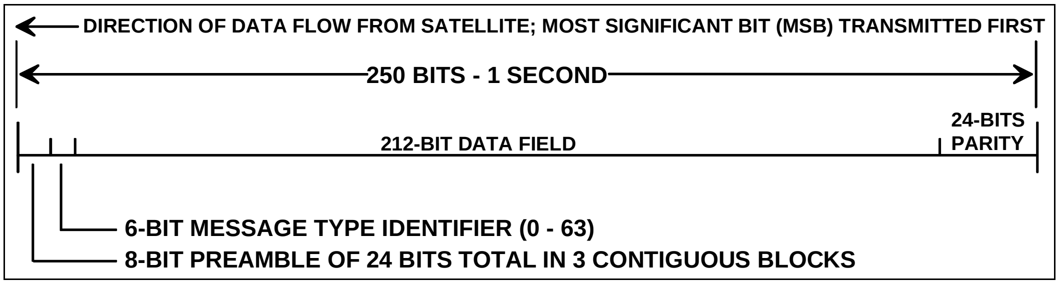


FIGURE A-5 DATA BLOCK FORMAT

A.4.3.1 Block Format

The block format for the 250 bits per second data rate is shown in Figure A-5. A block is defined as the complete 250 bits, while a message is defined as the 212 bit data field. The start of the first 8-bit part of every other 24-bit distributed preamble will be synchronous with the 6-second GPS subframe epoch to within the overall WAAS performance requirements. The block transmission time will be one second.

The 8-bit preamble starts at bit 0 of the 250-bit block followed by the 6-bit Message Type at bit 8. The data field then starts at bit 14, followed by the parity field that starts at bit 226. The sequence of the data words is shown in the figures describing the message formats while the number of bits per data word is given in the tables describing message contents. The order of the words in those tables is not related to the sequence of the words in the message.

A.4.3.2 Block Length and Content

Blocks will be 250 bits long (one second), consisting of an 8-bit part of a distributed preamble, a 6-bit message type, a 212-bit message and 24-bits of Cyclic Redundancy Check (CRC) parity. This block length is consistent with the required *time-to-alert*, and it provides an efficient parity-to-data ratio. Any message type can occur in any given one-second interval.

A.4.3.3 Parity

Twenty-four bits of CRC parity will provide protection against burst as well as random errors with a probability of undetected error $\leq 2^{-24} = 5.96\times10^{-8}$ for all channel bit error probabilities ≤ 0.5. The CRC word is calculated in the forward direction on the entire bit-oriented message, including the block header containing the preamble and message type identifier, and using a seed of 0. The sequence of 24 bits $(p_1,p_2,...,p_{24})$ is generated from the sequence of information bits $(m_1,m_2,...,m_{226})$. This is done by means of a code that is generated by the polynomial

$$g(X) = \sum_{i=0}^{24} g_i X^i \qquad \text{[A-12]}$$

where

$$\begin{aligned} g_i &= 1 \text{ for } i = 0, 1, 3, 4, 5, 6, 7, 10, 11, 14, 17, 18, 23, 24 \\ &= 0 \text{ otherwise} \end{aligned}$$

This code is called CRC-24Q (Q for Qualcomm Corporation) [4]. The generator polynomial of this code is in the following form (using binary polynomial algebra):

$$g(X) = (1 + X)p(X) \tag{A-13}$$

where $p(X)$ is the primitive and irreducible polynomial

$$p(X) = X^{23} + X^{17} + X^{13} + X^{12} + X^{11} + X^{9} + X^{8} + X^{7} + X^{5} + X^{3} + 1 \tag{A-14}$$

When, by the application of binary polynomial algebra, the above $g(X)$ is divided into $m(X)X^{24}$, where the information sequence $m(X)$ is expressed as

$$m(X) = m_k + m_{k-1}X + m_{k-2}X^2 + \cdots + m_1 X^{k-1} \tag{A-15}$$

the result is a quotient and a remainder $R(X)$ of degree < 24. The bit sequence formed by this remainder represents the parity check sequence. Parity bit p_i, for any i from 1 to 24, is the coefficient of x^{24-i} in $R(X)$.

This code has the following characteristics [5, 6, 7, 8]:

1. It detects all single bit errors per code word.
2. It detects all double bit error combinations in a codeword because the generator polynomial $g(X)$ has a factor of at least three terms.
3. It detects any odd number of errors because $g(X)$ contains a factor $1+X$.
4. It detects any burst error for which the length of the burst is ≤ 24 bits.
5. It detects most large error bursts with length greater than the parity length r = 24 bits. The fraction of error bursts of length b > 24 that are undetected is:
   a. $2^{-24} = 5.96 \times 10^{-8}$, if b > 25 bits.
   b. $2^{-23} = 1.19 \times 10^{-7}$, if b = 25 bits.

The encoding and decoding procedures can be found in [8] (for example). An example message (a Message Type 2) with passed parity is given as follows:

Preamble, Message ID, IODF, IODP:

	Binary: 11, followed by Hex: 1824
13 corrections:	Hex: 003|c00|3c2|200|03f|4bc|000|3c0|03c|003|c00|03f|fd8
13 UDREIs:	Hex: 0003cb240003f
Parity:	Hex: a0f7dd

A.4.3.4 Preamble

The distributed preamble will be a 24-bit unique word, distributed over three successive blocks. These three 8-bit words will be made up of the sequence of bits — 01010011 10011010 11000110. The start of every other 24-bit preamble will be synchronous with a 6-second GPS subframe epoch.

With respect to the convolutional encoding, the preamble is within the decoded bit stream. It will be encoded just like all of the other bits. It is a place marker, and cannot be used for acquisition or encoded bit synchronization prior to convolutional decoding. The users' convolutional decoding algorithm must provide synchronization to the data bits.

A.4.4 Messages and Relationships Between Message Types

Table A-3 presents the set of message types. Unless otherwise stated, data is represented in unsigned binary format.

In order to associate data in different message types, a number of issue of data (IOD) parameters are used. These parameters include:

- IOD_k (GPS IOD Clock - $IODC_k$, GPS IOD Ephemeris - $IODE_k$, GLONASS Data - $IODG_k$): Indicates GPS clock and ephemeris issue of data or GLONASS clock and ephemeris issue of data, where k = satellite
- IOD PRN Mask (IODP): Identifies the current PRN mask
- IOD Fast $Corrections_j$ ($IODF_j$): Identifies the current fast corrections, where j = fast corrections Message Type (Types 2 - 5)
- IOD Ionospheric Grid Point Mask (IODI): Identifies the current Ionospheric Grid Point mask
- IOD Service Message (IODS): Identifies the current Service Message(s) Type 27

The relationship among the messages is shown in Figure A-6. The IOD's (including GPS IODC and IODE and GLONASS equivalent term when defined) are specific to each satellite, and are updated separately. Broadcast data will only be referenced to one PRN mask, one Ionospheric Grid Point mask, and one active set of Service Messages at a time. Since fast corrections are always provided in different message types including blocks of 13 satellites, a different IODF is used for each block. Note that the WAAS will ensure that the long-term corrections are sent several times when modified, and the magnitude of the change will be small so that an issue of data is not necessary to connect Type 24 or 25 and Type 2-5 messages. In addition, the WAAS will update long term corrections at a rate high enough to accommodate these small changes, while also accommodating missed messages by the users.

TABLE A-3 MESSAGE TYPES

Type	Contents	Section No.
0	Don't use for safety applications (for WAAS testing)	A.4.4.1
1	PRN Mask assignments, set up to 51 of 210 bits	A.4.4.2
2 to 5	Fast corrections	A.4.4.3
6	Integrity information	A.4.4.4
7	Fast correction degradation factor	A.4.4.5
8	Reserved for future messages	—
9	GEO navigation message (*X*, *Y*, *Z*, time, etc.)	A.4.4.11
10	Degradation Parameters	A.4.4.6
11	Reserved for future messages	—
12	WAAS Network Time/UTC offset parameters	A.4.4.15
13 to 16	Reserved for future messages	—
17	GEO satellite almanacs	A.4.4.12
18	Ionospheric grid point masks	A.4.4.9
19 to 23	Reserved for future messages	—
24	Mixed fast corrections/long term satellite error corrections	A.4.4.8
25	Long term satellite error corrections	A.4.4.7
26	Ionospheric delay corrections	A.4.4.10
27	WAAS Service Message	A.4.4.13
28	Clock-Ephemeris Covariance Matrix Message	A.4.4.16
29 to 61	Reserved for future messages	—
62	Internal Test Message	—
63	Null Message	A.4.4.14

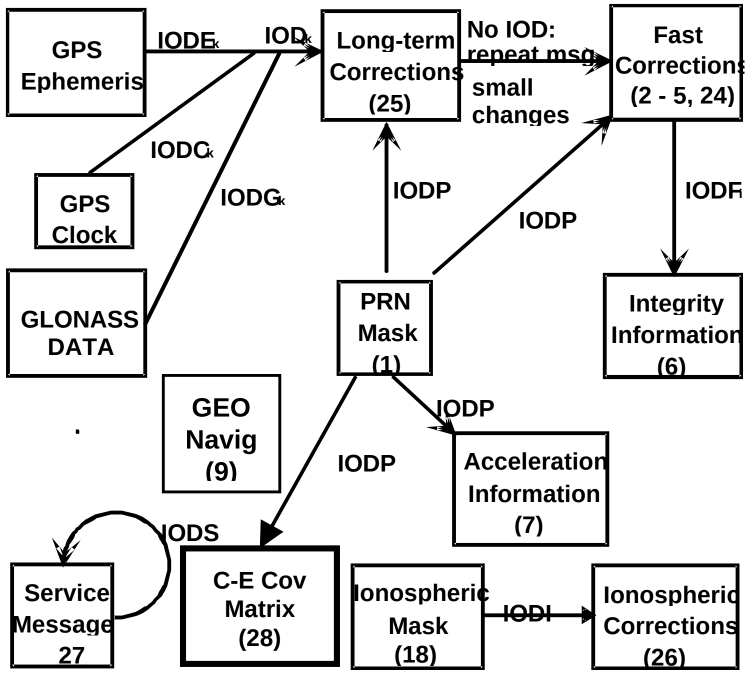


FIGURE A-6 INTERRELATIONSHIPS OF MESSAGES

A.4.4.1 Do Not Use for Safety Applications Message Type 0

The first message type, Message Type 0, will be used primarily during system testing. The receipt of a Message Type 0 will result in the cessation of the use of any ranging data and all message types 1-7, 9-10, 18, 24-28 obtained from that WAAS signal (PRN code). Other message types may be retained, such as message type 17, for potential performance enhancements. In addition, that WAAS signal (PRN code) shall be deselected for at least one minute.

While testing, WAAS will broadcast the contents of a type 2 message in each type 0 message. In the rare event that a Type 0 message is used to indicate a problem with the signal or broadcast data, it will not contain the Type 2 contents but will be empty (all 0's). For users who do not require integrity (equipment under test or equipment used for non-safety applications), the message type 0 that is not empty may be used for ranging and corrections. Other SBAS service providers may broadcast both Type 0 and Type 2 messages during testing.

A.4.4.2 PRN Mask Assignments Message Type 1

The PRN Mask is given in Message Type 1. It consists of 210 ordered slots, each of which indicates if data is provided for the corresponding satellite as defined in Table A-4. For example, a one in the fifth slot indicates data is being provided for GPS PRN 5 and the 40^{th} slot indicates GLONASS Slot Number 3. The mask will have up to 51 bits set in the 210 slots. Note that the satellites for which corrections are provided must be ordered from 1 to a maximum of 51, in order to decode Message Types 2-5, 6, 7, 24, 25 and 28. Data in Message Types 2-5, 6, 7 and the fast corrections part of Message Type 24 are provided sequentially. Long term corrections in Message Types 24 and 25 and clock-ephemeris covariance matrix data in Message Type 28 may or may not be provided sequentially, since the PRN Mask number is specified for each correction. The mask will be followed by a 2-bit issue of data PRN (IODP) to indicate the mask's applicability to the corrections and accuracies contained in messages to which the mask applies. An example of a PRN mask is shown in Figure A-7.

TABLE A-4 PRN MASK ASSIGNMENTS

PRN Slot	Assignment
1 to 37	GPS/GPS Reserved PRN
38 to 61	GLONASS Slot Number plus 37
62 to 119	Future GNSS
120 to 138	GEO/WAAS PRN
139 to 210	Future GNSS/GEO/WAAS/Pseudolites

Bit number (in order of transmission)	1	2	3	4	5	6	7		38	209	210
PRN Mask	0	0	1	0	1	0	1	10 ‘0’s 20 ‘1’s	1	0	0
PRN Code Number			PRN 3		PRN 5		PRN 7		GLONASS Slot 1	PRN Mask Value	
PRN Mask Number			1		2		3		24		

FIGURE A-7 EXAMPLE PRN MASK

A.4.4.2.1 PRN Mask Transition

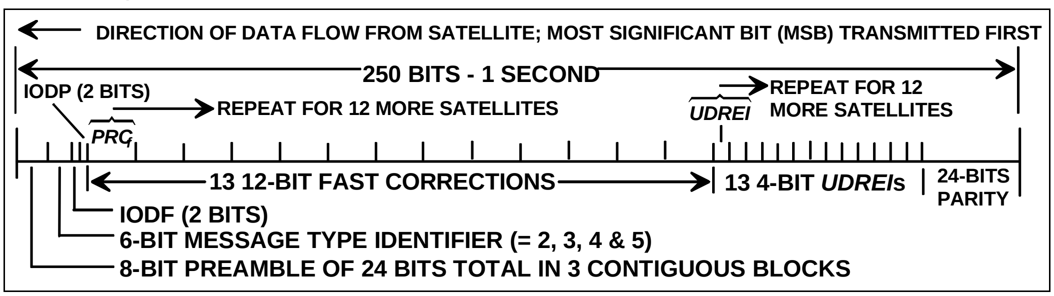
The transition of the PRN Mask to a new one (which will be infrequent) will be controlled with the 2-bit IODP, which will sequence to a number between 0 and 3. The same IODP will appear in the applicable Message Types 2 - 5, 7, 24, 25 and 28. This transition would probably only occur when a new satellite is launched or when a satellite fails and is taken out of service permanently. In the latter case, there would be no hurry to do so, unless the slot is needed for another satellite. It could simply be flagged as a *don't use* satellite. A degraded satellite may be flagged as a *don’t use* satellite temporarily.

If the IODP of the mask does not agree with the IODP in the applicable Message Types 2 - 5, 7, 24, 25 and 28, the user will not use the applicable message until a mask with the matching IODPs agree. The change of IODP in the PRN mask message will always occur before the IODP changes in all other messages. During a change-over of the IODP in the PRN mask, the user equipment continues to use the old mask to decode messages until a corrections message using the new mask is received, and stores the new mask so that there are no interruptions to service when the new mask becomes effective. As the new mask starts to be used, the user will use some data which correlated with the old mask and some data that correlated with the new mask. However, if the IODP changes in those message types before receipt of the new PRN mask, these message types cannot be used until receipt of the new mask.

A.4.4.3 Fast Corrections Message Types 2 - 5

The fast corrections messages format is illustrated in Figure A-8. Message Type 2 contains the data sets for the first 13 satellites designated in the PRN mask. Message Type 3 contains the data sets for satellites 14 - 26 designated in the PRN mask, etc., through Message Type 5, which contains the data sets for satellites 40 through 51 designated in the PRN mask. The last data set of Message Type 5 is not used due to the constraint that corrections can only be provided for 51 satellites (see Message Type 6). A fast corrections message type will only be sent if the number of satellites designated in the PRN mask requires it: e.g., Message Type 5 will only be broadcast if 40 or more satellites are designated. Message Types 2 - 5 and 24 contain a 2-bit $IODF_j$. The $IODF_j$, where j is the fast corrections Message Type (2 – 5, 24), is used to associate the σ^2_{UDRE} contained in a Message Type 6. When there is no alert condition for any of the satellites in a message type 2-5 and 24, the range of each $IODF_j$ counter is only 0 to 2. When an alert occurs in one or more of the satellites in a message type 2-5 or 24, $IODF_j = 3$. An $IODF_j = 3$ indicates that the σ^2_{UDRE} information in a Message Type 2-6 and 24 applies to all active data in the corresponding message type (j = 2 - 5), rather than a particular set of fast corrections. If there are 6 or fewer satellites in a block, they may be placed in a mixed corrections message, Type 24. The last half of Message Type 24 is reserved for long term corrections. The fast data set for each satellite consists of 16 bits; a 12-bit fast correction and a 4-bit UDRE Indicator (UDREI). The UDREI is described in Section A.4.4.4. Each message also contains a 2-bit IODP indicating the associated PRN mask. Refer to Section A.4.4.2 for the application of IODP.

The 12-bit fast correction (PRC_f) has a 0.125 meter resolution, for a valid range of -256.000 m to +255.875 m. If the range is exceeded, a *don't use* indication will be inserted into the UDREI field. The user should ignore extra data sets not represented in the PRN mask. The time of applicability (t_{of}) of the PRC_f is the start of the epoch of the WNT second that is coincident with the transmission at the GEO satellite of the first bit of the message block.



<u>FIGURE A-8</u> TYPES 2 - 5 FAST CORRECTIONS MESSAGES FORMAT

Range-rate corrections (*RRC*) of the fast corrections will not be broadcast. The user will compute these rates-of-change by differencing fast corrections (regardless of $IODF_j$) [9]. The total fast correction for a given satellite will be applied as

$$PR_{corrected}(t) = PR_{measured}(t) + PRC(t_{of}) + RRC(t_{of}) \times (t - t_{of}) \qquad \text{[A-16]}$$

If $ai_i \neq 0$, the *RRC* is computed by the user differencing fast corrections(Refer to Section A.4.4.5):

$$RRC(t_{of}) = \frac{PRC_{current} - PRC_{previous}}{\Delta t} \qquad \text{[A-17]}$$

where:

$PRC_{current}$	= the most recent fast correction (same as $PRC(t_{of})$)
$PRC_{previous}$	= a previous fast correction
Δt	= $(t_{of} - t_{of,previous})$
t_{of}	= time of applicability of the most recent fast correction
$t_{of,previous}$	= time of applicability of the $PRC_{previous}$

If $ai_i = 0$, the RRC is equal to zero (0).

The most recent fast correction received ($PRC_{current}$) must be used when computing the RRC. The range rate correction must time out if $\Delta t > I_{fc,j}$ (the shortest fast correction time-out interval for any satellite included in the associated fast corrections message (j=2,..,5) or fast corrections in Message Type 24). In addition, the RRC must time-out if $(t-t_{of} -1) > 8\Delta t$.

In selecting the previous fast correction to be used in determining the RRC, the user should select the fast correction which minimizes the degradation due to fast corrections and range rate corrections (A.4.5.1.2.2). During an alert condition, it is likely that several corrections will be sent over a short period of time. In this case, in order to minimize the noise effect on RRC, the previous fast correction closest to $I_{fc}/2$ seconds prior to the current fast correction should be used.

Anytime a “don’t use” or "not monitored" indication is received, and is then followed by a valid correction, the calculation of the RRC must be reinitialized. During reinitialization, the RRC will not be used and the variance in Appendix J.2.2 of $\sigma^2_{i,flt} = 60^2 m^2$ is used. The computation of *RRC* is required even in the case of an identical $IODF_j$.

The high degree of resolution of these fast corrections should not be confused with correction accuracy. The actual accuracy provided will be indicated by the σ^2_{UDRE} data.

A.4.4.4 Integrity Information Message Type 6

The integrity information message is shown in Figure A-9. Each message includes an $IODF_j$ for each fast corrections Message Type (2 - 5). The σ^2_{UDRE} information for each block of satellites applies to the fast corrections with the corresponding $IODF_j$. For example, if $IODF_3$=1, then the σ^2_{UDRE}’s for satellites 14 - 26 apply to the corrections provided in a previously broadcast Type 3 message that had the IODF = 1. An $IODF_j$ = 3 indicates that the σ^2_{UDRE}'s apply to all active data from the corresponding message type (j = 2 - 5). Since all satellites in the PRN mask are mapped to Message Types 2-5, it is not necessary to explicitly include an IODF for Message Type 24 in Message Type 6. The information transmitted in Message Type 6 should be applied to the applicable satellites in Message Type 24 (e.g., if the Type 24 message contains correction data for satellites 27 to 32, then $IODF_4$ is associated with that Type 24 message). The remaining 204 bits are divided into 51 slots of 4 bit UDREIs, one for each satellite in the mask. This message format is described in Table A-5. Message Type 6 allows the fast corrections of Message Type 2-5 and 24 to be updated infrequently, commensurate with the dynamics of the satellite clock errors. If all fast corrections are being updated at a six second rate, Message Type 6 may not be required since the UDREIs are also included in Message Types 2 - 5 and 24; however, under certain timing conditions a Type 6 will be needed even if only one satellite has an alert. Message Type 6 can also be used to indicate an alert condition on multiple satellites.

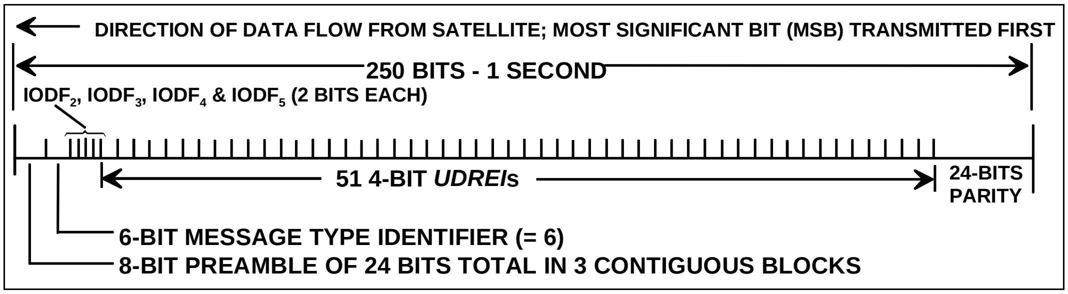


FIGURE A-9 TYPE 6 INTEGRITY MESSAGE FORMAT

The 4-bit UDREIs are used for the evaluation of the σ^2_{UDRE}'s, indicating the accuracy of combined fast and long-term error corrections, not including the accuracy of the iono-spheric delay corrections (indicated in σ^2_{GIVE}'s), which are computed from the indicators that are provided separately in Message Type 26. The ephemeris accuracy component is an "equivalent" range accuracy, rather than accuracy of each of the Earth-Centered-Earth-Fixed (ECEF) components. Evaluation of the model variance (σ^2_{UDRE}) versus indicator value is given in Table A-6. The σ^2_{UDRE} (in Type 2 – 6, 24) applies at a particular time and degrades as defined in Section A.4.4.5.

TABLE A-5 TYPE 6 INTEGRITY MESSAGE CONTENT

Parameter	No. of Bits	Scale Factor (LSB)	Effective Range	Units
$IODF_2$	2	1	0 to 3	unitless
$IODF_3$	2	1	0 to 3	unitless
$IODF_4$	2	1	0 to 3	unitless
$IODF_5$	2	1	0 to 3	unitless
For each of 51 satellites	—	—	—	—
UDREI	4	(see Table A-6)	(see Table A-6)	unitless

TABLE A-6 EVALUATION OF UDREI$_I$

UDREI$_i$	**UDRE$_i$ Meters**	**$\sigma^2_{i,UDRE}$ Meters^2**
0	0.75	0.0520
1	1.0	0.0924
2	1.25	0.1444
3	1.75	0.2830
4	2.25	0.4678
5	3.0	0.8315
6	3.75	1.2992
7	4.5	1.8709
8	5.25	2.5465
9	6.0	3.3260
10	7.5	5.1968
11	15.0	20.7870
12	50.0	230.9661
13	150.0	2078.695
14	Not Monitored	Not Monitored
15	Do Not Use	Do Not Use

A.4.4.5 Fast Correction Degradation Factor Message Type 7

The σ^2_{UDRE} broadcast in Types 2 - 6 and 24 applies at a time prior to or at the time of applicability of the associated corrections. The Type 7 message specifies the applicable IODP, system latency time (t_{lat}) and the fast correction degradation factor indicator (ai_i) for computing the degradation of fast and long term corrections as described in Section A.4.5.1.

The Type 7 message contents are described in Table A-7 and its format is shown in Figure A-10. Table A-8 provides the evaluation of the fast corrections degradation factor given the degradation factor indicator, ai_i. Table A-8 also shows the user time-out interval for fast corrections. The time-out interval for fast corrections is reckoned from the end of reception of the fast correction message.

TABLE A-7 TYPE 7 FAST CORRECTION DEGRADATION FACTOR MESSAGE CONTENTS

Parameter	No. of Bits	Scale Factor (LSB)	Effective Range	Units
System latency (t_{lat})	4	1	0 to 15	seconds
IODP	2	1	0 to 3	unitless
Spare	2	—	—	—
For each of 51 satellites	204	—	—	—
Degradation factor indicator (ai_i)	4	1	0 - 15	—

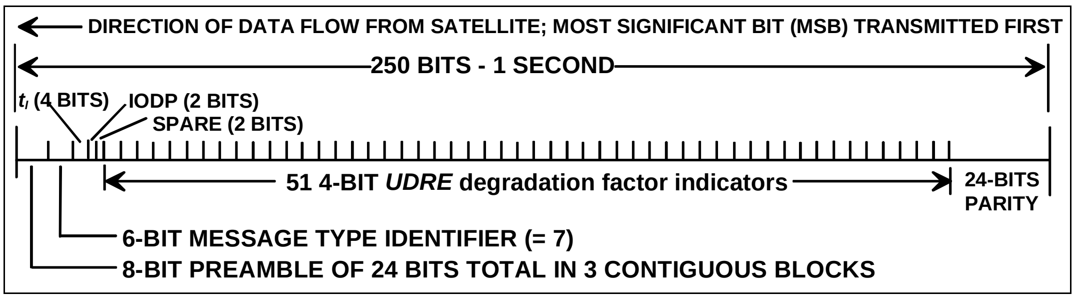


FIGURE A-10 TYPE 7 FAST CORRECTION DEGRADATION FACTOR MESSAGE FORMAT

TABLE A-8 FAST CORRECTIONS DEGRADATION FACTOR AND USER TIME-OUT INTERVAL EVALUATION

Fast Corrections Degradation Factor Indicator (ai_i)	Fast Corrections Degradation Factor (a_i)- m/s^2	User Time-Out Interval for fast corrections - seconds En Route through Nonprecision Approach (I_{fc})	User Time-Out Interval for fast corrections - seconds Precision Approach Mode (I_{fc})	Maximum Fast Correction Update Interval (seconds)
0	0.00000	180	120	60
1	0.00005	180	120	60
2	0.00009	153	102	51
3	0.00012	135	90	45
4	0.00015	135	90	45
5	0.00020	117	78	39
6	0.00030	99	66	33
7	0.00045	81	54	27
8	0.00060	63	42	21
9	0.00090	45	30	15
10	0.00150	45	30	15
11	0.00210	27	18	9
12	0.00270	27	18	9
13	0.00330	27	18	9
14	0.00460	18	12	6
15	0.00580	18	12	6

A.4.4.6 Degradation Factors Message Type 10

The degradation factors are described in Table A-9. These factors are used as described in Sections A.4.4.16 and A.4.5.

TABLE A-9 TYPE 10 DEGRADATION FACTORS

Parameter	No. of Bits	Scale Factor (LSB)	Effective Range	Units
B_{rrc}	10	0.002	0 to 2.046	m
C_{ltc_lsb}	10	0.002	0 to 2.046	m
C_{ltc_v1}	10	0.00005	0 to 0.05115	m/s
I_{ltc_v1}	9	1	0 to 511	s
C_{ltc_v0}	10	0.002	0 to 2.046	m
I_{ltc_v0}	9	1	0 to 511	s
C_{geo_lsb}	10	0.0005	0 to 0.5115	m
C_{geo_v}	10	0.00005	0 to 0.05115	m/s
I_{geo}	9	1	0 to 511	s
C_{er}	6	0.5	0 to 31.5	m
C_{iono_step}	10	0.001	0 to 1.023	m
I_{iono}	9	1	0 to 511	s
$C_{iono\ ramp}$	10	0.000005	0 to 0.005115	m/s
RSS_{UDRE}	1	—	0 to 1	unitless
RSS_{iono}	1	—	0 to 1	unitless
$C_{covariance}$	7	0.1	0 to 12.7	unitless
Spare	81	—	—	—

Notes: **1.** *The spare bits may be used to define degradation factors applicable to GLONASS satellites.*

2. *If message type 28 is not broadcast by a service provider, the term $C_{covariance}$ is not used.*

A.4.4.7 Long Term Satellite Error Corrections Message Type 25

Message Type 25 will be broadcast to provide error estimates for slow varying satellite ephemeris and clock errors with respect to WGS-84 ECEF coordinates. These corrections are estimated with respect to the GNSS broadcast clock and ephemeris parameters. These long-term corrections are not broadcast by an SBAS service provider for SBAS satellites operated by that service provider. Instead, the Type 9 GEO Navigation Message will be updated as required to prevent slow varying GEO satellite errors. For example, WAAS does not broadcast long term corrections for WAAS satellites, but it does broadcast them for EGNOS and MSAS satellites.

Table A-10 and Figure A-11 present the first half of the Type 25 message representing the corrections for the long term satellite position and clock offset errors of two satellites when only those corrections are needed for the required accuracy. Table A-11 and Figure A-12 present the first half of the Type 25 message representing corrections for the long term satellite position, velocity, clock offset and drift errors of one satellite when velocity and drift corrections are also needed. Table A-10 and Table A-11 only present the definition of the first 106 bits of the 212 bit message. The second 106 bits have the same definition. The first bit of the 106 bits is a velocity code, indicating whether or not this half-message includes clock drift and velocity component error estimates. If it is set to a 1, the message includes clock drift and velocity component estimates; otherwise it consists of only clock offset and position component error estimates, but for 2 satellites, instead of 1. Thus, the message can consist of error estimates for 1, 2, 3 or 4 satellites, depending upon the velocity codes in both halves of the message and how many satellites are being corrected. The error estimates are accompanied by the IODP associated with the PRN mask. Refer to Section A.4.4.2 for the application of IODP.

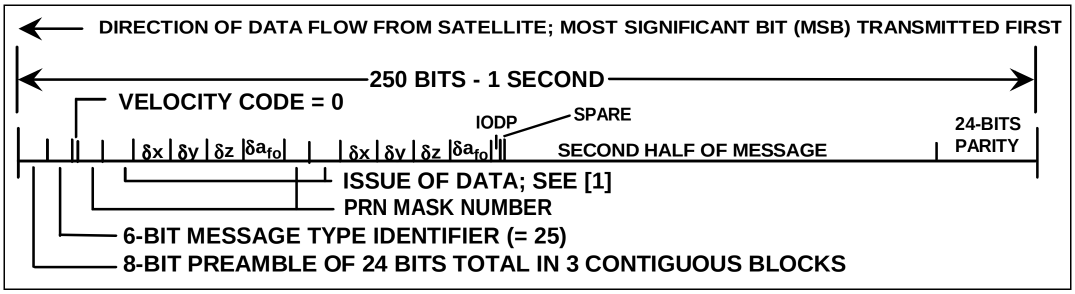


FIGURE A-11 TYPE 25 LONG TERM SATELLITE ERROR CORRECTIONS VELOCITY CODE = 0

The PRN Mask No. is the sequence number of the bits set in the 210 bit mask (that is, between 1 and 51). As opposed to data in Message Types 2 - 5, the data in this Type 25 message does not have to appear in sequence. Error corrections for satellites with faster changing long term errors can be repeated at a higher rate than ones with slower changing long term errors. The IODP of the message must agree with the IODP associated with the PRN mask in Message Type 1.

Note that the ranges of the clock offset and position component error estimates when the velocity code is 0 are less than if the velocity code is 1. The reason for this is for data rate efficiency. Usually, the necessity for clock drift and velocity component error estimates is small. Only the clock offset and position component error estimates will be broadcast, unless any of the errors (position, velocity, offset or drift) are large enough to warrant their use on a satellite-by-satellite basis.

Figure A-11 presents the case where 2 satellite position and clock offset corrections occupy the first half of the message. Figure A-12 presents the case where one satellite's position and velocity and clock offset and drift corrections occupy that position. Each could have just as well occupied the second half of the message while the other occupied the first, or one type could occupy both halves.

TABLE A-10 TYPE 25 LONG TERM SATELLITE ERROR CORRECTIONS HALF MESSAGE PARAMETERS WITH VELOCITY CODE OF 0 (POSITION AND CLOCK OFFSET CORRECTIONS ONLY)

Parameter	**No. of Bits** (Note 1)	**Scale Factor (LSB)**	**Effective Range** (Note 1)	**Units**
Velocity Code = 0	1	1	—	unitless
PRN Mask No.(Note 2)	6	1	0 to 51	—
Issue of Data (Note 3)	8	1	0 to 255	unitless
δx (ECEF)	9	0.125	±32	meters
δy (ECEF)	9	0.125	±32	meters
δz (ECEF)	9	0.125	±32	meters
δa_{f0}	10	2^{-31}	$\pm 2^{-22}$	seconds
PRN Mask No.(Note 2)	6	1	0 to 51	---
Issue of Data (Note 3)	8	1	0 to 255	unitless
δx (ECEF)	9	0.125	±32	meters
δy (ECEF)	9	0.125	±32	meters
δz (ECEF)	9	0.125	±32	meters
δa_{f0}	10	2^{-31}	$\pm 2^{-22}$	seconds
IODP	2	1	0 to 3	unitless
Spare	1	—	—	—

Note 1: *All signed values are coded as two's complement, with the sign bit occupying the MSB. The effective range is smaller than indicated, as the maximum positive value is actually constrained to be one value less (the indicated value minus the resolution).*

Note 2: *Mask sequence. The count of 1's in mask from the first position in mask to the position representing the subject satellite. If set to 0, no satellite is represented and the remainder of the message should be ignored.*

Note 3: *The Issue of Data has the format of the 8-bit GPS Issue of Data-Ephemeris. See [1].*

TABLE A-11 TYPE 25 LONG TERM SATELLITE ERROR CORRECTIONS HALF MESSAGE PARAMETERS WITH VELOCITY CODE OF 1 (VELOCITY AND CLOCK DRIFT CORRECTIONS INCLUDED)

Parameter	**No. of Bits (Note 1)**	**Scale Factor (LSB)**	**Effective Range** (Note 1)	**Units**
Velocity Code = 1	1	1	—	unitless
PRN Mask No.(Note 2)	6	1	0 to 51	—
Issue of Data (Note 3)	8	1	0 to 255	unitless
δx (ECEF)	11	0.125	±128	meters
δy (ECEF)	11	0.125	±128	meters
δz (ECEF)	11	0.125	±128	meters
δa_{f0}	11	2^{-31}	$\pm 2^{-21}$	seconds
δx rate-of-change (ECEF)	8	2^{-11}	±0.0625	meters/sec
δy rate-of-change (ECEF)	8	2^{-11}	±0.0625	meters/sec
δz rate-of-change (ECEF)	8	2^{-11}	±0.0625	meters/sec
δa_{f1}	8	2^{-39}	$\pm 2^{-32}$	seconds/sec
Time-of-Day Applicability t_o	13	16	0 to 86,384	seconds
IODP	2	1	0 to 3	unitless

Note 4: *1), 2) and 3) See footnotes to Table A-10.*

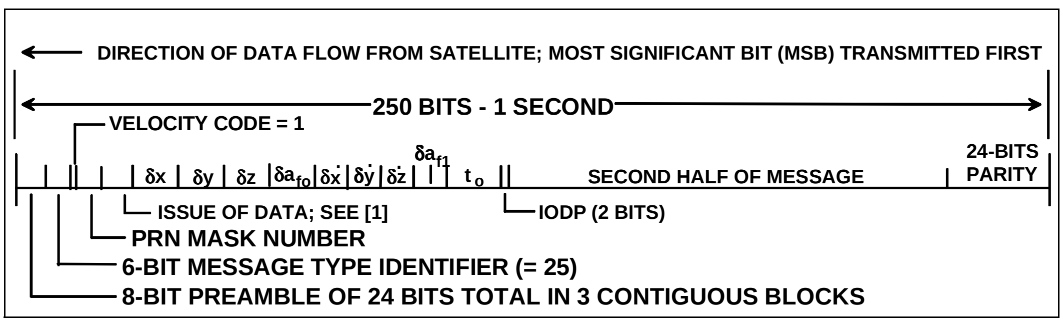


FIGURE A-12 TYPE 25 LONG TERM SATELLITE ERROR CORRECTIONS VELOCITY CODE = 1

In case of the clock offset error correction (δa_{f0}) and clock drift error correction (δa_{f1}), the user will compute the clock time error estimate $\delta\Delta t_{SV}$ at time-of-day t_k as

$$\delta\Delta t_{SV}(t_k) = \delta a_{f0} + \delta a_{f1}(t_k - t_0) + \delta a_{fG0} \qquad \text{[A-18]}$$

where t_0 is the time of day applicability, correcting for rollover if needed.

This correction will be added to Δt_{SV} as computed in Section 20.3.3.3.3.1 of [1]. If the velocity code is set to 0, the δa_{f1} term is simply set to 0. The δa_{fG0} is an additional correction for the GLONASS satellites (that may be) provided in the Type 12 message. It is set to 0 for the GPS satellites. Note that the t_o provided in the Type 25 message has nothing to do with the reference times broadcast from the GNSS satellites. It is the time of applicability of the error corrections, and not the GNSS satellite parameters. This time of applicability will usually be approximately 2 minutes in the future of the transmission time of the message, minimizing resolution errors for at least 4 minutes.

Likewise, the user will compute the position error correction vector as

$$\begin{bmatrix} \delta x_k \\ \delta y_k \\ \delta z_k \end{bmatrix} = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta \dot{x} \\ \delta \dot{y} \\ \delta \dot{z} \end{bmatrix} (t_k - t_0) \qquad \text{[A-19]}$$

This correction vector will be added to the satellite coordinate vector $[x_k\ y_k\ z_k]^T$ (WGS-84 ECEF) computed from the equations in Table 20-IV of [1], or from Section 4.5 of [3]. If the velocity code is set to 0, the rate-of-change vector is simply set to 0. The rules on the time of applicability are the same as for the clock error correction computations. Note that for velocity code = 0, the time of applicability is the time the message is sent. If the time of applicability is in the future, velocity code must = 1; however, for velocity code = 1, the time of applicability may be in the past if the prior long-term message is missed.

The 8-bit issue of data (IOD) broadcast in the message must match that of the GPS broadcast IODC and IODE (in the case of IODC, the least significant 8 bits). If the GNSS broadcast IOD's do not match the IOD broadcast in Message Type 25, it is an indication that the broadcast IOD's have changed. The user will continue to use the matched data previously broadcast until a new matching Message Type 24 or 25 is broadcast for that particular satellite. (All satellites do not have the same IOD.) These new matching messages will be broadcast within the time constraints for user initialization.

Upon transmission of new clock and ephemeris data from GNSS satellites, the WAAS will continue to broadcast corrections to the old long term clock and ephemeris data for a period of 2 to 4 minutes. This delay enables all WAAS users to acquire the new GNSS data.

A.4.4.8 Mixed Fast Corrections/Long Term Satellite Error Corrections Messages Type 24

The Type 24 mixed fast/long-term message will be broadcast under the conditions described in Section A.4.4.3. Figure A-13 presents the Type 24 Mixed Fast Correction/Long Term Satellite Error Corrections Message. The first half of the message consists of six fast data sets (12 bits for PRC_f and 4 for UDREI as defined in A.4.4.3) according to the PRN mask sequence, followed by the 2-bit IODP, a 2-bit Block ID indicating which corrections block is provided, and the 2-bit IODF, leaving 4 spare bits, for a total of 106 bits. The Block ID (0, 1, 2, 3) will indicate whether the Type 24 message contains the fast corrections associated with a Type 2, Type 3, Type 4, or Type 5 message, respectively. The final 106 bits of the data field are composed of a 106-bit half message as described in Section A.4.4.7. With this message type, when the total number of satellites being corrected by WAAS is between 1 and 6, 14 and 19, 27 and 32 or 40 and 45, long-term corrections for one or two satellites can be accommodated every time a set of fast error corrections is broadcast for satellites 1 through 6, 14 through 19, 27 through 32 or 40 through 45.

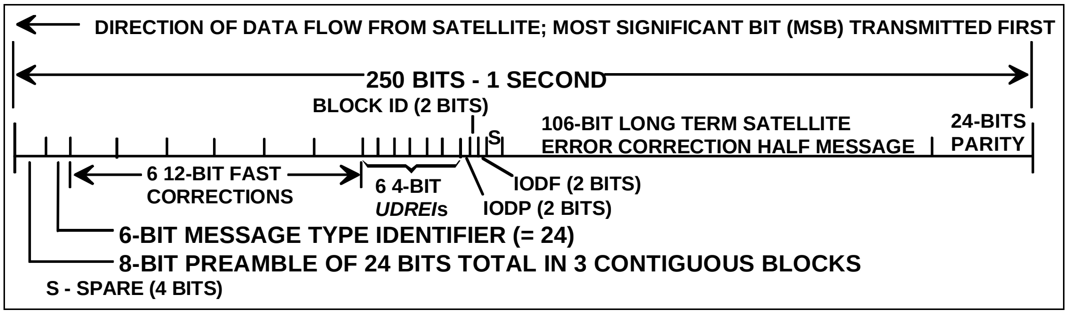


FIGURE A-13 TYPE 24 MIXED FAST CORRECTION/LONG TERM SATELLITE ERROR CORRECTIONS MESSAGE FORMAT

A.4.4.9 Ionospheric Grid Point Masks Message Type 18

The ionospheric delay corrections are broadcast as vertical delay estimates at specified ionospheric grid points (IGPs), applicable to a signal on L1. In order to facilitate flexibility in the location of these IGPs, a fixed definition of densely spaced IGP locations is used, resulting in a large number of possible IGPs. The predefined IGPs are contained in 11 bands (numbered 0 to 10). Bands 0-8 are vertical bands on a Mercator projection map, and bands 9-10 are horizontal bands on a Mercator projection map. The density of these predefined IGPs, given in Table A-12 for bands 0-8 and Table A-13 for bands 9-10, is dictated by the possible large variation in the ionosphere vertical delay during periods of high solar activity, especially at lower latitudes. Since it would be impossible to broadcast IGP delays for all possible locations, a mask is broadcast to define the IGP locations providing the most efficient model of the ionosphere at the time.

TABLE A-12 PREDEFINED WORLD-WIDE IGP SPACING — BANDS 0 - 8

Latitudes Degrees	Latitude Spacing Degrees	Longitude Spacing Degrees
N85	10	90
N75 to N65	10	10
S55 to N55	5	5
S75 to S65	10	10
S85	10	90 (Offset 40° East)

TABLE A-13 PREDEFINED WORLD-WIDE IGP SPACING — BANDS 9 - 10

Latitudes Degrees	Latitude Spacing Degrees	Longitude Spacing Degrees
N85	10	30
N75 to N65	5	10
N60	5	5
S60	5	5
S75 to S65	5	10
S85	10	30 (Offset 10° East)

The predefined 1808 possible IGP locations in bands 0-8, given in latitude and longitude coordinates, are illustrated in Figure A-13. These IGP locations must be stored permanently by the user. The IGP locations are denser at lower latitudes because of the fact that the distance represented by a degree of longitude becomes smaller at higher latitudes. The IGP grid at the equator has 5° spacings, increasing to 10° north of N55° and south of S55°, and finally becoming spaced 90° at N85° and S85° around the poles. (The IGPs at S85° are offset by 40° to accommodate an even distribution of bands as described below.) There are 384 possible IGP locations in bands 9 and 10, given by latitude and longitude. These IGP locations must also be stored permanently by the user. When using these bands, the IGP grid at 60° has 5° longitudinal spacings, increasing to 10° spacings at 65°, 70°, and 75°, and finally becoming spaced 30° at N85° and S85° around the poles. The IGPs at S85° are offset by 10° to align with the spacings in bands 0-8 described above.

The total IGP grid represents too many IGPs for broadcasting in a single message. Thus, the grid is divided into 11 Bands (numbered 0 to 10), and each message indicates the Band associated with 201 possible IGPs (bands are designated with rectangular areas with bold numbers in Figure A-14). Each of bands 0-8 covers 40° of longitude; bands 9-10 cover 25 of latitude and 360 of longitude. When bands 9 and/or 10 are sent, the IGP mask values are set to 0 in bands 0-8 for all IGPs north of 55°N and south of 55°S. Message Type 18 provides a mask for any one of the 11 bands indicated by the band number. Each message also contains an ionospheric mask issue of data (IODI) to ensure that the ionospheric corrections are properly decoded. An additional 4-bit number indicates how many band masks are being broadcast by the subject GEO, so that a user knows whether all available data has been received or whether to wait for another band mask. Note that the user only has to collect and save the vertical delays for IGPs located within a limited distance of his location. A given GEO would only broadcast IGPs in bands (up to 8) that cover the observable IGPs visible from the intersection of its footprint and the controlling system's service volume. If the number of bands is 0, the message is used to indicate that no ionospheric delay corrections are being provided, indicating the precision approach service is not being provided by the broadcasting GEO.

Within bands 0 through 7, the IGPs are numbered from 1 to 201. Within band 8, the IGPs are numbered from 1 through 200. Within bands 9 and 10, the IGPs are numbered from 1 through 192. In bands 0 to 8, the IGPs are numbered counting up from the southwest corner (bottom-left) up each longitude column of the band (from south to north) and continuing for each column from west to east (left-to-right) from the bottom of each column. For example, in Band 0, IGP #1 is at S75, W180, and IGP #201 is at N55, W145 (See Table A-14). In bands 9 and 10, the IGPs are numbered counting eastward from the western corner closest to the equator along each latitude row of the band (from west to east) and continuing for each row towards the poles. For example, in band 9, IGP #1 is at N60, W180, and IGP #192 is at N85, E150 (See Table A-14).

In the mask, a bit set to one ("1") indicates that ionospheric correction information is being provided for the associated IGP. If the bit is set to zero ("0"), no ionospheric correction information is provided for that IGP. An example of an ionospheric grid point mask is shown in Figure A-14.

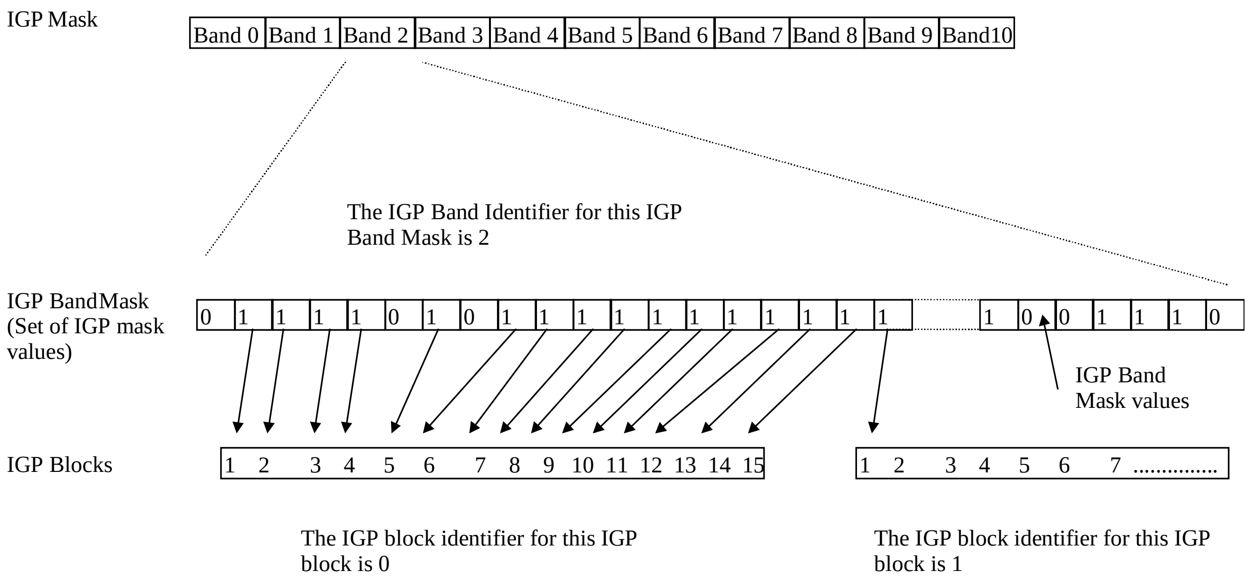


FIGURE A-14 EXAMPLE OF AN IONOSPHERIC GRID MASK

The IODI will sequence through the range from 0 to 3, changing each time the IGP mask changes, which is expected to happen rarely. The user will ensure that the IODI of the bands being used agree with the corresponding IODI in Message Type 26 before applying the vertical delays to the model. The format of Message Type 18 is illustrated in Figure A-16 with contents described in Table A-15.

At the edge of the GEO footprint, the ionospheric pierce points (IPPs) could be located beyond IGPs of the bands being broadcast. However, because of overlap of GEO foot-prints, those IPPs would be covered by an adjacent GEO broadcasting an adjacent band. The adjacent GEO itself would be at a higher elevation angle.

TABLE A-14 IONOSPHERIC MASK BANDS

		Bits in Mask
Band 0		
180 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	1 to 28
175 W	55S, 50S, 45S, ..., 45N, 50N, 55N	29 to 51
170 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	52 to 78
165 W	55S, 50S, 45S, ..., 45N, 50N, 55N	79 to 101
160 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102 to 128
155 W	55S, 50S, 45S, ..., 45N, 50N, 55N	129 to 151
150 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 to 178
145 W	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 1		
140 W	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 28
135 W	55S, 50S, 45S, ..., 45N, 50N, 55N	29 to 51
130 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	52 to 78
125 W	55S, 50S, 45S, ..., 45N, 50N, 55N	79 to 101
120 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102 to 128
115 W	55S, 50S, 45S, ..., 45N, 50N, 55N	129 to 151
110 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 to 178
105 W	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 2		
100 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
95 W	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
90 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	51 to 78
85 W	55S, 50S, 45S, ..., 45N, 50N, 55N	79 to 101
80 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102 to 128
75 W	55S, 50S, 45S, ..., 45N, 50N, 55N	129 to 151
70 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 to 178
65 W	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 3		
60 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
55 W	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
50 W	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 78
45 W	55S, 50S, 45S, ..., 45N, 50N, 55N	79 to 101
40 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102 to 128
35 W	55S, 50S, 45S, ..., 45N, 50N, 55N	129 to 151
30 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 to 178
25 W	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 4		
20 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
15 W	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
10 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 77
5 W	55S, 50S, 45S, ..., 45N, 50N, 55N	78 to 100
0	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	101 to 128
5 E	55S, 50S, 45S, ..., 45N, 50N, 55N	129 to 151
10 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 to 178
15 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 5		

20 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
25 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
30 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 77
35 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 to 100
40 E	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 to 128
45 E	55S, 50S, 45S, ..., 45N, 50N, 55N	129 to 151
50 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 to 178
55 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 6		
60 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
65 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
70 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 77
75 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 to 100
80 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 to 127
85 E	55S, 50S, 45S, ..., 45N, 50N, 55N	128 to 150
90 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	151 to 178
95 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 7		
100 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
105 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
110 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 77
115 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 to 100
120 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 to 127
125 E	55S, 50S, 45S, ..., 45N, 50N, 55N	128 to 150
130 E	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	151 to 178
135 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 8		
140 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
145 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
150 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 77
155 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 to 100
160 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 to 127
165 E	55S, 50S, 45S, ..., 45N, 50N, 55N	128 to 150
170 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	151 to 177
175 E	55S, 50S, 45S, ..., 45N, 50N, 55N	178 to 200
Band 9		
60 N	180W, 175W, 170W, …, 165E, 170E, 175E	1 to 72
65 N	180W, 170W, 160W, …, 150E, 160E, 170E	73 to 108
70 N	180W, 170W, 160W, …, 150E, 160E, 170E	109 to 144
75 N	180W, 170W, 160W, …, 150E, 160E, 170E	145 to 180
85 N	180W, 150W, 120W, … ,90E, 120E, 150E	181 to 192
Band 10		
60 S	180W, 175W, 170W, …, 165E, 170E, 175E	1 to 72
65 S	180W, 170W, 160W, …, 150E, 160E, 170E	73 to 108
70S	180W, 170W, 160W, …, 150E, 160E, 170E	109 to 144
75 S	180W, 170W, 160W, …, 150E, 160E, 170E	145 to 180
85 S	170W, 140W, 110W, …, 100E, 130E, 160E	181 to 192

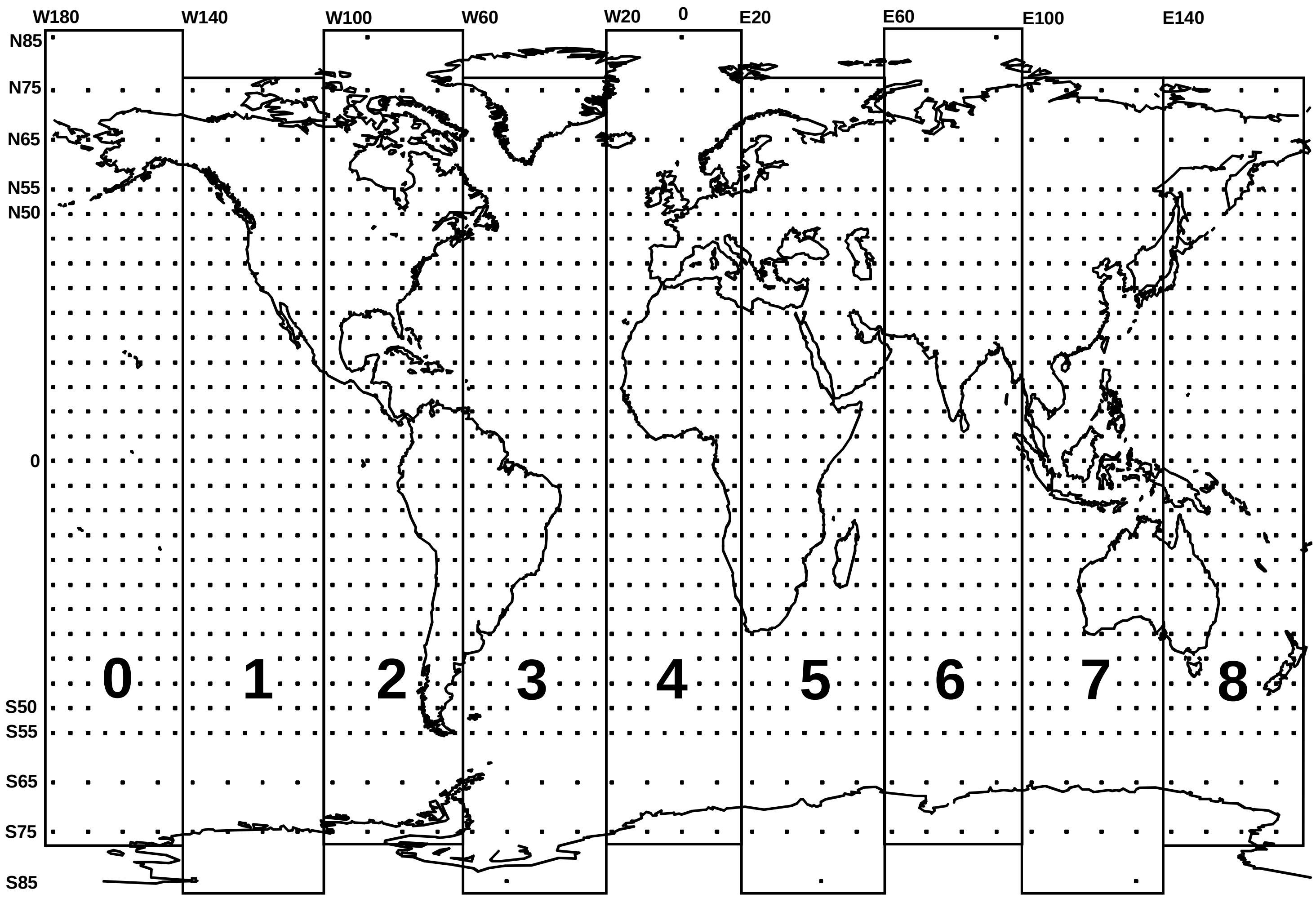


FIGURE A-15 PREDEFINED GLOBAL IGP GRID (BANDS 9 AND 10 ARE NOT SHOWN)

TABLE A-15 TYPE 18 IGP MASK MESSAGE CONTENTS

Parameter	No. of Bits	Scale Factor (LSB)	Effective Range	Units
Number of Bands being broadcast	4	1	0 to 11	unitless
Band Number	4	1	0 to 10	unitless
Issue of Data - Ionosphere (IODI)	2	1	0 to 3	unitless
IGP Mask	201	—	—	unitless
Spare	1	—	—	—

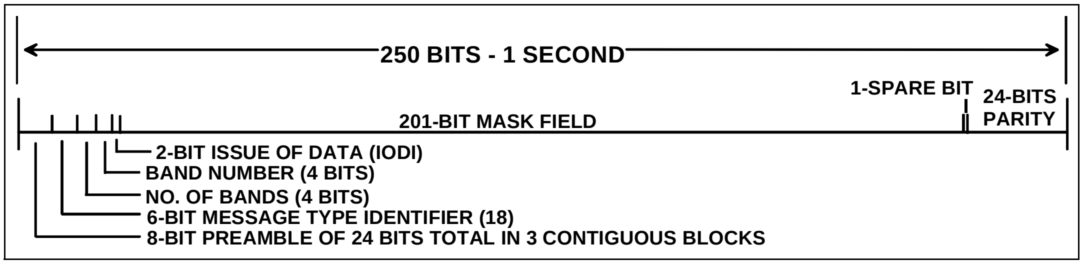


FIGURE A-16 TYPE 18 IGP MASK MESSAGE FORMAT

A.4.4.10 Ionospheric Delay Corrections Messages Type 26

The Type 26 Ionospheric Delay Corrections Message provides the users with vertical delays (relative to an L1 signal) and their accuracy (σ^2_{GIVE}'s) at geographically defined IGPs identified by band number and IGP number in Table A-14. The grid points are indicated in Figure A-14.

Each message contains a band number and a block ID, which indicates the location of the IGPs in the respective band mask. The 4-bit block ID (0-13) indicates to which IGPs the corrections apply. Block 0 contains the IGP corrections for the first 15 IGPs designated in the band mask. Block 1 contains the IGP corrections for IGPs 16 - 30 designated in the band mask, etc. Each band is therefore divided into a maximum of 14 blocks. Corrections associated with slot numbers that exceed the number of IGPs indicated in the IGP band mask should be ignored.

The data content for this message is given in Table A-16 with a format presented in Figure A-17. The evaluation of the σ^2_{GIVE}'s is given in Table A-17. These vertical delays and the evaluated σ^2_{GIVE}'s will be interpolated by the user to the IPP of the observed satellite. This computed vertical delay and the associated σ^2_{UIVE} (model variance for user ionospheric vertical error computed from associated σ^2_{GIVE}'s) must then be multiplied by the obliquity factor computed from the elevation angle to the satellite to obtain a slant range correction and the slant range correction error (σ^2_{UIRE}).

TABLE A-16 IONOSPHERIC DELAY MODEL PARAMETERS FOR MESSAGE TYPE 26

Parameter	No. of Bits	Scale Factor (LSB)	Effective Range	Units
Band Number	4	1	0 to 10	unitless
Block ID	4	1	0 to 13	unitless
For Each of 15 Grid Points	13	—	—	—
IGP Vertical Delay Estimate	9	0.125	0 to 63.875	meters
Grid Ionospheric Vertical Error Indicator (GIVEI)	4	1	0 to 15	unitless
IODI	2	1	0 to 3	unitless
Spare	7	—	—	—

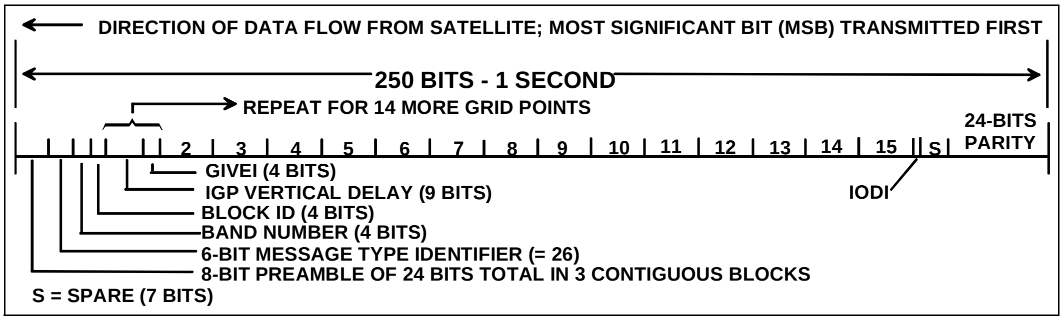


FIGURE A-17 TYPE 26 IONOSPHERIC DELAY CORRECTIONS MESSAGE FORMAT

The 9-bit IGP vertical delays have a 0.125 meter resolution, for a 0-63.750 meter valid range. A vertical delay of 63.875 meters (111111111) will indicate *don't use*. That is, there are no IGP vertical delays greater than 63.750 meters. If that range is exceeded, a *don't use* indication will be used.

TABLE A-17 EVALUATION OF GIVEI$_I$

GIVEI$_i$	**GIVE$_i$ Meters**	**$\sigma^2_{i,GIVE}$ Meters2**
0	0.3	0.0084
1	0.6	0.0333
2	0.9	0.0749
3	1.20	0.1331
4	1.5	0.2079
5	1.8	0.2994
6	2.1	0.4075
7	2.4	0.5322
8	2.7	0.6735
9	3.0	0.8315
10	3.6	1.1974
11	4.5	1.8709
12	6.0	3.3260
13	15.0	20.7870
14	45.0	187.0826
15	Not Monitored	Not Monitored

A.4.4.10.1 Pierce Point Location Determination

Considering the satellite and user locations, the user must first determine the location of the ionospheric pierce point of the signal path from satellite. The location of an ionospheric pierce point (IPP) is defined to be the intersection of the line segment from the receiver to the satellite and an ellipsoid with constant height of 350 km above the WGS-84 ellipsoid. The following equations provide a method for determining the latitude and longitude of that pierce point. First, the latitude is computed as

$$\phi_{pp} = \sin^{-1}\left(\sin\phi_u \cos\psi_{pp} + \cos\phi_u \sin\psi_{pp} \cos A\right)_{\text{radians}} \quad \text{[A-20]}$$

where, as illustrated in Figure A-18, Ψ_{pp} is the earth's central angle between the user position and the earth projection of the pierce point computed as:

$$\psi_{pp} = \frac{\pi}{2} - E - \sin^{-1}\left(\frac{R_e}{R_e + h_I}\cos E\right)_{\text{radians}} \quad \text{[A-21]}$$

A is the azimuth angle of the satellite from the user's location (ϕ_u, λ_u) measured clockwise from north. E is the elevation angle of the satellite from the user's location (ϕ_u, λ_u) measured with respect to the local-tangent-plane. R_e is the approximate radius of the earth's ellipsoid (taken to be 6378.1363 km). h_I is the height of the maximum electron density (taken to be equal to 350 km). The longitude of the pierce point is:

If $\phi_u > 70°$, and $\tan \psi_{pp} \cos A > \tan(\pi/2 - \phi_u)$

or if $\phi_u > -70°$, and $-\tan \psi_{pp} \cos A > \tan(\pi/2 - \phi_u)$

$$\lambda_{pp} = \lambda_u + \pi - \sin^{-1}\left(\frac{\sin\psi_{pp}\sin A}{\cos\phi_{pp}}\right) \text{ radians} \qquad \text{[A-22]}$$

Otherwise,

$$\lambda_{pp} = \lambda_u + \sin^{-1}\left(\frac{\sin\psi_{pp}\sin A}{\cos\phi_{pp}}\right) \text{ radians} \qquad \text{[A-22a]}$$

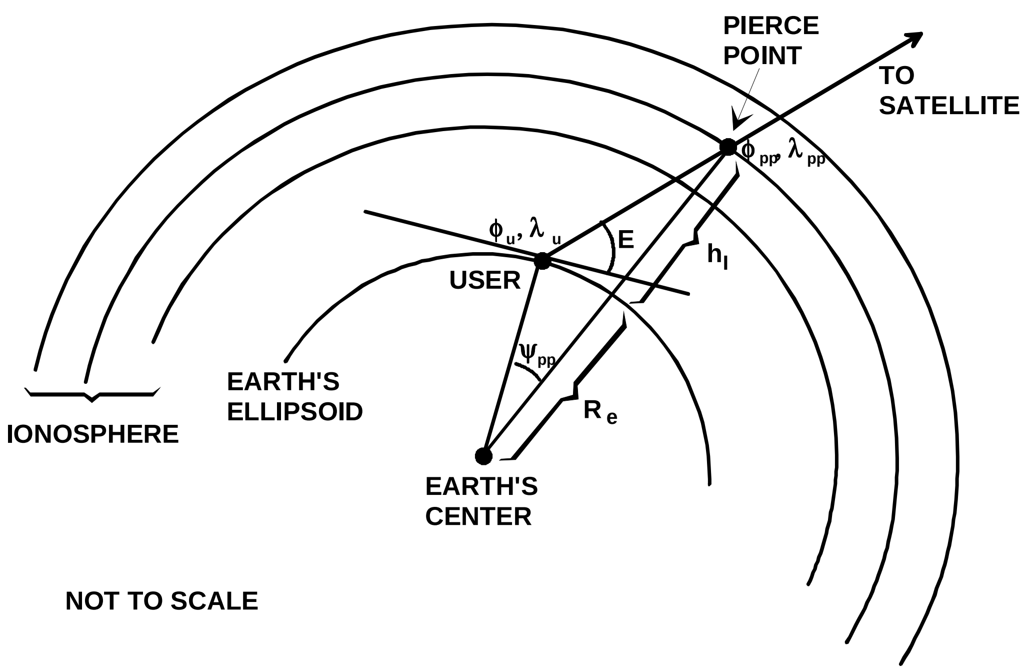


FIGURE A-18 IONOSPHERIC PIERCE POINT GEOMETRY

A.4.4.10.2 Selection of Ionospheric Grid Points

After determining the location of the user ionospheric pierce point, the user must select the IGPs to be used to interpolate the ionospheric correction and model variance. This selection is done based only on the information provided in the mask, and must be done without regard to whether or not the selected IGPs are monitored, not monitored, or don't use. The selection process will take place as described below. Flowcharts for the IGP process are in Appendix P.

1. For an IPP between N60° and S60°:
   a. if four IGPs that define a 5-degree-by-5-degree cell around the IPP are set to one in the IGP mask, they are selected; else,
   b. if any three IGPs that define a 5-degree-by-5-degree triangle that circumscribes the IPP are set to one in the IGP mask, they are selected; else,

c. if any four IGPs that define a 10-degree-by-10-degree cell around the IPP are set to one in the IGP mask, they are selected; else,

d. if any three IGPs that define a 10-degree-by-10-degree triangle that circumscribes the IPP are set to one in the IGP mask, they are selected; else,

e. an ionospheric correction is not available.

2. For an IPP between N60° and N75° or between S60° and S75°:

a. if four IGPs that define a 5-degree latitude-by-10-degree longitude cell around the IPP are set to one in the IGP mask, they are selected; else,

b. if any three IGPs that define a 5-degree latitude -by-10-degree longitude triangle that circumscribes the IPP are set to one in the IGP mask, they are selected; else,

c. if any four IGPs that define a 10-degree-by-10-degree cell around the IPP are set to one in the IGP mask, they are selected; else,

d. if any three IGPs that define a 10-degree-by-10-degree triangle that circumscribes the IPP are set to one in the IGP mask, they are selected; else,

e. an ionospheric correction is not available.

3. For an IPP between N75° and N85° or between S75° and S85°:

a. if the two nearest IGPs at 75° and the two nearest IGPs at 85° (separated by 30° longitude if Band 9 or 10 is used, separated by 90°◦ otherwise) are set to one in the IGP mask, a 10-degree-by-10-degree cell is created by linearly interpolating between the IGPs at 85° to obtain virtual IGPs at longitudes equal to the longitudes of the IGPs at 75°; else,

Note: *The σ^2_{GIVE}s are linearly interpolated along the 85 degree line to form virtual σ^2_{GIVE}s to go with the virtual IGPs.*

b. an ionospheric correction is not available.

4. For an IPP north of N85°:

a. if the four IGPs at N85° latitude and longitudes of W180°, W90°, 0° and E90° are set to one in the IGP mask, they are selected; else,

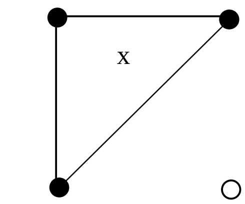
b. an ionospheric correction is not available.

5. For an IPP south of S85°:

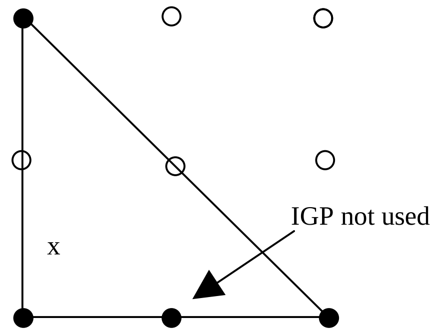
a. if the four IGPs at S85° latitude and longitudes of W140°, W50°, E40° and E130° are set to one in the IGP mask, they are selected; else,

b. an ionospheric correction is not available.

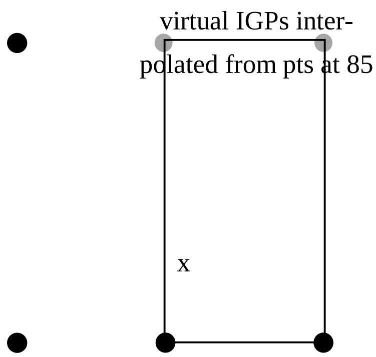
This selection is based only on the information provided in the mask, without regard to whether the selected IGPs are monitored, “Not Monitored”, or “Do Not Use”. If any of the selected IGPs is identified as “Do Not Use”, an ionospheric correction is not available. If four IGPs are selected, and one of the four is identified as “Not Monitored”, then three-point interpolation is used if the IPP is within the triangular region covered by the three corrections that are provided.



a) Example of 5 x 5 degree triangle



b) Example of 10 x 10 degree triangle



c) Example of interpolation north of 75 N, south of 85 N

FIGURE A-19 IONOSPHERIC GRID POINT INTERPOLATION

A.4.4.10.3 Ionospheric Pierce Point Vertical Delay and Model Variance Interpolation

Although the data broadcast to the user is in the form of vertical IGP delays, these points do not generally correspond with his computed IPP locations. Thus, it is necessary for the user to interpolate from the broadcast IGP delays to that at his computed IPP locations. Given three or four nodes of a cell of the IGP grid described above that surround the user's IPP to a satellite, the user interpolates from those nodes to his pierce point (examples are presented in Figure A-19) using the following algorithm.

The IGPs selected as described in A.4.4.10.2 must be used in this interpolation, with one exception. If four IGPs were selected, and one of the four is identified as “not monitored”, then the three-point interpolation should be used if the user’s pierce point is within the triangular region covered by the three corrections that are provided. If one of the four is identified as “don’t use”, the entire square must not be used.

For four-point interpolation, the mathematical formulation for interpolated vertical IPP delay $\tau_{vpp}(\phi_{pp}, \lambda_{pp})$ as a function of IPP latitude ϕ_{pp} and longitude λ_{pp} is

$$\tau_{vpp}\left(\phi_{pp},\lambda_{pp}\right)=\sum_{i=1}^{4} W_i\left(x_{pp},y_{pp}\right)\tau_{vi} \qquad \text{[A-23]}$$

where the general equation for the weighting function is

$$f\left(x,y\right)=xy \qquad \text{[A-24]}$$

and τ_{vi} are the broadcast grid point vertical delay values at four corners of the IGP grid, as shown in Figure A-20. In particular, τ_{vpp} is the output value at desired pierce point *pp*, whose geographical coordinates are ϕ_{pp}, λ_{pp},

$$W_1 = x_{pp} y_{pp} \qquad \text{[A-25]}$$

$$W_2 = (1 - x_{pp}) y_{pp} \qquad \text{[A-26]}$$

$$W_3 = (1 - x_{pp})(1 - y_{pp}) \qquad \text{[A-27]}$$

$$W_4 = x_{pp} (1 - y_{pp}) \qquad \text{[A-28]}$$

$$\Delta\lambda_{pp} = \lambda_{pp} - \lambda_1 \qquad \text{[A-29]}$$

$$\Delta\phi_{pp} = \phi_{pp} - \phi_1 \qquad \text{[A-30]}$$

For IPP's between N85° and S85°,

$$x_{pp} = \frac{\Delta\lambda_{pp}}{\lambda_2 - \lambda_1} \qquad \text{[A-31]}$$

$$y_{pp} = \frac{\Delta\phi_{pp}}{\phi_2 - \phi_1} \qquad \text{[A-32]}$$

where (see Figure A-20)

λ_1 = longitude of IGPs west of IPP

λ_2 = longitude of IGPs east of IPP

ϕ_1 = latitude of IGPs south of IPP

ϕ_2 = latitude of IGPs north of IPP

For IPPs north of N85° or south of S85°,

$$y_{pp} = \frac{|\phi_{pp}| - 85°}{10°} \qquad \text{[A-33]}$$

$$x_{pp} = \frac{\lambda_{pp} - \lambda_3}{90°} \cdot (1 - 2y_{pp}) + y_{pp} \qquad \text{[A-34]}$$

where:

λ_1 = longitude of the second IGP to the east of the IPP.

λ_2 = longitude of the second IGP to the west of the IPP.

λ_3 = longitude of the closest IGP to the west of the IPP.

λ_4 = longitude of the closest IGP to the east of the IPP.

Note that if λ_1 and λ_2 cross 180° of longitude, the calculation of x_{pp} must account for the discontinuity in longitude.

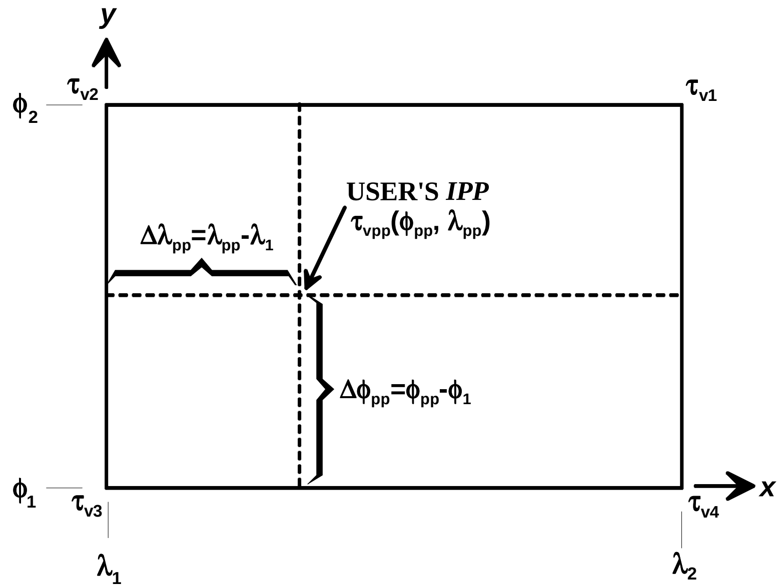


FIGURE A-20 FOUR-POINT INTERPOLATION ALGORITHM DEFINITIONS

For three-point interpolation between 75°S and 75°N, a similar algorithm is used:

$$\tau_{vpp}\left(\phi_{pp},\lambda_{pp}\right)=\sum_{i=1}^{3}W_i\left(x_{pp},y_{pp}\right)\tau_{vi} \qquad [A\text{-}35]$$

$$W_1 = y_{pp} \qquad [A\text{-}36]$$

$$W_2 = 1 - x_{pp} - y_{pp} \qquad [A\text{-}37]$$

$$W_3 = x_{pp} \qquad [A\text{-}38]$$

The pierce points are numbered as shown in Figure A-21 so that grid point #2 is always the vertex opposite the hypotenuse and the distance-ratios (x, y) are always determined relative to the distance to grid point #2. It should be noted that there are three additional orientations of the triangle shown in Figure A-21.

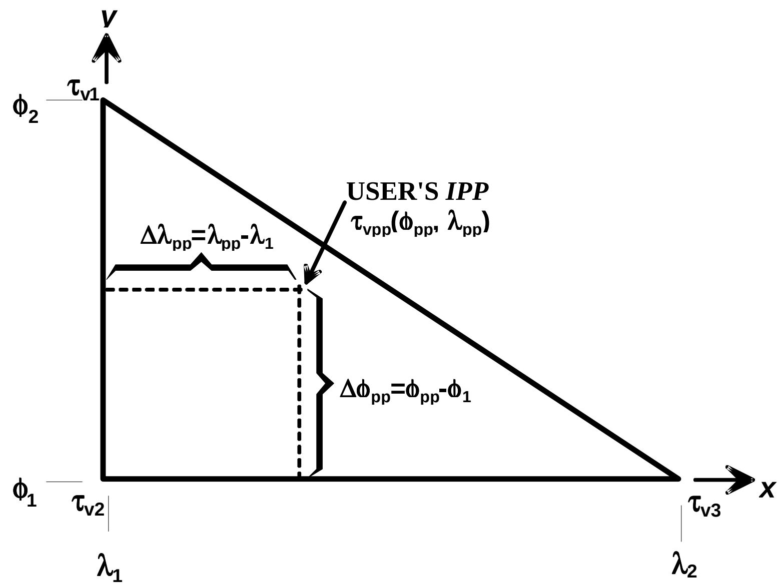


FIGURE A-21 THREE-POINT INTERPOLATION ALGORITHM DEFINITIONS

The σ^2_{UIVE} will be interpolated by the users from the $\sigma^2_{ionogrid}$'s defined at the IGPs to the IPP as follows:

$$\sigma^2_{UIVE} = \sum_{n=1}^{4} W_n\left(x_{pp}, y_{pp}\right) \cdot \sigma^2_{n,ionogrid} \qquad \text{[A-39]}$$

or

$$\sigma^2_{UIVE} = \sum_{n=1}^{3} W_n\left(x_{pp}, y_{pp}\right) \cdot \sigma^2_{n,ionogrid} \qquad \text{[A-40]}$$

where $\sigma^2_{ionogrid}$ is the model variance of ionospheric vertical delays at an IGP. If the degradation model (using Message Types 7 and 10) is used, $\sigma^2_{ionogrid}$ is calculated as described in section A.4.5.2. If the degradation model is not used, but WAAS provided ionospheric model is used, $\sigma^2_{ionogrid}$ equals σ^2_{GIVE}.

A.4.4.10.4 Computing Slant Ionospheric Delay and Ionospheric Model Variance

Once the user establishes the vertical delay at the pierce point, the user can then multiply that vertical delay by the obliquity factor F_{pp} to obtain the ionospheric correction *(ICi)* to be added to the pseudorange measurement:

$$IC_i = -\tau_{spp}(\lambda_{pp}, \phi_{pp}) = -F_{pp} \cdot \tau_{vpp}(\lambda_{pp}, \phi_{pp}) \qquad \text{[A-41]}$$

where τ_{vpp} is the interpolated vertical delay at the user-to-satellite IPP derived as described above, and

$$F_{pp} = \left[1 - \left(\frac{R_e \cos E}{R_e + h_I}\right)^2\right]^{-\frac{1}{2}} \qquad \text{[A-42]}$$

The σ^2_{UIRE} is computed as:

$$\sigma^2_{UIRE} = F^2_{pp} \cdot \sigma^2_{UIVE} \qquad [A-43]$$

A.4.4.11 GEO Navigation Message Type 9

Figure A-22 and Table A-18 present the Type 9 GEO Navigation Message representing the position, velocity and acceleration of the geostationary satellite, in ECEF Coordinates, and its apparent clock time and frequency offsets. Also included is the time of applicability (t_0) and an accuracy exponent (URA) representing the estimated accuracy of the message. a_{Gf0} and a_{Gf1} will be an estimate of the time offset and drift with respect to WAAS Network Time. Their combined effect will be added to the estimate of the satellite's transmit time.

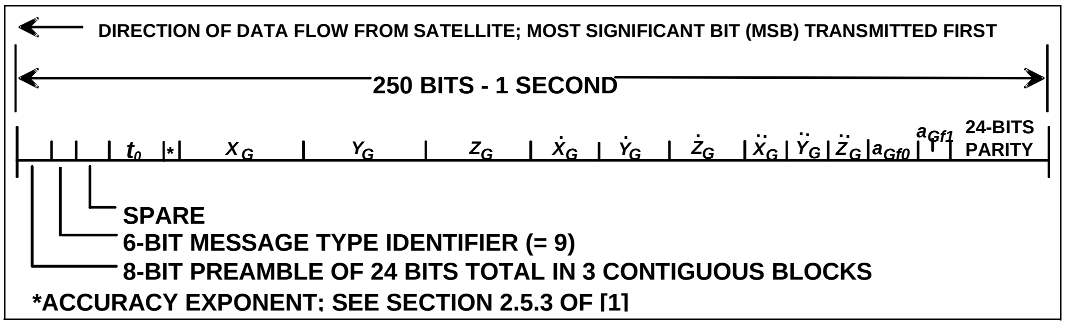


FIGURE A-22 TYPE 9 GEO NAVIGATION MESSAGE FORMAT

The position and time of the GEO will be propagated to time-of-day t_k, corrected for end-of-day cross-over, as

$$\begin{bmatrix} X_{Gk} \\ Y_{Gk} \\ Z_{Gk} \end{bmatrix} = \begin{bmatrix} X_G \\ Y_G \\ Z_G \end{bmatrix} + \begin{bmatrix} \dot{X}_G \\ \dot{Y}_G \\ \dot{Z}_G \end{bmatrix} (t_k - t_0) + \frac{1}{2} \begin{bmatrix} \ddot{X}_G \\ \ddot{Y}_G \\ \ddot{Z}_G \end{bmatrix} (t_k - t_0)^2 \qquad [A-44]$$

and

$$t_G(t_k) = t_G + \Delta t_G(t_k) = t_G + a_{Gf0} + a_{Gf1}(t_k - t_0) \qquad [A-45]$$

where t_0 is the time of applicability of the message, corrected for end-of-day cross-over. The ranges of the parameters in this message allow for GEO inclination angles of up to ±8°.

In contrast to the time correction for GPS satellites, there is no user correction for general relativity to GEO time. Any relativity effects will be removed by the earth station controlling the GEO signal.

Note 1: *The Sagnac corrections must accounted for. One method is: add t_s to GEO pseudoranges where $\delta t_S = \dot{\Omega}_e \frac{(R_G \times R_u)_z}{c}$ and $\dot{\Omega}_e$ is the spin rate of the earth, R_G is the position of the GEO, R_u is the user position vector, $\times$ is vector cross-product, z represents the z-component, and c is the speed of light. Another method is to modify the GEO x-y-z position accordingly.*

TABLE A-18 TYPE 9 GEO NAVIGATION MESSAGE PARAMETERS

Parameter	**No. of Bits** (Note 2)	**Scale Factor (LSB)**	**Effective Range** (Note 2)	**Units**
Spare	8			
t_0	13	16	0 to 86,384	seconds
URA (Note 3)	4	(Note 3)	(Note 3)	(Note 3)
X_G (ECEF)	30	0.08	±42,949,673	meters
Y_G (ECEF)	30	0.08	±42,949,673	meters
Z_G (ECEF)	25	0.4	±6,710,886.4	meters
X_G Rate-of-Change	17	0.000625	±40.96	meters/sec
Y_G Rate-of-Change	17	0.000625	±40.96	meters/sec
Z_G Rate-of-Change	18	0.004	±524.288	meters/sec
X_G Acceleration	10	0.0000125	±0.0064	meters/sec^2
Y_G Acceleration	10	0.0000125	±0.0064	meters/sec^2
Z_G Acceleration	10	0.0000625	±0.032	meters/sec^2
a_{Gf0}	12	2^{-31}	$\pm 0.9537 \times 10^{-6}$	seconds
a_{Gf1}	8	2^{-40}	$\pm 1.1642 \times 10^{-10}$	seconds/sec

Note 2: *All signed values are coded as two's complement, with the sign bit occupying the MSB. The effective range is smaller than indicated, as the maximum positive value is actually constrained to be one value less (the indicated value minus the resolution).*

Note 3: *See Section 20.3.3.3.1.3 of [1].*

A.4.4.12 GEO Almanacs Message Type 17

Almanacs for all GEOs will be broadcast periodically to alert the user of their existence, location, the general service provided and health and status. Almanacs for three satellites will be broadcast in the GEOs Almanacs Message Type 17 illustrated in Type 17 Geo Almanacs Message Format and defined in Table A-19. These messages will be repeated to include all GEOs. Unused almanacs will have a PRN number of 0 and should be ignored.

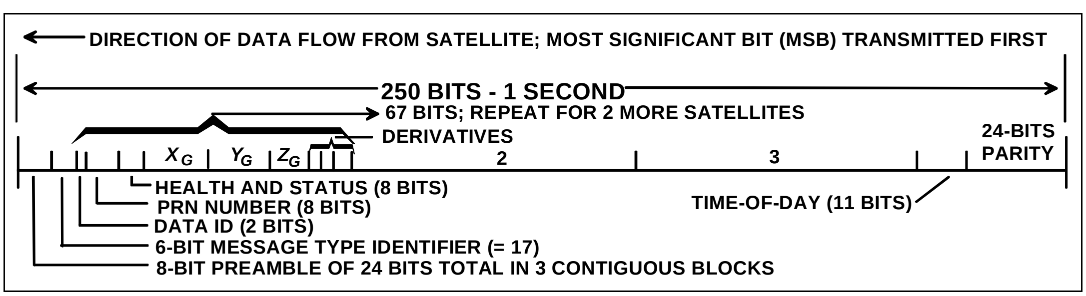


FIGURE A-23 TYPE 17 GEO ALMANACS MESSAGE FORMAT

TABLE A-19 TYPE 17 GEO ALMANACS MESSAGE PARAMETERS

Parameter	No. of Bits (Note 1)	Scale Factor (LSB)	Effective Range (Note 1)	Units
For each of 3 satellites	67	—	—	—
Data ID	2	1	0 to 3	unitless
PRN Number	8	1	0 to 210	—
Health and Status	8	—	—	unitless
X_G (ECEF)	15	2,600	±42,595,800	meters
Y_G (ECEF)	15	2,600	±42,595,800	meters
Z_G (ECEF)	9	26,000	±6,630,000	meters
X_G Rate-of-Change	3	10	± 40	meters/sec
Y_G Rate-of-Change	3	10	± 40	meters/sec
Z_G Rate-of-Change	4	60	± 480	meters/sec
t_o (Time-of-Day)	11	64	0 to 86,336	seconds

Note: *All signed values are coded as two's complement, with the sign bit occupying the MSB. The effective range is smaller than indicated, as the maximum positive value is actually constrained to be one value less (the indicated value minus the resolution).*

The position of a GEO using the parameters of Table A-19 will be evaluated using Equations A-44 and A-45 with the acceleration components set to 0 and t_0 set to the Time-of-Day given in the message.

The Data ID for the current Signal Specification format is 00. Other states of the data ID are reserved for the possibility of future Signal Specification formats.

Health and Status bits are defined as follows:

Bit 0 (LSB)	Ranging On (0), Off (1)
Bit 1	Corrections On (0), Off (1)
Bit 2	Broadcast Integrity On (0), Off (1)
Bits 3	Reserved
Bits 4-7	Service Provider ID

Note that if all bits are 0, the Health and Status are OK for all functions. The service provider ID is given as:

ID	**Service Provider**
0	WAAS
1	EGNOS
2	MSAS
3-15	Reserved

A.4.4.13 WAAS Service Message Type 27

Type 27 messages may be transmitted to increase the σ_{UDRE} values in selected areas. The format of Message Type 27 is given in Figure A-24 and Table A-20. Type 27 message parameters apply only to the service provider transmitting the message.

The Number of Service Messages parameter in each Type 27 message indicates the total number of unique Type 27 messages for the current Issue of Data, Service (IODS). Each unique message for that IODS includes a sequential Service Message Number. The IODS is incremented in all messages, each time that any parameter in any Type 27 message is changed.

Each Type 27 message specifies δUDRE factors to be applied to integrity monitoring algorithms of users when inside or outside of the set of geographic regions defined in that message. δUDRE indicators are associated with δUDRE values of Table A-21 that multiply the model standard deviation defined using the UDREI parameters in the Type 2 - 6 and Type 24 Messages. One δUDRE indicator applies to users within any of the regions specified in that message. A second δUDRE indicator applies to users outside all regions in all Type 27 messages. When more than one Type 27 message is broadcast with a common IODS, the δUDRE Indicator – Outside parameter has the same value in all messages.

A.4.4.13.1 Definition of Regions

Each message contains up to five geographic regions, as indicated in the Number of Regions parameter. If less than five regions are specified, they occupy the lowest available bit positions.

Each geographic region has either triangular or rectangular shape, in a latitude/longitude coordinate frame, as indicated by its Region Shape parameter. Three or four coordinates specify the corners of the region, depending on its shape. The latitudes and longitudes of Coordinates 1 and 2 are broadcast. Coordinate 3 takes the Coordinate 1 latitude and the Coordinate 2 longitude. For a square region, Coordinate 4 takes the Coordinate 2 latitude and the Coordinate 1 longitude.

Each region boundary is a closed polygon connecting its set of assigned coordinates. The boundary segments have constant slopes in the latitude/longitude co-ordinate frame, and the change in latitude or longitude along the boundary segment between two co-ordinates will not exceed ±179°. (For example, a segment between co-ordinates at N70°/E170° and N50°/W12° would pass through the location N60°/W101°.) Points on a region boundary are considered to be inside the region.

Regions defined within a single message or in separate messages may overlap each other. Associated with each message is a Priority Code parameter, used to establish precedence of UDRE factors where regions in two or more messages overlap. The Priority Code indicates the relative rank for the regions defined in that message. Where two regions overlap, the UDRE factor for the region with the higher Priority Code value is applicable. Where two regions of equal Priority Code overlap, the lower UDRE factor (i.e., - better performance) is applicable.

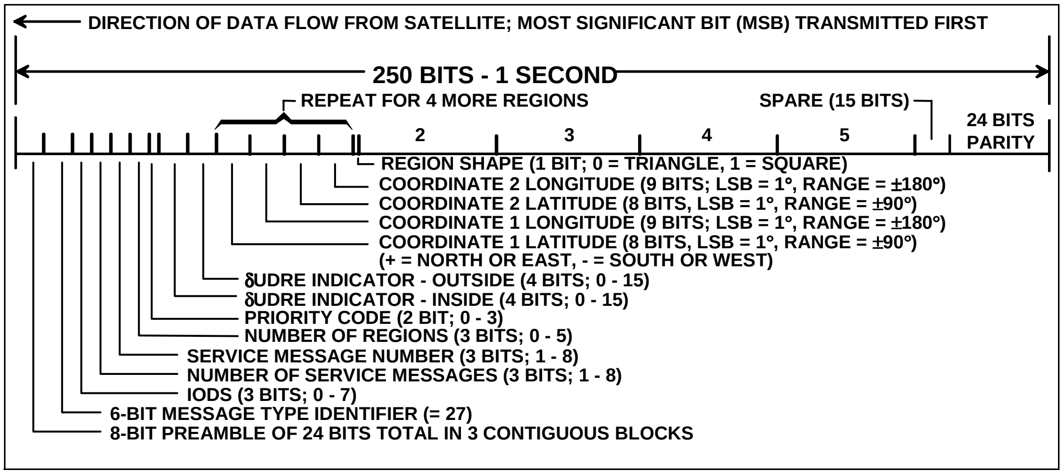


FIGURE A-24 SERVICE MESSAGE TYPE 27

TABLE A-20 TYPE 27 SERVICE MESSAGE PARAMETERS

Parameter	No. Of Bits (Note 1)	Scale Factor (LSB)	Effective Range	Units
Issue of Data , Service (IODS)	3	1	0 to 7	—
Number of Service Messages (Note 2)	3	1	1 to 8	—
Service Message Number (Note 2)	3	1	1 to 8	—
Number of Regions	3	1	0 to 5	—
Priority Code	2	1	0 to 3	—
δUDRE Indicator – Inside (Note 3)	4	1	0 to 15	—
δUDRE Indicator – Outside (Note 3)	4	1	0 to 15	—
For each of up to 5 regions:	—	—	—	—
Coordinate 1 Latitude (Note 4)	8	1	±90	degrees
Coordinate 1 Longitude (Note 4)	9	1	±180	degrees
Coordinate 2 Latitude (Note 4)	8	1	±90	degrees
Coordinate 2 Longitude (Note 4)	9	1	±180	degrees
Region Shape (Note 5)	1	—	—	—
Spare	15	—	—	—

Notes:

1. *All signed values are coded as two's complement, with the sign bit occupying the MSB.*
2. *Value is coded with an offset of one, such that a coded value of 7 (binary '111') indicates that Number of Messages or Message Number is 8.*
3. *δUDRE Indicators are interpreted using Table A-21.*
4. *Positive values denote North latitude or East longitude.*
5. *Coding of Region Shape: 0 denotes a triangular region, 1 denotes a square region.*

TABLE A-21 δUDRE INDICATOR EVALUATION

δUDRE Indicator	δUDRE
0	1
1	1.1
2	1.25
3	1.5
4	2
5	3
6	4
7	5
8	6
9	8
10	10
11	20
12	30
13	40
14	50
15	100

A.4.4.14 Null Message Type 63 and Internal Test Message 62

The Null Message Type 63 is used as a filler message if no other message is available for broadcast for the one-second time slot. The Internal Test Message Type 62 is used for internal testing purposes. The user will continue to use the GEO broadcast and ranging capabilities.

A.4.4.15 WAAS Network Time/UTC/GLONASS Time Offset Parameters Message Type 12

Message Type 12 will consist of the 8-bit preamble, a 6-bit message type identifier (= 12) followed by 104 information bits for the UTC parameters, then followed by 3 bits to indicate the UTC time standard from which the offset is determined. The next 20 bits are the Time of Week (TOW) in seconds of the beginning of the message, followed by a 10 bit GPS Week number (WN) as defined in Section 20.3.3.3.1.1 of [1]. The final 75 bits are spare bits (possibly to be partially replaced with the difference between WAAS Network Time and GLONASS time). Table A-22 defines the UTC parameters along with the other 33 bits defined above. The definition of these parameters and the applicable algorithms are in Sections 20.3.3.5.1.8 and 20.3.3.5.2.4 of [1], with the exception that the UTC parameters will correlate UTC time with the WAAS Network Time rather than with GPS time. The UTC standard used is indicated by the three bits interpreted as indicated in Table A-23. A GLONASS Indicator of “0” indicates that GLONASS time parameters are not provided.

TABLE A-22 WAAS NETWORK TIME/UTC PARAMETERS

Parameter	No. of Bits (Note 1)	Scale Factor (LSB)	Effective Range (Note 1)	Units
A_{1WNT}	24	2^{-50}	$\pm 7.45\times10^{-9}$	seconds/second
A_{0WNT}	32	2^{-30}	±1	seconds
t_{0t}	8	2^{12}	0 to 602112	seconds
WN_t	8	1	0 to 255	weeks
Δt_{LS}	8	1	±128	seconds
WN_{LSF}	8	1	0 to 255	weeks
DN	8 (Note 2)	1	1 to 7	days
Δt_{LSF}	8	1	±128	seconds
UTC Standard Identifier	3	—	—	unitless
GPS Time-of-Week — *TOW*	20	1	0 to 604,799	seconds
GPS Week Number	10	1	0 to 1023	weeks
GLONASS Indicator	1	1	0 to 1	unitless
GLONASS time offset - reserved	74	TBD	TBD	TBD

Notes: **1.** *All signed values are coded as two's complement, with the sign bit occupying the MSB. The effective range is smaller than indicated, as the maximum positive value is actually constrained to be one value less (the indicated value minus the resolution).*

2. *Right justified.*

TABLE A-23 UTC STANDARD IDENTIFIER

UTC Identifier	UTC Standard
0	UTC as operated by the Communications Research Laboratory (CRL), Tokyo, Japan
1	UTC as operated by the National Institute of Standards and Technology (NIST)
2	UTC as operated by the U. S. Naval Observatory (USNO)
3	UTC as operated by the International Bureau of Weights and Measures (BIPM)
4	UTC as operated by European Laboratory TBD
5 to 6	Reserved for future definition
7	UTC not provided

A.4.4.16 Clock-Ephemeris Covariance Matrix Message Type 28

Message Type 28 may be broadcast to provide the relative covariance matrix for clock and ephemeris errors. This is an expansion of the information contained in the σ_{UDRE} in that it specifies the correction confidence as a function of user location. Message Type 28 provides increased availability inside the service volume and increased integrity outside.

The covariance matrix is a function of satellite location, reference station observational geometry, and reference station measurement confidence. Consequently it is a slowly changing function of time. Each covariance matrix only needs to be updated on the same order as the long-term corrections. Each message is capable of containing relative covariance matrices for two satellites. This maintains the real-time six-second updates of integrity and scales the matrix to keep it within a reasonable dynamic range.

Cholesky factorization is used to reliably compress the information in the covariance matrix, **C**. The matrix Cholesky factor is an upper triangular matrix, **R**. This information can be used to reconstruct the relative covariance matrix as $\mathbf{R}^T\mathbf{R} = \mathbf{C}$, where the superscript T denotes the matrix transpose. This factorization guarantees that the received covariance matrix remains positive-definite despite quantization errors. Because **R** is upper triangular, it contains only 10 non-zero elements for each satellite. These 10 elements are divided by a scale factor (SF) to determine the matrix, **E**, and broadcast in half of Message Type 28. The elements of **R** can be written as shown in equation A-46.

$$\mathbf{R} = \mathbf{E} \cdot \mathrm{SF}, \qquad E = \begin{bmatrix} E_{1,1} & E_{1,2} & E_{1,3} & E_{1,4} \\ 0 & E_{2,2} & E_{2,3} & E_{2,4} \\ 0 & 0 & E_{3,3} & E_{3,4} \\ 0 & 0 & 0 & E_{4,4} \end{bmatrix} \qquad \text{[A-46]}$$

and $\mathrm{SF} = 2^{(\text{scale exponent} - 5)}$.

The relative clock-ephemeris correction covariance is reconstructed as shown in equation A-47.

$$C = R^T \cdot R \qquad \text{[A-47]}$$

The covariance matrix is used to modify the broadcast σ_{UDRE} values as a function of user position. The location-specific modifier is specified by equation A-48.

$$\delta UDRE = \sqrt{I^T \cdot C \cdot I} + \varepsilon_C \qquad \text{[A-48]}$$

where I is the 4-D line of sight vector from the user to the satellite in the WGS-84 coordinate frame, where the first three components are the unit vector from the user to the satellite and the fourth component is a one. The additional term ε_C is to compensate for the errors introduced by quantization. If degradation data from a Type 10 message is available, the ε_c value is derived from $C_{covariance}$ (broadcast in a Type 10 message) as shown in equation A-49.

$$\varepsilon_C = C_{covariance} \cdot SF \qquad \text{[A-49]}$$

If $C_{covariance}$ type 10 data is not available, ε_C is set to zero, but there is an 8 meter degradation applied as defined in Appendix J, J.2.2.

The δUDRE is used in equation A-50. Thus a service provider could use Type 27 or Type 28, but not both.

Table A-24 and Figure A-25 present the contents of the Type 28 message representing the Cholesky factor of the clock-ephemeris covariance matrix for two PRN codes. The covariance matrices are accompanied by the IODP associated with the PRN mask. Refer to Section A.4.4.2 for the application of IODP.

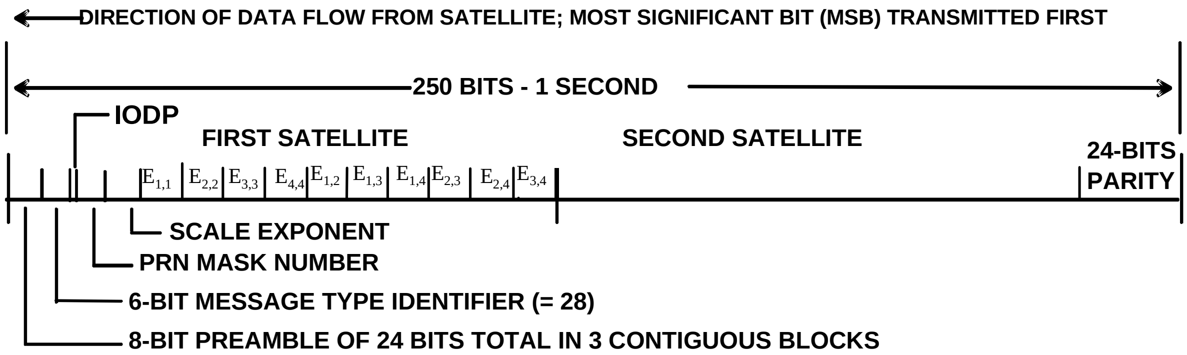


FIGURE A-25 TYPE 28 CLOCK-EPHEMERIS COVARIANCE MATRIX MESSAGE FORMAT

The PRN Mask No. is the sequence number of the bits set in the 210 bit mask (that is, between 1 and 51). The data in this Type 28 message does not have to appear in sequence. The IODP of the message must agree with the IODP associated with the PRN mask in Message Type 1.

Figure A-25 shows the contents of Type 28 message. There is a single IODP, which will apply to both matrices broadcast in the message. The remainder of the 212 data bits are divided in two matrices for two satellites.

TABLE A-24 TYPE 28 CLOCK-EPHEMERIS COVARIANCE MATRIX MESSAGE PARAMETERS

Parameter	**No. of Bits** (Note 1)	**Scale Factor (LSB)**	**Effective Range** (Note 1)	**Units**
IODP	2	1	0 to 3	unitless
PRN Mask No. (Note 2)	6	1	0 to 51	---
Scale exponent	3	1	0 to 7	unitless
$E_{1,1}$	9	1	0 to 511	unitless
$E_{2,2}$	9	1	0 to 511	unitless
$E_{3,3}$	9	1	0 to 511	unitless
$E_{4,4}$	9	1	0 to 511	unitless
$E_{1,2}$	10	1	±512	unitless
$E_{1,3}$	10	1	±512	unitless
$E_{1,4}$	10	1	±512	unitless
$E_{2,3}$	10	1	±512	unitless
$E_{2,4}$	10	1	±512	unitless
$E_{3,4}$	10	1	±512	unitless
PRN Mask No. (Note 2)	6	1	0 to 51	---
Scale exponent	3	1	0 to 7	unitless
$E_{1,1}$	9	1	0 to 511	unitless
$E_{2,2}$	9	1	0 to 511	unitless
$E_{3,3}$	9	1	0 to 511	unitless
$E_{4,4}$	9	1	0 to 511	unitless
$E_{1,2}$	10	1	±512	unitless
$E_{1,3}$	10	1	±512	unitless
$E_{1,4}$	10	1	±512	unitless
$E_{2,3}$	10	1	±512	unitless
$E_{2,4}$	10	1	±512	unitless
$E_{3,4}$	10	1	±512	unitless

Notes:

1. *All signed values are coded as two's complement, with the sign bit occupying the MSB. The effective range is smaller than indicated, as the maximum positive value is actually constrained to be one value less (the indicated value minus the resolution).*
2. *Mask sequence. The count of 1's in mask from the first position in mask to the position representing the subject satellite. If set to 0, no satellite is represented and the remainder of the message should be ignored.*

A.4.5 Modeling the Degradation of Data

The fast corrections, long-term corrections, and ionospheric corrections are all designed to provide the most recent information to the user. However, there is always the possibility that the user will fail to receive one of these messages, either due to momentary shadowing or a random bit error. In order to guarantee integrity even when some messages are not received, the user performing a precision approach operation must apply models of the degradation of this information. For other navigation modes, the use of this model is optional and a global degradation factor can be used instead as described in Appendix J, J.2.2. The system, in turn, will monitor the old data to ensure that it remains valid until it times out. This section describes the degradation of data.

A.4.5.1 Fast and Long-Term Correction Degradation

The residual error associated with the fast and long-term corrections is characterized by the variance ($\sigma_{flt}{}^2$) of a model distribution. This term is computed as:

$$\sigma_{flt}^2 = \begin{cases} \left(\sigma_{UDRE} + \varepsilon_{fc} + \varepsilon_{rrc} + \varepsilon_{ltc} + \varepsilon_{er}\right)^2, & \text{if } RSS_{UDRE} = 0 \text{ (} \textit{Message Type } 10\text{)} \\ \sigma_{UDRE}^2 + \varepsilon_{fc}^2 + \varepsilon_{rrc}^2 + \varepsilon_{ltc}^2 + \varepsilon_{er}^2, & \text{if } RSS_{UDRE} = 1 \text{ (} \textit{Message Type } 10\text{)} \end{cases} \quad \text{[A-50]}$$

where:

RSS_{UDRE}	=	root-sum-square flag in Message Type 10
σ_{UDRE}	=	model parameter from Message Type 2-6, 24 (ref. A.4.4.4)
δUDRE	=	δUDRE factor for user location, if defined in Message Type 27 or 28 (ref. A.4.4.13 for type 27 and A.4.4.16 for type 28), otherwise δUDRE equals 1
ε_{fc}	=	degradation parameter for fast correction data (ref. A.4.5.1.1)
ε_{rrc}	=	degradation parameter for range rate correction data (ref. A.4.5.1.2)
ε_{ltc}	=	degradation parameter for long term correction or GEO navigation message data (ref. A.4.5.1.3)
ε_{er}	=	degradation parameter for en route through NPA applications (ref. A.4.5.1.4)

Note: *Airborne equipment which does not miss any messages will have a 0 for all degradation terms except for $\varepsilon_{fc,}$ (which will typically be less than 0.35 meters), and ε_{rrc} which will be non-zero following an alarm condition.*

A.4.5.1.1 Fast Correction Degradation

The degradation parameter for fast correction data is defined as:

$$\varepsilon_{fc} = a\left(t - t_u + t_{lat}\right)^2 / 2 \quad \text{[A-51]}$$

where:

a	=	the fast correction degradation factor determined from Message Type 7 (ref. A.4.4.5)
t	=	the current time
t_u	=	For UDREIs broadcast in Type 2-5 and 24, this time equals the time of applicability of the fast corrections. For UDREIs broadcast in Type 6 and if the IODF = 3, this time also equals the time of applicability of the fast corrections (t_{fc}). For UDREIs broadcast in Type 6 and IODF ≠ 3, this time is defined to be the time of transmission of the first bit of the Type 6 message at the GEO. Note that the most recent UDREI data cannot be used if

it is broadcast in a Type 6 message, the $IODF_j$ does not equal 3, and the $IODF_j$ does not equal the $IODF_j$ broadcast in the fast correction message for the same satellite.

t_{lat} = the system latency determined from Message Type 7 (ref. A.4.4.5)

A.4.5.1.2 Range-Rate Correction Degradation

If the RRC = 0 then the range-rate correction degradation is also equal to zero (i.e., $\varepsilon_{rrc} = 0$ if $ai_i = 0$, see Section A.4.4.5). Otherwise, the range-rate degradation is divided into two cases. The first case covers the situation where the IODFs of both the current and previous fast corrections are not equal to 3. The second case covers the situation where at least one of the IODFs is equal to 3. The following terms are used to define these degradation functions:

a = the fast corrections degradation factor determined from Message Type 7 (ref. A.4.4.5). This parameter is satellite-specific.

t = the current time

$I_{f,j}$ = the shortest time-out interval for any satellite included in the associated fast corrections message (j=2,..,5).

B_{rrc} = a parameter associated with the relative estimation noise and round-off error derived from Message Type 10.

$IODF_{current}$ = IODF associated with most recent fast correction

$IODF_{previous}$ = IODF associated with previous fast correction

Δt = $(t_{of} - t_{of,previous})$

t_{of} = time of applicability of the most recent fast correction

$t_{of,previous}$ = time of applicability of the previous fast correction

A.4.5.1.2.1 Range-Rate Correction Degradation — IODF ≠ 3

The degradation parameter for range-rate correction data is defined as:

$$\varepsilon_{rrc} = \begin{cases} 0, & if\ \ (IODF_{current} - IODF_{previous})\ MOD\ 3 = 1 \\ \left(\dfrac{aI_{fc}}{4} + \dfrac{B_{rrc}}{\Delta t}\right)(t - t_{of}), & if\ \ (IODF_{current} - IODF_{previous})\ MOD\ 3 \neq 1 \end{cases} \qquad \text{[A-52]}$$

A.4.5.1.2.2 Range-Rate Correction Degradation — Either IODF = 3

The degradation parameter for range-rate correction data is defined as:

$$\varepsilon_{rrc} = \begin{cases} 0, & if\ \left|\Delta t - \dfrac{I_{fc}}{2}\right| = 0 \\ \left(\dfrac{a\left|\Delta t - I_{fc}/2\right|}{2} + \dfrac{B_{rrc}}{\Delta t}\right)(t - t_{of}), & if\ \left|\Delta t - \dfrac{I_{fc}}{2}\right| \neq 0 \end{cases} \qquad \text{[A-53]}$$

This function will not take on any one value since there are possibly many choices of fast corrections as alert conditions do not necessarily occur at regularly spaced intervals.

A.4.5.1.3 Long Term Correction Degradation

The degradation associated with long-term corrections is covered by two cases depending on whether both offset and velocity (Type 24 and 25 with velocity code=1) or only offset (Type 24 and 25 with velocity code=0) is included in the message.

The degradation associated with the GEO navigation message is described in A.4.5.1.3.3. When long-term corrections are applied to a GEO satellite, the long-term correction degradation is applied and the GEO navigation message degradation is not applied. The system will ensure that the resulting degradation protects the user, even during a transition of the velocity code.

A.4.5.1.3.1 Long Term Correction Degradation — Velocity Code =1

For velocity code = 1, the degradation parameter for long-term corrections is:

$$\varepsilon_{ltc} = \begin{cases} 0, & \text{if } t_0 < t < t_0 + I_{ltc\_v1} \\ C_{ltc\_lsb} + C_{ltc\_v1} \max\left(0, t_0 - t, t - t_0 - I_{ltc\_v1}\right), & \text{otherwise} \end{cases} \quad \text{[A-54]}$$

where:

t	=	the current time
t_o	=	the time of applicability for the long term correction (ref. A.4.4.7)
I_{ltc_v1}	=	the update interval for v=1 long term corrections determined from Message Type 10
C_{ltc_lsb}	=	is the maximum round-off error due to the lsb resolution of the orbit and clock information determined from Message Type 10
C_{ltc_v1}	=	is the velocity error bound on the maximum range rate difference of missed messages due to clock and orbit rate differences derived from Message Type 10

Note: *If no long term correction messages are missed, it is always possible to have $t_o < t < t_o+I_{ltc,v1}$. If the airborne equipment misses long term correction messages, the equipment may be forced to either use a long term correction before t_o or use the long term correction after $t_o+I_{ltc,v1}$. Typically, a long term correction message will be broadcast once before t_o and two more times after t_o but before $t_o + I_{ltc,v1}$. If $t_o < t < t_o + I_{ltc,v1}$, then no degradation function is applied.*

A.4.5.1.3.2 Long Term Correction Degradation — Velocity Code = 0

For Velocity Code = 0, the degradation parameter for long-term corrections is:

$$\varepsilon_{ltc} = C_{ltc\_v0}\left\lfloor \frac{t - t_{ltc}}{I_{ltc\_v0}} \right\rfloor \quad \text{[A-55]}$$

where:

t	= the current time
t_{ltc}	= the time of transmission of the first bit of the long term correction message at the GEO

I_{ltc_v0} = the minimum update interval for velocity code v=0 long term messages determined from Message Type 10

C_{ltc_v0} = is the bound on the update delta between successive long term corrections determined from Message Type 10

$\lfloor x \rfloor$ = the floor or greatest integer less than x function.

A.4.5.1.3.3 GEO Navigation Message Degradation

The degradation parameter for GEO navigation message data is:

$$\varepsilon_{ltc} = \begin{cases} 0, & if\ t_0 < t < t_0 + I_{geo} \\ C_{geo\_lsb} + C_{geo\_v} \max\left(0, t_0 - t, t - t_0 - I_{geo}\right), & otherwise \end{cases} \quad \text{[A-56]}$$

where:

t = the current time

t_o = the time of applicability for the GEO navigation message (ref. A.4.4.11)

I_{geo} = the update interval for GEO navigation messages determined from Message Type 10

C_{geo_lsb}= is the maximum round-off error due to the lsb resolution of the orbit and clock information determined from Message Type 10

C_{geo_v}= is the velocity error bound on the maximum range rate difference of missed messages due to clock and orbit rate differences derived from Message Type 10

This degradation function is similar to that of long term corrections (Velocity Code = 1) and the same principles apply as to the periods of applicability. For example, if $t_o < t < t_o + I_{geo}$ then no degradation function is applied.

A.4.5.1.4 Degradation for En Route Through NPA

When using fast or long term corrections which have timed out for precision approach, but have not timed out for other navigation modes, an extra "catch-all" degradation factor is applied. This degradation is:

$$\varepsilon_{er} = \begin{cases} 0, & \begin{array}{l} neither\ \ fast\ \ nor\ \ long\ \ term\ \ corrections \\ have\ \ timed\ \ out\ \ for\ \ precision\ \ approach \end{array} \\ C_{er}, & \begin{array}{l} if\ \ fast\ \ or\ \ long\ \ term\ \ corrections \\ have\ \ timed\ \ out\ \ for\ \ precision\ \ approach \end{array} \end{cases} \quad \text{[A-57]}$$

where:

C_{er} = degradation parameter determined from Message Type 10

A.4.5.2 Degradation of Ionospheric Corrections

The residual error associated with the ionospheric corrections is characterized by the variance ($\sigma_{ionogrid}^2$) of a model distribution. This parameter is applicable at each ionospheric grid point, and must be interpolated to the user pierce point and translated to slant range (A.4.4.10). This term is computed as:

$$\sigma_{ionogrid}^2 = \begin{cases} \left(\sigma_{GIVE} + \varepsilon_{iono}\right)^2, & if \;\; RSS_{iono} = 0 \; (Message\ Type\ 10) \\ \sigma_{GIVE}^2 + \varepsilon_{iono}^2, & if \;\; RSS_{iono} = 1 \; (Message\ Type\ 10) \end{cases} \qquad \text{[A-58]}$$

where:

RSS_{iono} = root-sum-square flag from Message Type 10

σ_{GIVE} = model parameter from Message Type 26 (ref. A.4.4.10)

and

$$\varepsilon_{iono} = C_{iono\_step}\left\lfloor \frac{t - t_{iono}}{I_{iono}} \right\rfloor + C_{iono\_ramp}(t - t_{iono}) \qquad \text{[A-59]}$$

where:

C_{iono_step} = the bound on the difference between successive ionospheric grid delay values determined from Message Type 10

t = the current time

t_{iono} = the time of transmission of the first bit of the ionospheric correction message at the GEO

C_{iono_ramp} = the rate of change of the ionospheric corrections determined from Message Type 10

I_{iono} = the minimum update interval for ionospheric correction messages determined from Message Type 10

$\lfloor x \rfloor$ = the floor or greatest integer less than x function

A.4.6 Principles and Rules for the Generation and Use of Data

The following principles and rules apply for the WAAS capable receiver (from these principles, the necessary message generation rules at the control center Station may be inferred).

1. The CRC must pass on the received block.
2. The user should correlate with the entire 24 bits of the preamble, but not necessarily in successive 1-second blocks. This assures frame synchronization while allowing for occasional block errors without repeating a complete synchronization.
3. "*Use/don't use*" or error correction data cannot be used until a Type 1 message providing the PRN mask with an issue of data (IODP) applicable to the data have been decoded. However, long term satellite error corrections and UDREIs can be stored by the users prior to this event and tagged useful once this event and the event in 4) below occurs. Type 1 messages will be broadcast at a rate sufficient to not degrade the user's first fix capability.
4. The embedded Issues of Data (IOD's) in the long term satellite error corrections will match those in use by the receiver prior to use.

5. Long term satellite error corrections, ionospheric delay error corrections and GEO Navigation Messages will all be broadcast at a rate sufficient to not degrade the user's first fix capability.

A.4.7 Timing

Integrity information (σ^2_{UDRE}'s encoded in Types 2 - 5, Type 24 or Type 6) will be broadcast at least once every six seconds. All other messages will be broadcast in-between, meeting the constraints imposed in Section A.4.5 above and not exceeding the maximum update interval in Table A-25 below. The required intervals apply to data content, not arbitrary messages.

The update intervals do not imply that update rates consistent with Table A-25 will meet all required performance requirements (such as ionospheric delay accuracy). In addition, the data link will broadcast a valid message every second to provide a continuity of signal. The Type 62 and Type 63 messages are valid messages but contain no data. The user time-out intervals defined in Tables A-25 and A-8 limit the time interval of applicability of all correction, integrity and GEO navigation data. The time-out interval for each data is reckoned from the end of reception of the message containing the data.

In addition to the normal messages listed in Table A-25, every alert condition (broadcast in a Type 2 - 5, Type 24, Type 6, Type 26 message) will be repeated three times after the initial notification of the alert condition (for a total of four times in four seconds). Subsequent messages can be broadcast at the normal update rate.

TABLE A-25 MESSAGE CONTENT BROADCAST INTERVALS

Data	Associated Message Types	Maximum Update Interval (seconds)	En Route, Terminal, NPA Time-Out (seconds)	Precision Approach Time-Out (seconds)
Don't Use for Safety Applications	0	6	N/A (Note 1)	N/A (Note 1)
PRN Mask	1	120 (Note 2)	600	600
UDREI	2 to 6, 24	6	18	12
Fast Corrections	2 to 5, 24	See Table A-8	See Table A-8	See Table A-8
Long Term Corrections	24, 25	120	360	240
GEO Navigation Data	9	120	360	240
Fast Correction Degradation	7	120	360	240
Degradation Parameters	10	120	360	240
Ionospheric Grid Mask	18	300 (Note 2)	1200	1200
Ionospheric Corrections	26	300	600	600
UTC Timing Data	12	300	86,400	86,400
Almanac Data	17	300	None	None
Service Level	27	300 (if used)	86,400	86,400
Clock-Ephemeris Covariance Matrix	28	120	360	240

Notes: **1.** *For safety applications, reception of a Type 0 message results in de-selection of the WAAS signal (PRN code) for one minute and all data from that signal is discarded.*

2. *When the PRN or ionospheric mask is changed, it should be repeated several times before the new masks are used. This will ensure that all users receive the new mask before it is applied, maintaining high continuity.*

A.5 References

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Appendix B

STANDARD GPS/WAAS ASSUMPTIONS

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Appendix B—STANDARD GPS/WAAS ASSUMPTIONS

B.1 GPS Constellation

The following parameters describe the target location orbital elements of the Optimized 24 GPS Constellation (Table B-1).

TABLE B-1 OPTIMIZED 24 GPS CONSTELLATION

	Orbital Plane	Semimajor Axis (a)	Eccentricity (e)	Inclination Angle (i)	Rt. Ascension of Ascending Node (Ω)	Arg. of Perigee (ω)	Mean Anomaly (M)
1.	A1	26559800	0.0	55.0	272.847	0.0	268.126
2.	A2	26559800	0.0	55.0	272.847	0.0	161.786
3.	A3	26559800	0.0	55.0	272.847	0.0	11.676
4.	A4	26559800	0.0	55.0	272.847	0.0	41.806
5.	B1	26559800	0.0	55.0	332.847	0.0	80.956
6.	B2	26559800	0.0	55.0	332.847	0.0	173.336
7.	B3	26559800	0.0	55.0	332.847	0.0	309.976
8.	B4	26559800	0.0	55.0	332.847	0.0	204.376
9.	C1	26559800	0.0	55.0	32.847	0.0	111.876
10.	C2	26559800	0.0	55.0	32.847	0.0	11.796
11.	C3	26559800	0.0	55.0	32.847	0.0	339.666
12.	C4	26559800	0.0	55.0	32.847	0.0	241.556
13.	D1	26559800	0.0	55.0	92.847	0.0	135.226
14.	D2	26559800	0.0	55.0	92.847	0.0	265.446
15.	D3	26559800	0.0	55.0	92.847	0.0	35.156
16.	D4	26559800	0.0	55.0	92.847	0.0	167.356
17.	E1	26559800	0.0	55.0	152.847	0.0	197.046
18.	E2	26559800	0.0	55.0	152.847	0.0	302.596
19.	E3	26559800	0.0	55.0	152.847	0.0	333.686
20.	E4	26559800	0.0	55.0	152.847	0.0	66.066
21.	F1	26559800	0.0	55.0	212.847	0.0	238.886
22.	F2	26559800	0.0	55.0	212.847	0.0	345.226
23.	F3	26559800	0.0	55.0	212.847	0.0	105.206
24.	F4	26559800	0.0	55.0	212.847	0.0	135.346

The epoch date for this constellation is June 30, 1993 at 23:34:24 (1993, 6, 30, 23 hr, 34 min, 24 sec UTC, or GPS Week 703, 344064 seconds).

B.2 WAAS Constellation

For the purpose of simulator testing, WAAS satellites are located at the following longitudes and inclination angles.

WAAS Satellite	Longitude	Inclination
PRN 120	W 15.5	2.3 degrees
PRN 122	W 55.5	2.3 degrees
PRN 134	W 179.5	2.3 degrees

B.3 Selective Availability

Selective Availability shall be modeled as the sum of (1) a second-order Gauss-Markov process with an auto-correlation time of 118 seconds and a standard deviation of 23 m, and (2) a random constant with normal distribution, a mean of zero and a standard deviation of 23 m.

The second-order Gauss-Markov process is described by the power spectral density:

$$s(\omega) = \frac{c^2}{\omega^4 + \omega_o^4} \frac{m^2}{rad^4 / \sec^4}$$

where

$C^2 = 0.002585\ m^2$

$\omega_0 = 0.012$ rad/sec

The SA processes on all satellites are to be statistically independent. When modeling a single independent SA sample (for a single snapshot or for samples greater than 2 minutes apart), SA can be modeled by a Gaussian random variable with a mean of zero and a standard deviation of 33 m.

B.4 GPS Satellite Failure

The probability of a satellite integrity failure is 10^{-4} per hour for the GPS position solution (based on 3 satellite major service failures/year/constellation, assuming 8 satellites in view). A satellite integrity failure is defined to be an insidious failure that contributes to a hazardously misleading situation.

B.5 GPS Constellation for Availability Analysis

Table B-2 contains the location of the GPS satellites on December 1, 1995 at 0000UTC. These locations can be used for the FDE availability analysis, and may also be used to test simulation orbit software.

TABLE B-2 GPS CONSTELLATION ON DECEMBER 1, 1995 AT 00:00 UTC
(GPS Week: 829 GPS Seconds: 00432000)

SVID	MEAN ANOMALY	OMEGA_O	X-Position	Y-Position	Z-Position
1	268.126	-2.253	-14870571.94	8899797.75	-20126665.56
2	161.786	-2.253	23589887.94	11991875.55	-2266072.27
3	11.676	-2.253	-16176102.35	-16770562.96	12747741.24
4	41.806	-2.253	-4355434.09	-17071145.97	19875340.13
5	80.956	57.747	15395084.60	5233826.18	21000509.74
6	173.336	57.747	-1695661.81	25682884.00	-6552646.52
7	309.976	57.747	-9297858.71	-23002281.98	-9479864.10
8	204.376	57.747	-9361634.66	18753790.62	-16311900.87
9	111.876	-242.253	-9092026.91	19872361.08	15094611.22
10	11.796	-242.253	22600908.12	-5583452.08	12784638.87
11	339.666	-242.253	21913985.95	-14935082.68	1464070.04
12	241.556	-242.253	-10617702.92	-11042774.34	-21696647.11
13	135.226	-182.253	-24936980.94	-5007408.16	7648256.07
14	265.446	-182.253	13908721.33	-9596379.71	-20490972.24
15	35.156	-182.253	7188942.92	17419062.74	18716792.70
16	167.356	-182.253	-22645671.90	-13176689.83	-4355613.11
17	197.046	-122.253	7720020.91	-20979445.69	-14341795.98
18	302.596	-122.253	10802779.38	21135634.15	-11916706.88
19	333.686	-122.253	3560816.01	26307697.10	-805381.07
20	66.066	-122.253	-15149811.05	1603096.34	21756292.96
21	238.886	-62.253	11566835.96	10254727.75	-21597959.17
22	345.226	-62.253	-22547453.11	13577895.19	3560350.61
23	105.206	-62.253	6551951.60	-19489487.66	16812340.02
24	135.346	-62.253	16838480.90	-19079928.60	7605580.96

All semi-major axes are 26559800 meters.

All eccentricities are 0.0

All orbital planes are inclined at 55 degrees.

OMEGA_0 = omega - 275.1.

B.6 Signal Quality Monitoring

The signal effects that might cause a Double Delta (DD) Delay Lock Loop (DLL) discriminator to track the wrong peak can be categorized into three different effects on the correlation function as follows:

B.6.1 Dead Zones

If the correlation function loses its peak, then the receiver's discriminator function will include a flat spot or dead zone. If the reference receiver and aircraft receiver settle in different portions of this dead zone, then Misleading Information (MI) can result.

B.6.2 False Peaks

If the reference receiver and aircraft receiver lock to different peaks, then MI could exist.

B.6.3 Distortions

If the correlation peak is misshapen, then an aircraft that uses a correlator spacing other than the one used by the reference receivers may well suffer MI.

B.6.4 Threat Models

The GPS threat model has three parts that can create the three correlation peak pathologies listed above.

B.6.4.1 Threat Model A

Threat Model A consists of the normal C/A code signal except that all positive chips have a falling edge that leads or lags relative to the correct end time for that chip. This threat model is associated with a failure in the Navigation Data Unit (NDU), the digital partition of a GPS satellite. Threat Model A has a single parameter Δ, which is the lead ($\Delta < 0$) or lag ($\Delta > 0$) expressed in fractions of a chip. The range for this parameter is $-0.12 < \Delta \leq 0.12$. Within these ranges, Threat Model A generates the dead zones described above. (Note that waveforms with lead need not be tested, because their correlation functions are simply advances of the correlation functions for lag. Hence the MI threat is identical.)

B.6.4.2 Threat Model B

Threat Model B introduces amplitude modulation and models degradations in the analog section of the GPS satellite. More specifically, it consists of the output from a second order system when the nominal C/A code baseband signal is the input. Threat Model B assumes that the degraded satellite subsystem can be described as a linear system dominated by a pair of complex conjugate poles. These poles are located at $\sigma \pm j2\pi f_d$, where σ is the damping factor in nepers/second and f_d is the resonant frequency with units of cycles/second. They can also be used to specify the impulse response $h_{2nd}(t)$ or the unit step response e(t). The unit step response of a second order system is given by

$$e(t) = \begin{Bmatrix} 0 & t \leq 0 \\ 1 - \exp(-\sigma t)\left[\cos\omega_d t + \dfrac{\sigma}{\omega_d}\sin\omega_d t\right] & t > 0 \end{Bmatrix}$$

Threat Model B corresponding to 2nd order anomalies uses the following ranges for the parameters defined above:

$\Delta = 0$; $4 \leq f_d \leq 17$ and $0.8 \leq \sigma \leq 8.8$.

Within these parameter ranges, Threat Model B generates distortions of the correlation peak as well as false peaks.

B.6.4.3 Threat Model C

Threat Model C introduces both lead/lag and amplitude modulation. More specifically, it consists of outputs from a second order system when the C/A code signal at the input suffers from lead or lag. This waveform is a combination of the two effects described above. Threat Model C includes all three parameters described above with the following ranges:

$-0.12 \leq \Delta \leq 0.12$; $7.3 \leq f_d \leq 13$ and $0.8 \leq \sigma \leq 8.8$.

Within these parameter ranges, Threat Model C generates dead zones, distortions of the correlation peak, and false peaks.

Appendix C

STANDARD RECEIVED SIGNAL AND INTERFERENCE ENVIRONMENT

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Appendix C—STANDARD RECEIVED SIGNAL AND INTERFERENCE ENVIRONMENT

C.1 Introduction

This appendix specifies the RF Interference environment at and around L-band frequencies for GPS/WAAS receivers.

All signal levels in this appendix are specified in dBm measured at the antenna port.

C.2 Operating Interference Environment

Interference levels specified in this appendix are defined relative to received satellite signal levels (at the antenna port) of -134.5 dBm (GPS) and -135.5 dBm (WAAS satellite). These satellite signal levels represent that which is received at the antenna port that include a minimum standard antenna gain above 5° elevation angle of -4.5 dB. For non-standard antennas with a different minimum gain above 5° elevation angle, the signal and interference levels can be adjusted accordingly, as long as the relative interference-to-signal level is maintained.

Figure C-1 represents the operating interference environment. The regions of this figure indicated as having interference with bandwidths other than CW are considered to represent in-band and near-band interference with received power levels defined in Figure C-2 as a function of bandwidth.

C.2.1 Out-of-Band Interference

The out-of-band continuous wave (CW) interfering signals can be as high as the levels shown in Figure C-1, measured at the antenna port. The CW interference level below 1500 MHz increases linearly to 25.5 dBm at 1315 MHz. The CW level increases linearly above 1640 MHz, to 21.5 dBm at 2 GHz, accounting for High Intensity Radiation Fields (HIRF).

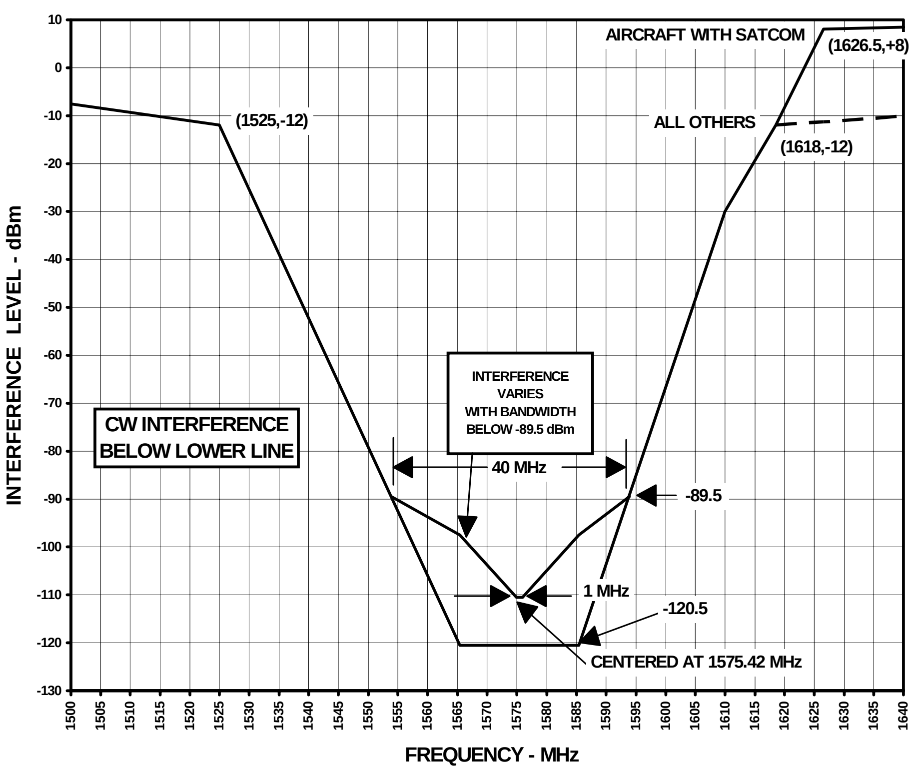

FIGURE C-1 INTERFERENCE LEVELS AT THE ANTENNA PORT

C.2.1.1 Out-of-Band Pulse Interference

After steady state navigation has been established, equipment operating in all flight phases could receive pulsed interference in the out-of-band frequency ranges specified above having the characteristics described in Table C-1.

TABLE C-1 OUT-OF-BAND PULSE INTERFERENCE

	GPS/WAAS	GPS Only
Peak Power	+30 dBm	+30 dBm
Pulse Width	125 μsec	1 ms
Pulse Duty Cycle	10%	10%

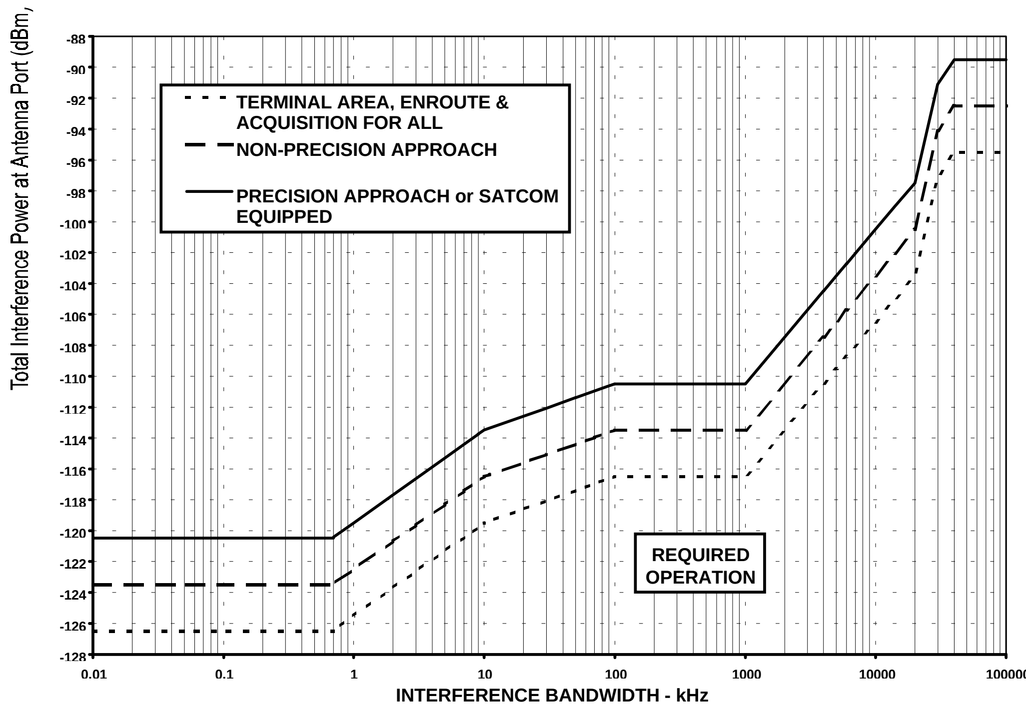

FIGURE C-2 IN-BAND AND NEAR-BAND INTERFERENCE ENVIRONMENTS

C.2.2 In-Band and Near-Band Interference

The baseline in-band and near-band interference environments apply to precision approach operations and to all aircraft equipped with SATCOM terminals. The environments for all other flight phases are relative to those environments. The interference bandwidth is the 3 dB bandwidth.

Figure C-1 and Figure C-2 are related as follows: The upper mask of Figure C-1 (the mask that varies with bandwidth) at 1575.42 MHz ±0.5 MHz relates to the level in Figure C-2 between the bandwidths of 100 and 1000 kHz. For interference bandwidths outside of that range, the level of the mask in Figure C-1 is adjusted up or down according to the levels of Figure C-2. For example, for the upper curve of Figure C-2, interference with a bandwidth of 0.1 kHz lowers the mask to the CW interference mask at 1575.42 MHz (-120.5 dBm), while interference with a bandwidth of 20 MHz raises the mask at 1575.42 MHz at a level of -97.5 dBm. In addition, if the center of the interference moves away from 1575.42 MHz, the levels of Figure C-2 for bandwidths not greater than 20 MHz are raised according to the mask of Figure C-1. For example, for the upper curve of Figure C-2, for interference centered at 1565.42 MHz, the curve of Figure C-2 is increased by 13 dB.

After steady state navigation has been established, the equipment could receive an interfering signal in the frequency range of 1575.42 $\pm BW_I/2$ MHz that is as high as the levels defined in Table C-2 as a function of interfering signal bandwidth BW_I:

TABLE C-2 IN-BAND AND NEAR-BAND INTERFERENCE BANDWIDTH DEFINITIONS

Bandwidth	Interference Level
$0 \le BW_I \le 700$ Hz	-120.5 dBm
700 Hz $< BW_I \le$ 10 kHz	Linearly increasing[1] from -120.5 dBm to -113.5 dBm
10 kHz $< BW_I \le$ 100 kHz	Linearly increasing[1] from -113.5 dBm to -110.5 dBm
100 kHz $< BW_I \le$ 1 MHz	-110.5 dBm
1 MHz $< BW_I \le$ 20 MHz	Linearly increasing[1] from -110.5 to -97.5 dBm[2]
20 MHz $< BW_I \le$ 30 MHz	Linearly increasing[1] from -97.5 to -91.1 dBm[2]
30 MHz $< BW_I \le$ 40 MHz	Linearly increasing[1] from -91.1 to -89.5 dBm[2]
40 MHz $< BW_I$	-89.5 dBm[2]

[1] Increase in interference power is linear for the units shown in Figure C-2.

[2] Interference levels will not exceed –110.5 dBm/MHz in the frequency range of 1575.42 ± 10 MHz.

These interfering levels as a function of bandwidth are shown in Figure C-2.

The in-band and near-band interference levels for the non-precision approach steady-state navigation operations are 3 dB less than those for precision approach steady-state navigation operations. For terminal area and enroute steady-state navigation operations, and for initial acquisition of the GPS and WAAS signals prior to steady-state navigation for all flight phase operations, the in-band and near-band interference levels are 6 dB less than those for precision approach steady-state navigation operations.

C.2.2.1 In-Band and Near-Band Pulsed Interference

After steady state navigation has been established, equipment operating in all flight phases could receive pulsed interference in the in-band and near-band frequency ranges specified above having the characteristics described in Table C-3.

TABLE C-3 IN-BAND AND NEAR-BAND PULSE INTERFERENCE

	GPS/WAAS	GPS Only
Peak Power	+20 dBm	+20 dBm
Pulse Width	125 μsec	1 ms
Pulse Duty Cycle	10%	10%

Note: *The signal bandwidths for in-band and near-band pulse interference in Table C-3 are specified to be at least 100 kHz. Therefore, for the purposes of verification, testing, or demonstration of compliance, only the signals with bandwidths greater than 100 kHz are applicable.*

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Appendix D

DATA FORMAT FOR HIGH INTEGRITY INFORMATION TO SUPPORT STRAIGHT AND ADVANCED LANDING APPROACH OPERATIONS

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Appendix D—DATA FORMAT FOR HIGH INTEGRITY INFORMATION TO SUPPORT STRAIGHT AND ADVANCED LANDING APPROACH OPERATIONS

D.1 Introduction

Unlike the ILS or MLS where the approach path is defined by radio signals originating from a properly aligned ground station antenna, the GNSS precision approaches are based on reference paths defined by surveyed points. Coordinates defining these points must be of high resolution and integrity. This appendix defines the format for this type of data.

The information to support computed straight and advanced approach procedures is comprised of several items. These include runway and airport information, procedure naming and approach and departure procedure waypoint information. The information for straight-in approaches is fully described in the following paragraphs. This format provides integrity protection for the data it contains. The primary purpose of this format is to support straight-in precision approaches for navigation systems requiring this data to determine the reference path. The first and principal application is the provision of high accuracy and high integrity data for GPS WAAS precision approach operations. Precision approach airborne equipment must be capable of interpreting this format.

The format is also capable of supporting precision advanced approaches and departures. The specific format for advanced procedures is currently undefined.

D.2 Format

D.2.1 Overall Structure

Although data may be stored or transmitted in any way, the data is organized in data blocks for the purpose of computing the CRC. Each data block contains all the information necessary for one single path. This appendix describes the data block structure only for the computation of the CRC. The database organization, including how this information is stored in a database, is left to the industry. The data suppliers and the equipment manufacturers will find ways of assembling the data blocks into the databases for the users.

To organize the databases additional data elements may need to accompany the data blocks. Because these extra elements do not necessarily require high integrity protection and also because any additional data may change while the final approach path segment remains constant, it was chosen not to include them in this appendix.

D.2.2 Data Block Description

The block contains data for a single operation. It is self-contained and includes a means to preserve integrity from the time it is generated and validated to the time that it is used in airborne equipment. All of the information necessary to describe the paths and its designation is contained within it. This primarily includes the following: airport identification, runway designation and position, procedure type (provides flexibility for advanced procedures such as departure or curved approach), procedure name, and runway surveyed points. The data block is generated, protected by a CRC code and validated by the appropriate authorities before distribution. The data block can be transported, reformatted and distributed as long as the original format can be recovered, thereby allowing the verification of the original CRC.

D.2.3 Data Block Structure

The data block structure consists of a series of fields of different size. The sequence of the fields depends on the operation type the data block supports. Fields common to the different types of operations are placed in the beginning of the data blocks. It is recognized that the data does not have to be stored or transferred in this format; a more suitable condensed format may be used.

Only the format for straight-in procedures is defined at this time. Note that the data blocks for advanced procedures are likely to have different lengths. Table D-1 indicates the overall structure for straight-in approaches. The data items are defined in Section D.3.

The CRC field always terminates the data block.

D.3 Final Approach Segment Data Block

The Final Approach Segment Data Block contains the parameters, which define a single precision approach. Figure D-1 depicts a final approach segment and illustrates the parameters, which define the approach path. Each FAS data block ends with a CRC, which wraps around the approach data.

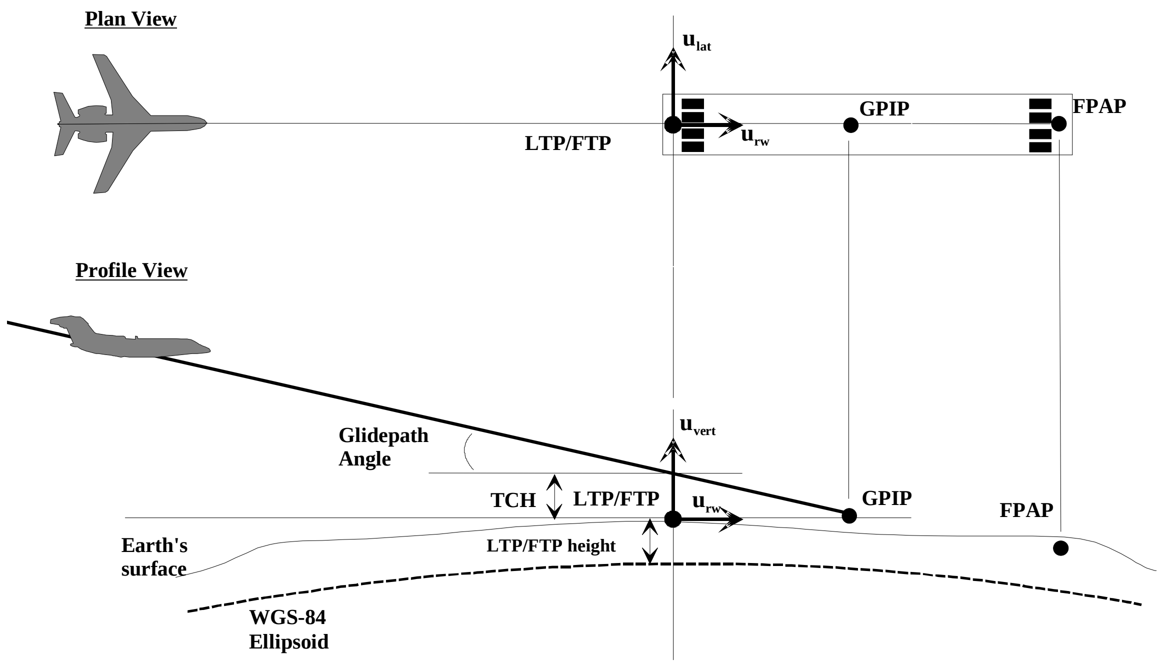

FIGURE D-1 FINAL APPROACH SEGMENT DIAGRAM

The protected FAS data blocks are validated individually by the civil authorities. The data blocks include data that allow for an unambiguous FAS selection against the desired approach charts.

D.3.1 Final Approach Segment Parameter Definition

Airport Identification: represents the three or four alphanumeric characters used to designate airport facilities. Only upper case alpha characters are used. The most significant two bits of every character (8-bit word) are zero. Alphanumeric characters are coded using bits b_1 to b_6 of International Alphabet ISO No. 5. When a three-character identifier is used, the most significant character b1 to b6 are set to blank (“10 0000”). Only capital letters and numbers are used.

Approach Design Information: represents the general information about the approach design (offset, FPAP at the end of runway, …). The convention for the coding is as follows:

000 = Straight in approach FPAP at the end of the runway

001 = Straight in approach, FPAP not at the end of the runway

002 = Offset approach

003 - 111 = Not defined

Approach Performance Designator: general information about the approach design. Coding:

0 = spare

1 = Category I

2, 3 = Reserved

4-7 = spare

CRC code: is a 32 bit cyclic redundancy check (CRC) appended to the end of each FAS Data Block in order to ensure approach data integrity. The CRC word is calculated on the entire data block. A complete description of the CRC is provided in Section D.5.

Flight Path Alignment Point – Latitude: represents the latitude of the runway Flight Path Alignment Point (FPAP) in WGS-84 coordinates and transmitted in arc seconds. The most significant bit is the sign bit:

0 = positive (Northern Hemisphere)

1 = negative (Southern Hemisphere)

Flight Path Alignment Point – Longitude: represents the longitude of the Flight Path Alignment Point defined in WGS-84 coordinates and transmitted in arc seconds. The most significant bit is the sign bit:

0 = positive (Eastern Hemisphere)

1 = negative (Western Hemisphere)

Glidepath Angle (GPA): represents the angle of the approach path (glide path) with respect to the horizontal plane defined according to WGS-84 at the LTP/FTP.

Operation Type: indicates whether the operation is an approach procedure, an advanced operation or others to be defined later. The valid range is limited to 0-15, so the four most significant bits are zero. The convention for coding is as follows:

0 = straight-in approach procedure

1-15 = reserved for future definition

Note: *Advanced operation can be straight-in approaches followed by a missed-approach, a precision curved approach or departure procedure and roll-out and taxiing procedures.*

Reference Path Data Selector: is a numerical identifier used to select the FAS data block (desired approach). It is intended for LAAS and is not used for WAAS operations.

Reference Path Identifier: represents the three or four alphanumeric characters used to uniquely designate the reference path. Only upper-case alpha characters or numeric digits are used. The most significant two bits of every character (8-bit word) are zero. Alphanumeric characters are coded using bits b_1 to b_6 of International Alphabet ISO No. 5. When a three-character identifier is used, the most significant character b1 to b6 are set to indicate a blank (10 0000).

Route Indicator: One-letter identifier used to differentiate between multiple approaches to the same runway end. The letter is an upper-case alpha character, excluding the letters "I" and "O". A blank may also be used (“10 0000”). The most significant three bits of every character (8-bit word) are zero. Alphanumeric characters are coded using bits b_1 to b_5 of International Alphabet No. 5.

Landing Threshold Point (LTP)/Fictitious Threshold Point (FTP) Height Above Ellipsoid: represents the WGS-84 height of the LTP/FTP. This field is coded as an unsigned value with an offset of -512 m. A value of zero in this field places the DP 512 m below the earth ellipsoid.

LTP/FTP Latitude: represents the latitude of the threshold defined in WGS-84 coordinates and transmitted in arc seconds. The most significant bit is the sign bit:

0 = positive (Northern Hemisphere)

1 = negative (Southern Hemisphere)

LTP/FTP Longitude: represents the longitude of the threshold defined in WGS-84 coordinates and transmitted in arc seconds. The most significant bit is the sign bit:

0 = positive (Eastern Hemisphere)

1 = negative (Western Hemisphere)

Runway Letter: represents the runway letter, where used to differentiate between parallel runways. The valid range is 00 through 11. The convention for coding is as follows:

00 = no letter	10 = C (center)
01 = R (right)	11 = L (left)

Runway Number: represents the approach runway number. The valid range is 0-36. Runway numbers 1 through 36 designate runway operations and the designation 0 identifies heliport operations.

SBAS Service Provider ID: represents the SBAS service provider ID of the SBAS which is authorized to be used for the approach. Service provider ID of 15 indicates that any provider may be used. Service provider ID of 14 indicates the FAS data block is not intended for SBAS use.

Threshold Crossing Height (TCH): represents the height of the path above the LTP/FTP. The height can be defined in either feet or meters as defined in the TCH Units Selector bit.

Threshold Crossing Height (TCH) Units Selector: this bit defines the units used to describe the Threshold Crossing Height. The definition of the bit is:

0 = feet

1 = meters

D.3.2 Final Approach Segment Data Table

TABLE D-1 FINAL APPROACH SEGMENT (FAS)

Data content	Bits used	Range of values	Resolution
Operation type	4	0 to 15	1
SBAS provider ID	4	0 to 15	1
Airport ID	32	-	-
Runway number (Note 1)	6	0 to 36	1
Runway letter	2	-	-
Approach performance designator	3	0 to 7	1
Route indicator	5	-	-
Reference path data selector	8	0 to 48	1
Reference path identifier	32	-	-
LTP/FTP latitude	32	± 90.0 °	0.0005 arcsec
LTP/FTP longitude	32	± 180.0 °	0.0005 arcsec
LTP/FTP height	16	-512.0 to 6041.5 m	0.1 m
ΔFPAP latitude	24	± 1.0 °	0.0005 arcsec
ΔFPAP longitude	24	± 1.0 °	0.0005 arcsec
Approach threshold crossing height (TCH) (Note 1)	15	0 to 1638.4 m (0 to 3276.8 ft)	0.05 m (0.1 ft)
Approach TCH units selector	1	-	-
Glidepath angle (GPA)	16	0 to 90.0 °	0.01°
Course width at threshold (Note 1)	8	80.0 to 143.75 m	0.25 m
ΔLength offset	8	0 to 2032 m	8 m
Final approach segment CRC	32	-	-

Note: *When the runway number is set to 00, then the course width field is ignored and the course width is 38 meters.*

D.4 Advanced Procedures Data Blocks

The data format has the capability through the procedure identifier, to accommodate advanced procedures. The format for those procedures is currently undefined.

D.5 CRC Definition

The CRC code consists of the coefficients of the remainder R(x) of the modulo-2 division of two polynomials:

$$\left[x^K \frac{M(x)}{G(x)} \right]_{\mathrm{mod}_2} = Q(x) + \frac{R(x)}{G(x)}$$

Where k is the number of bits in the CRC and the polynomial and M(x) consists of the sequence of data bits to be protected by the CRC (excluding the CRC bits):

$$M(x) = \sum_{i-1}^{n} m_i x^{n-i}$$

The data bits (m_1, ...,m_n) are treated as a single word of n bits, arranged in order of transmission without any byte-wise reversal of bits.

Numbering of the data block goes from the LSB to the MSB, beginning with the operation type and following through all of the data. The CRC follows with R_1 as the MSB (i.e., x^k) and the last bit is R_k (i.e., x^1).

G(x) is the FAS Data Block generator polynomial:

$$G(x) = x^{32} + x^{31} + x^{24} + x^{22} + x^{16} + x^{14} + x^8 + x^7 + x^5 + x^3 + x + 1$$

Q(x) is the quotient of the division.

The quotient Q(x) is obtained by dividing x^k *M(x) by G(x) starting with m_1(or m_i) and $G_1 = x^k$ considered as being the highest bits in their respective polynomial as follows:

$$[m_1*x^{(n+32)} + m_2*x^{(n+31)} + ... + m_n*x^{32}] / [x^{32} + x^{31} + x^{24} + x^{22} + x^{16} + x^{14} + x^8 + x^7 + x^5 + x^3 + x + 1]$$

The remainder of the division must match the received CRC R_1 through R_{32} bits

$$R_1*x^{32} + R_2*x^{31} + R_3*x^{30} \cdots\cdots + R_{32}*x^1$$

D.6 Informative Section

D.6.1 Integrity Protection of Data Blocks

The principle of integrity protection resides in the presence of a CRC code for each data block. The CRC is added to the data block when it is generated. The airborne equipment verifies the data integrity by generating the CRC code and comparing it to the CRC code part of the data block. A perfect match indicates the data is not corrupted and can be used. The use of a CRC code provides a theoretical bound on the probability of undetected error of 2^{-r}, where r is the number of bits of the CRC code. For this format a 32 bit CRC code is used. The corresponding upper bound for the 32 bit code is 2.3283×10^{-10}. The CRC code, CRC-32Q(Q for Qualcomm) was chosen [1]. It has proven well behaved at all the bit error rates for message length of the same order magnitude as the ones likely to occur for the data blocks.

ILS and MLS certifying authorities commission ground installations and create approach procedures for precision landing using the facility. The integrity is ensured by proper alignment of the transmitting antennas, flight checks and integrity monitors on the transmitted signal. For precision approaches based on data, the integrity of the approach rests on the data describing the approach path. Likewise the integrity is ensured by the certifying authorities when they issue the data block for use. They design the approach procedure, calculate the parameters, organize the data block and calculate the CRC code. The data block is then validated by flight test or other suitable means before being issued. The integrity is ensured when the airborne equipment making use of the data successfully passes the CRC on the data block. The CRC assumes the data block and its CRC code in the same format as when issued.

It is allowed to reformat the data blocks for the purpose of distribution, creating databases customized to operator missions. However the on-board equipment must be able to recover the original format bit-for-bit without any exception. The original CRC code should be transferred as is without any transformation.

D.6.2 Approach Path Selection

Another element key to the integrity of the precision approaches based on data is the approach selection. The CRC verification does not guarantee that the proper approach has been selected. It is the responsibility of the pilot to verify proper approach path selection. This may be accomplished through the approach identifier, or a combination of the airport, runway, and route indicators.

D.6.3 Data Block Generation

The data generation typically starts with a precise survey of both ends of the runway to be served. The geodetic coordinates are based on the WGS-84 system. The landing threshold point/fictitious threshold point (LTP/FTP) and flight path alignment point (FPAP) are determined from these surveyed points, and will usually be coincident with the runway threshold at both runway ends. The TCH and glidepath angle are determined by the obstacle avoidance criteria in use for the operations to be supported.

Once the FPAP geodetic coordinates are determined, the FPAP position can be expressed by the difference of coordinates with respect to the LTP/FTP. The FPAP does not require a vertical component in order to define the glidepath. Its sole role is to define the vertical plane which defines the lateral deviation reference. For the calculations on-board the aircraft and for the procedure designer, the FPAP is defined to be at the same ellipsoid height as for the LTP/FTP.

The data block is then finalized by adding the other data and by calculating the CRC.

The data block is then entered into flight inspection equipment for validation. The authorities fly the approach and validate the data and CRC. They must also ensure that the data on the approach plates correspond to the data block.

The data is then issued to the industry for distribution.

D.6.4 Database Formatting and Distribution

Data blocks need to be transferred to the data providers preferably on electronic media. A transportation layer compatible with the media must be defined.

A standard textual-based version of the binary data needs to be defined to be able to share data whenever transfer of the binary data block is not possible. Care must be taken to ensure that transformation to and from binary and textual format can be done such that every bit can be recovered. This ensures a successful CRC.

The same sub-committee also needs to standardize means of integrating data blocks into databases to allow for seamless departure, en-route, terminal and precision approach.

Industry may elect to standardize a method of data reformatting and high integrity database transportation. For example, high integrity data could be integrated in the ARINC-424 format. For this purpose the data block elements can be extracted and reformatted, provided certain rules are followed. The values contained in the numeric fields should be expressed in the new format such that they can be retrieved in the original format without a change in any of the bits. There should be no transformation that truncates or rounds numbers. In addition, the original CRC must be transferred unchanged throughout the distribution chain.

The industry must define where the reverse transformation must take place and define a protocol for passing the high integrity data from the storage equipment to the GPS/WAAS equipment on-board the aircraft.

Equipment manufacturers or data providers gather into a database the information required for the operation of their customers. The data blocks need to be organized (or merged) into the database. In this case data block transformation can take place. The rules governing data block transformation set in the previous paragraph are also followed.

D.6.5 CRC Generation and Decoding

Using an (n,k) cyclic code, the encoded message can be formulated in systematic form (parity bits follow information bits) using a three step procedure.

1. Multiply the message polynomial M(x) by x^r, where r = n-k = 32. This effectively appends 32 zero bits to the end of the dividend.
2. Divide the product x^r M(x) by the generator polynomial, G(x). The CRC code contains the coefficients of the remainder polynomial resulting from this division operation.
3. Add the remainder, R(x), from the division operation in step 2 to the product calculated in step 1 to form the codeword

$$v(x) = R(x) + x^r M(x) = Q(x) G(x),$$

where Q(x) is the quotient polynomial from step 2.

$$x^{(32)} M(x)/G(x) = Q(x) + R(x)/G(x)$$

Notes: ***1.*** *All arithmetic operations are performed modulo 2.*

2. *G(x) is of the form (1 +x)P(x), where P(x) is a primitive and irreducible polynomial of order r-1 = n-k-1.*

D.6.6 CRC Selection

Performance comparisons of several CRC codes were done by Qualcomm Corporation.

The results of this performance analysis are presented in Reference 1. The code labelled *CRC-32Q* demonstrates a probability of undetected error below the upper bound of:

$$2^{-32} = 2.3283E^{-10}$$

for a wide range of message lengths.

D.6.7 Reference Coordinate System

The geodetic coordinate system based on WGS-84 has been chosen for the LTP/FTP and FPAP because they correspond to surveyed points on the ground. The unit of measure adopted is the 0.01 arc-second. It provides adequate resolution anywhere on earth. With it coordinates can be converted back and forth from degrees, minutes, seconds notation to the binary format adopted without any change in the conversion outcome. This is of primary importance if the CRC is to be successful.

D.7 References

1. Wolf, J. K., and R. D. Blakeney, II, 1988, "An Exact Evaluation of the Probability of Undetected Error for Certain Shortened Binary CRC Codes", MILCOM '88 Conference Proceeding, pp. 287- 292 (paper 15-2), Vol. 1, Washington, DC.
2. Lin, S., and D. J. Costello, Jr., 1983, Error Control Coding: Fundamentals and Applications, Englewood Cliffs, NJ: Prentice-Hall, Inc.

Appendix E

BASELINE WEIGHTED NAVIGATION SOLUTION AND NAVIGATION SYSTEM ERROR ALGORITHMS FOR PRECISION APPROACH

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Appendix E—BASELINE WEIGHTED NAVIGATION SOLUTION AND NAVIGATION SYSTEM ERROR ALGORITHMS FOR PRECISION APPROACH

E.1 Introduction

This appendix describes the baseline algorithm for computing the navigation solution during precision approach, where this algorithm makes use of a weighted least squares method to solve the navigation equations. This appendix also details the general approach to monitoring the navigation system error associated with the approach, where this algorithm uses a weighted form of autonomous fault detection to estimate the quality of the navigation solution.

All classes of equipment must realize navigation solutions which perform at least as well as the algorithm described in Section E.2. Only Class Gamma and Delta equipment need to implement a navigation system error algorithm which performs as well as the algorithm described in Section E.3.

E.2 Baseline Navigation Solution

The basic linearized GPS measurement equation is [1]

$$y = G \bullet x + \varepsilon$$

where x is the four dimensional position vector (north, east, up and clock) about which the linearization has been made, y is an N dimensional vector containing the raw pseudorange measurements minus the expected ranging values based on the location of the satellites and the location of the user (x), G is the observation matrix and ε is an N dimensional vector containing the errors in y. The expected pseudoranges from the linearization point to the satellites are determined from the linearization point. The observation matrix consists of N rows of line of sight vectors from x to each satellite, augmented by a 1 for the clock. Thus the i^{th} row corresponds to the i^{th} satellite in view and can be written in terms of the elevation angle El_i and the azimuth angle Az_i

$$\mathbf{G_i} = \begin{bmatrix} \cos El_i \cos Az_i & \cos El_i \sin Az_i & \sin El_i & 1 \end{bmatrix} = i^{th} \text{ row of } \mathbf{G}$$

when positive azimuth is defined clockwise from North.

The weighted least squares solution for x is the solution (found by iteration) to [2]

$$\hat{\mathbf{x}} = \left(\mathbf{G}^{\mathbf{T}} \cdot \mathbf{W} \cdot \mathbf{G}\right)^{\mathbf{-1}} \cdot \mathbf{G}^{\mathbf{T}} \cdot \mathbf{W} \cdot \mathbf{y} \equiv \mathbf{S} \cdot \mathbf{y}$$

where the definition has been made

$$\mathbf{S} \equiv \left(\mathbf{G}^{\mathbf{T}} \cdot \mathbf{W} \cdot \mathbf{G}\right)^{\mathbf{-1}} \cdot \mathbf{G}^{\mathbf{T}} \cdot \mathbf{W}$$

and where W is the weighting matrix (see below). In this case, the weighted least squares solution is also a minimum variance solution. This baseline algorithm assumes that the error sources for each satellite are uncorrelated with the error sources for any other satellite. The weighting matrix will be diagonal and its inverse will look like

$$\mathbf{W}^{-1} = \begin{bmatrix} \sigma_1^2 & 0 & \cdots & 0 \\ 0 & \sigma_2^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_N^2 \end{bmatrix}$$

While this assumption may not be strictly true, it should be a reasonably good approximation. For the baseline weighting algorithm, the variances are described in Appendix J.

E.3 Baseline Navigation System Error Warning Algorithm

The positioning error protected by WAAS and weighted RAIM is the difference between the actual position of the airplane and the position fix provided by the navigation system. This is commonly referred to as Navigation System Error or NSE. A block diagram of the baseline NSE monitoring algorithm is shown in Figure E-1. As shown, the GPS receiver will calculate the weighted position solution, VPL_{WAAS} and HPL_{WAAS}. If VPL_{WAAS} or HPL_{WAAS} is greater than the threshold initially allowed for NSE the landing must not be initiated. Since the values of VPL and HPL can be noisy from the fast correction degradation factor, the maximum VPL and HPL observed over the fast correction time-out interval (I_{fc}) is used for this prediction. Otherwise the receiver will continue to calculate these values each epoch and the approach is begun.

After the pre-approach check VPL_{WAAS} and HPL_{WAAS} must be less than the total error allowed for NSE. Whenever there are more than 4 satellites in view, autonomous fault detection is used (similar to nonprecision approach) with a probability of false alarm equal to 10^{-5} per approach. It is irrelevant to this calculation how large the protection levels are. If an error is detected, a caution is provided and the pilot must conduct a missed approach. Otherwise, if there is no detection or when autonomous fault detection is unavailable but all of the other conditions are met, the pilot continues the approach. The equipment processes the next data for the next epoch and the cycle continues.

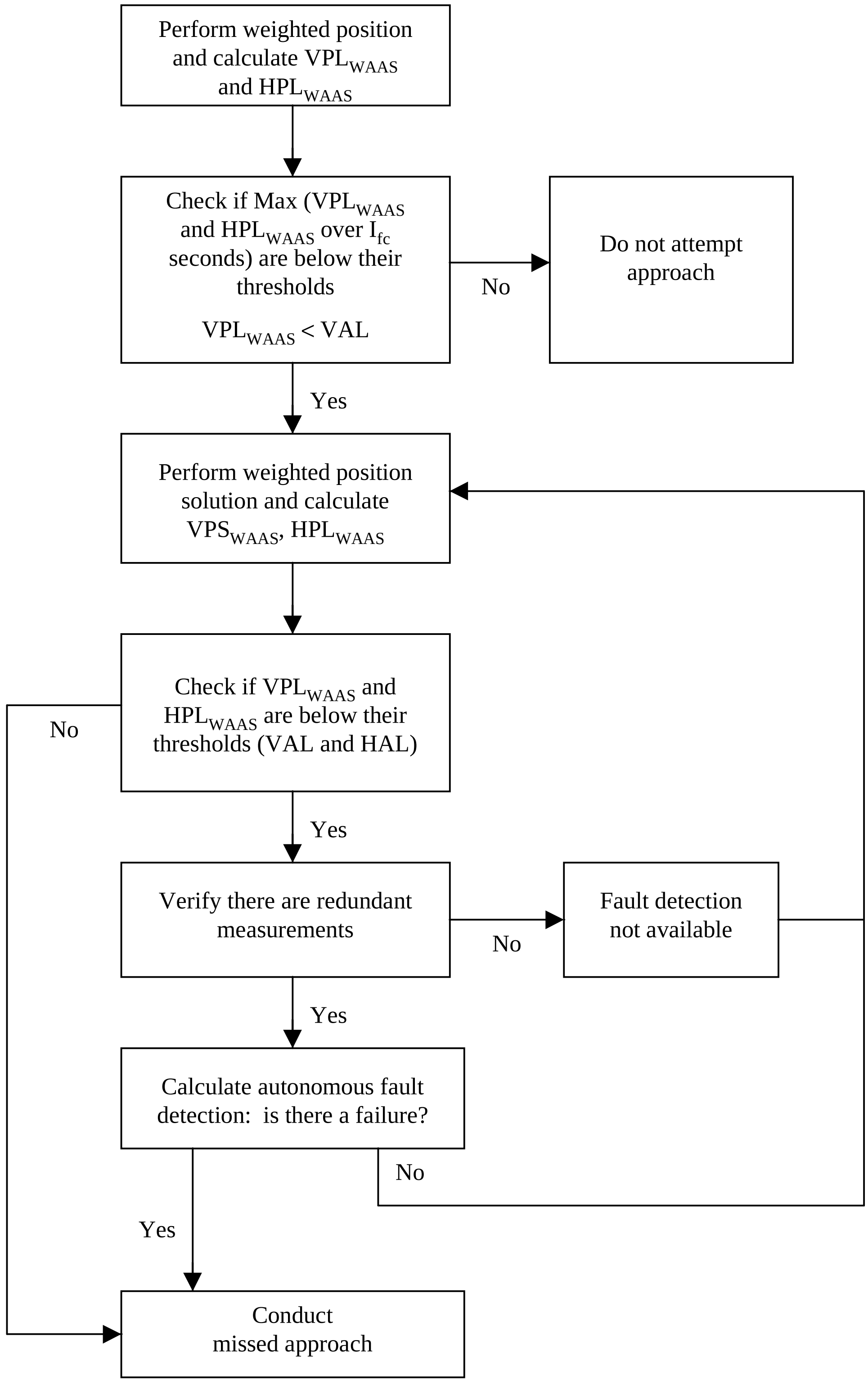

FIGURE E-1 FUNCTIONAL DIAGRAM OF NSE ALGORITHM

E.4 References

1. Milliken, R. J. and Zoller, C. J., *Principle of Operation of NAVSTAR and System Characteristics, Global Positioning System* Vol I, published by the Institute of Navigation, 1980, pp 3-14.
2. Strang, G., *Introduction to Applied Mathematics*, Wellesly-Cambridge Pub., 1986.

Appendix F

VERTICAL NAVIGATION (VNAV)

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Appendix F—VERTICAL NAVIGATION (VNAV)

Note: *For a complete discussion of VNAV requirements and associated operational issues, see RTCA/ DO-236A. SC 181 is developing a MOPS for RNP systems that addresses VNAV requirements.*

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Appendix G

REQUIREMENTS FOR BAROMETRIC ALTIMETER AIDING

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Appendix G—REQUIREMENTS FOR BAROMETRIC ALTIMETER AIDING

G.1 General

Barometric altimeter data may be used to augment GPS. There are two different methods of obtaining barometric altimeter data and deweighting it before the data gets incorporated in the GPS position solution: one uses altimeter data calibrated with GPS derived altitude data and the other uses pressure altitude data corrected for the local barometric pressure setting. The incorporation of pressure altitude data calibrated by GPS significantly improves the availability of detection and exclusion for en route and terminal modes. The use of local barometric pressure setting increases the availability of detection and exclusion for nonprecision approach. This appendix specifies the requirements for equipment which incorporates barometric altimeter data using either method, as defined below.

In both methods, a weighted linearized equation shall be used:

$$\mathbf{wy} = \mathbf{wGx}$$

where

$$w = \begin{bmatrix} \sigma_1^{-1} & 0 & \ldots & 0 \\ 0 & \sigma_2^{-1} & \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & \ldots & \sigma_{baro}^{-1} \end{bmatrix}$$

where σ_i is the standard deviation of the pseudorange measurement error for the i^{th} satellite and σ_{baro} is standard deviation of the barometric altitude error estimated as described in this appendix.

Note: *Consideration should be given to the selection of when to incorporate altitude aiding to improve availability and minimize HPL_{FD}. If baro-corrected pressure altitude is used, altitude aiding should only be used when necessary, in order to reduce the pilot workload associated with entering the barometric correction.*

G.2 Altimeter Aiding with GPS Calibration

This method involves two steps: calibration of the altimeter data with GPS data when the integrity of GPS data can be assured with good user-to-satellite geometry, and actual use of the data.

G.2.1 Requirements for Calibration

1. The equipment shall use altimeter data with the same altimeter setting. This requirement can be met by consistently using pressure altitude without local barometric altitude correction.
2. Prior to calibration, the vertical calibration error, σ_{vc}, shall be calculated using fault detection only with GPS satellites in a manner similar to the calculation of a VPL_{FD} with the following requirements:
   a. A false alarm probability (P_{fa}) shall be no more than 0.05 and
   b. Missed detection probability (P_{md}) shall be no more than 0.32

Calibration shall not be performed if a detection condition exists relative to this detection threshold.

Note: *P_{md} of 0.32 is the probability of a normally distributed variable having a value larger than 1σ. (See [1] for the rationale.)*

3. Upon calculation of σ_{vc}, recalibration shall be done (i.e., the most recent calibration shall be replaced with the new calibration) when and only when all the following conditions are met:

   a. Both navigation and FD functions exist and no fault has been detected with the FD algorithm.

   b. The test statistic for FD is less than a threshold that corresponds to the 95th percentile given that no other errors are present.

   c. The σ_{vc} calculated in 2 above is less than σ_{baro} calculated on the basis of the most recent calibration, using the growth model described below.

4. For calibration (or recalibration), the following shall be recorded:

   a. The offset between the pressure altitude and the GPS-derived altitude

   b. σ_{vc}

   c. The time of calibration

G.2.2 Calculation of σ_{baro}

The parameter σ_{baro} is used to deweight the pressure altitude data before it is incorporated in the position solution equation. When σ_{baro} is determined using a GPS vertical calibration, it shall be calculated as follows:

σ_{baro} = RSS (σ_{vc}, σ_{h}, σ_t, σ_v), where

σ_{vc} = GPS vertical calibration error (at the time of the most recent calibration)

At the time of each new GPS vertical calibration, the following errors are zero. Otherwise,

σ_h = $k_h * d_h$, where

k_h = horizontal error growth rate = 0.5 m/nmi

d_h = horizontal distance between current position and the position of most recent GPS vertical calibration

σ_t = $k_t * t$, where

k_t = time error growth rate = 15 m/hr

t = time elapsed since the most recent GPS vertical calibration

σ_v = Algebraic sum of the errors obtained for each of the applicable pressure gradient regions in Table G-1 or G-2, for the aircraft altitude change since the most recent GPS calibration.

Table G-1 may be used if local ground level (GL) is known or can be estimated as follows. If local GL is not explicitly known, and if the nearest flight plan "TO" or "FROM" waypoint is within 30 nmi (horizontal) of the estimated present position, GL may be estimated as the GL associated with the waypoint (e.g., published elevation of a Navaid or airport). If both waypoints are more than 30 nmi, but less than 100 nmi from the present position, and both have an associated GL, then local GL may be estimated as the HIGHER of the GLs associated with the "TO" or "FROM" waypoint.

Table G-2 shall be used If GL is not known and cannot be estimated using these methods. In this case, GL is assumed to be 6,000 ft MSL and the surface effects causing the largest pressure gradient error are assumed to be present between 6,000 ft and 12,000 ft MSL. If GL is below 6,000 MSL, table may result in a small to moderate overestimation of the altimeter error.

Table G-2 may always be used in lieu of Table G-1 to simplify calculations.

TABLE G-1 PRESSURE GRADIENT ERRPRS (KNOWN GL)

Indicated (Geometric) Altitude	**Pressure Gradient Error (1 σ)**
Above 18,000 ft, MSL	13 m per 1000 ft altitude change
6,000 ft AGL to 18,000 ft, MSL	23 m per 1000 ft. altitude change
Below 6000 ft, AGL	32.5 m per 1000 ft. altitude change

TABLE G-2 PRESSURE GRADIENT ERRORS (UNKNOWN GL)

Indicated (Geometric) Altitude	**Minimum Pressure Gradient Error (1σ)**
Above 18,000 ft, MSL	13 m per 1000 ft altitude change
12,000 ft MSL to 18,000 ft MSL	23 m per 1000 ft. altitude change
Below 12,000 ft MSL: First, 6,000 ft of change Remainder of change	 32.5 m per 1000 ft. altitude change 23m per 1000 ft. altitude change

For example, suppose that σ_{vc} = 200 m, d_h = 40 nmi, t = 30 min = 0.5 hr, and

altitude at the time of the last calibration = 12,000 ft, MSL

current aircraft altitude = 5,000 ft, MSL

i. If it is known or estimated that local ground level is at 2,000 ft, MSL, then:

σ_v = 23 x (12000 - 8000) / 1000 + 32.5 (8000 - 5000) / 1000

= 189.5 m, and

σ_{baro} = RSS (200, 40 x 0.5, 189.5, 0.5 x 15)

= 276.3 m.

ii. If local ground level is unknown or cannot be estimated, then:

σ_v = 32.5 x (12000 - 6000) / 1000 + 23 (6000 - 5000) / 1000

= 218 m, and

σ_{baro} = RSS (200, 40 x 0.5, 218, 0.5 x 15)

= 296.6 m

G.2.3 Actual Use of the Altitude Measurement to Augment GPS

Pressure data can only be incorporated into the position solution after calibration. The pressure altitude, properly scaled as shown above, should be used to augment GPS when the navigation and/or the necessary FDE functions cannot be provided by GPS alone. This method can be used in any of the en route, terminal, and nonprecision approach operations as long as it maintains the consistency of data between the time of calibration and the time of actual use of the data. This consistency requirement is met if pressure altitude is consistently used.

G.3 Barometric Altimeter Aiding Using Baro-corrected Pressure Altitude

This method is to use pressure altitude data corrected for the local barometric pressure setting and the difference between the WGS-84 ellipsoid altitude and mean sea level altitude at the present position. Although this method can achieve the most benefit in the non-precision approach operations, it may also be used for en route and terminal operations as long as it consistently uses the properly corrected the pressure altitude.

Note: *Consideration must be given to the pilot workload associated with baro-corrected pressure altitude. The necessity for the pilot to double-enter the local pressure setting into the barometer and the GPS/WAAS equipment should be avoided. The possible lack of integrity associated with the manual entry of the setting should also be considered.*

G.3.1 Requirements for Calibration

The correction for the pressure altitude data shall meet the following requirements:

1. This correction may be provided by automatic or manual input.
2. The pressure altitude data corrected for the local barometric pressure setting shall be corrected with the difference between the WGS-84 ellipsoid altitude and mean sea level altitude at the present position with sufficient accuracy. This requirement can be met with a table which stores the ellipsoid bounded by 10 deg of latitude and longitude.

G.3.2 Calculation of σ_{baro}

In the method of using baro-corrected pressure altitude, σ_{baro} shall be calculated as follows:

$$\sigma_{baro} = \mathrm{RSS}\,(\sigma_{ht}, \sigma_{a}, \sigma_{v})$$

where:

σ_{ht} = 33 m, representing errors due to horizontal and temporal separation between the aircraft and baro correction (See [2] for its derivation)

σ_{a} = Altimeter accuracy error = 10 m

σ_{v} = Algebraic sum of the errors obtained for each of the applicable pressure gradient regions in Table G-1, for the difference between the aircraft altitude and the altitude of the reference station

For this calculation, GL is the lower of the reference station GL or local GL. If local GL is not explicitly known, and if the nearest flight plan "TO" or "FROM" waypoint is within 30 nmi of the estimated present (horizntal) position, GL may be estimated as the GL associated with the waypoint (e.g., published elevation of a Navaid or airport). If both waypoints are more than 30 nmi, but less than 100 nmi from the present position, and both have an associated GL, then local GL may be estimated as the LOWER of the GLs associated with the "TO" or "FROM" waypoint. If either the reference station GL or an estimate of the local GL is not available or if both waypoints are not within 100 nmi from the present location, GL should be estimated as MSL. To simplify calculations, GL may always be estimated as MSL.

For example, suppose that:

altitude of the reference station= 1000 ft, MSL

= 0 ft, AGL

current aircraft altitude = 6,000 ft, MSL

Then,

$$\sigma_v = 32.5 \text{ x } (5000 - 0) / 1000$$
$$= 162.5 \text{ m}$$

and thus

$$\sigma_{baro} = \text{RSS } (162.5, 33, 10)$$
$$= 166.12 \text{ m.}$$

G.3.3 Actual Use of the Barometric Altitude Measurement to Augment GPS

When navigation and/or FDE functions cannot be provided by GPS alone, properly corrected pressure altitude data and scaled as shown above, may be used to augment GPS. This method can be used in any of the en route, terminal, and nonprecision approach operations as long as properly corrected and scaled data is used.

G.3.4 Requirements for Pilot Interaction

If the system has a capability to accept an automatic input of barometric corrected altitude data, then this method of barometric altimeter aiding may be used with no requirements for pilot interaction.

However, if the equipment is to use this method only for the nonprecision approach, and if there is no automatic barometric input capability, then the equipment shall provide the following:

Concurrent with the approach alert, a suitable means to alert the pilot of the need to manually insert the barometric pressure setting shall be provided. This alert will be followed by the pilot's insertion of the barometric pressure setting and then a pilot's input with a single action indicating to the receiver that the insertion has been made. Upon receipt of this indication, the receiver shall incorporate the altitude measurement in the navigation solution and the FDE algorithm according to the procedure outlined above. If such an insertion is not made, pressure altitude shall continue to be used with GPS calibration.

G.4 Test Procedures

It is recognized that equipment manufacturers will have different implementations of FDE algorithms and barometric aiding in these algorithms. Differences in implementation will greatly influence any test procedures. It is therefore left to the manufacturer to define tests that show compliance with the requirements listed in this appendix. However, such tests shall cover all applicable requirements and cases (e.g., when testing compliance with Table G-2, all cases in the table have to be tested — at altitudes between 0 and 6000 ft, between 6000 and 12000 ft, between 12000 and 18000 ft, and above 18000 ft).

G.5 References

1. John Studenny, "Baro-Altimeter Calibration for GPS Integrity", RTCA Paper No. 235-95/SC159-639, April, 1995.
2. John Dobyne, "Barometric Altimeter Aiding of GPS", Proceedings of the International Technical Meeting of the Satellte Division of the Institute of Navigation, September, 1989.

Appendix H

STANDARD OUTPUT FORMAT

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Appendix H—STANDARD OUTPUT FORMAT

H.1 Introduction

As GPS receivers meeting this MOPS are certified for primary means of navigation, it is anticipated that the GPS/WAAS position output will be made available for other on-board and external applications. On-board examples include: ground navigation moving map displays, cockpit displays of traffic information, and weather mapping systems. Users of GPS position which are external to the aircraft include: Traffic Alert and Collision Avoidance System (TCAS) [e.g.,RTCA/DO-185], Automatic Dependent Surveillance (ADS) [e.g., RTCA/DO-212], and Automatic Dependent Surveillance-Broadcast (ADS-B) [RTCA/SC-186]. It is important that the GPS position outputs sent to these applications convey the accuracy and integrity provided by the certified GPS receiver. This appendix therefore recommends a minimum output standard for GPS/WAAS equipment which will be able to provide reliable position data to these applications.

Particularly for external applications used to separate aircraft, it is essential that there be no ambiguity in comparing aircraft positions and velocities. For this reason, not only the aircraft position but its time of applicability must meet a common definition.

H.2 GPS Minimum Output and Output Timing

This section describes the recommended minimum output as well as output timing.

H.2.1 Minimum GPS/WAAS Output

The GPS/WAAS equipment outputs recommended here are based on the data items specified in the ADS MOPS (RTCA/DO-212) as well as the industry standards (e.g., ARINC 743A). The parameters listed in Table H-1 represent a minimum set of parameters that should be available from GPS/WAAS equipment meeting this MOPS. Clearly, additional data may be provided and provisions to request specific data at various rates may be desirable options. While the intent in not to require a specific output interface, it is recommended that industry standards (e.g., ARINC 743A, 429) be adhered to in the interest of avionics interoperability.

Table H-1 summarizes key characteristics of the twelve basic parameters that are recommended for a minimum GPS output. The first column is provided for reference to the ARINC 743A field labels used to identify each parameter as it is output on the ARINC 429 output bus. The output formats are typically two's complement binary numbers (BNR) except for the date which is in binary coded decimal (BCD). The units for each parameter are listed. The positive sense is indicated but many are magnitudes only. The range or maximum is given for each variable. The size in bytes and number of significant bits (excluding sign) are also shown. The resolution of the least significant bit is given for the number of significant bits shown, though some implementations may provide greater accuracy.

TABLE H-1 MINIMUM GPS OUTPUT

743A Label	Parameter	Fmt	Units	pos+	Range**	Sig Bits	Resolut. LSB
110, 120	GPS Latitude*	BNR	degrees	N	±180	31	8.38E-8
111, 121	GPS Longitude*	BNR	degrees	E	±180	31	8.38E-8
247	Horiz. Figure of Merit	BNR	nm	***	16	15	4.88E-4
130	Horiz. Protection Level	BNR	nm	***	16	15	4.88E-4
076	GPS Altitude	BNR	ft	up	±131,072	20	0.125
136	Vert. Figure of Merit	BNR	ft	***	32,768	15	1.0
133	Vertical Protection Level	BNR	ft	***	32,768	15	1.0
103	GPS True Track Angle	BNR	degrees	cw-N	±180	15	0.0055
112	GPS Ground Speed	BNR	knots	***	4,096	15	0.125
165	Vertical GPS Velocity	BNR	ft/min	up	±32,768	15	1.0
150,140	Time (UTC, UTC Fine)	BNR	seconds	***	86,400	31	61.035µs
260	Date	BCD	ddmmyy	***	N/A	6	1 day

*** Always Positive

** When no value is available or the value is invalid, the default will be all "ones".

* When either latitude or longitude for a position are invalid, both set to -180E.

The resolution of the least significant bit for latitude and longitude is 8.38E-8, which is less than 9.4 centimeters. This should be sufficient accuracy for even the most accurate modes of operation. The GPS altitude field gives the geodetic height above the WGS-84 ellipsoid and is not corrected for geoidal or barometric variations.

The Horizontal and Vertical Figure of Merit are the current assessment of the 95% accuracy (i.e., 2drms) of the reported position in these dimensions. The Horizontal and Vertical Protection Levels are the current assessment of the 10^{-7} integrity bound on the reported position in each dimension. It is recognized that the GPS solution may incorporate various levels of augmentation from sources such as inertial navigation, altitude aiding, clock coasting, the Wide Area Augmentation System (WAAS) or the Local Area Augmentation System (LAAS). In each case the equipment is expected to assess its accuracy (i.e., Figure of Merit) as well as its integrity (i.e., Protection Level) in both the horizontal and vertical dimensions. Reporting these parameters should, therefore, replace the need for discrete information about the equipment configuration or status. These parameters are expected to be valid at the time of the report and any delay in recognizing a change in them should be commensurate with the required integrity warning time for that mode.

The GPS True Track Angle is the bearing from true north of the velocity vector of the aircraft's GPS antenna. Likewise, the GPS Ground Speed is the speed of the GPS antenna relative to the ground. Vertical Velocity is a signed binary integer in units of feet per minute.

The time parameter is the UTC (universal coordinated time) time of day in seconds. The time of day (contained in the first 17 bits) advances to 86,399 and then starts over at zero. The remainder of the field (14 bits) allow time to be specified to a precision of 61µs. The interpretation of the time field is discussed under Section H.2.2. Finally, the date is given in three two-digit BCD fields of day, month, and year.

H.2.2 Timing

In producing an output of GPS position there are four times of interest: (a) the time the measurement is made, (b) the time the output is available to external applications, (c) the time for which the position solution is valid (i.e., User Time Epoch), and (d) the UTC Epoch (i.e., the start of a new UTC second). Figure H-1 depicts these events with the lower line representing the measurement of the satellite (SV) data by the tracking loops in the GPS receiver signal processor. Once the measurement has been made, the receiver's data processor can compute a solution including the correction for the receiver clock bias as depicted on the middle line. This solution is computed to be valid at the User Time Epoch which in general may differ from the UTC Epoch. In most GPS receivers (e.g., ARINC 743A) the receiver hardware also generates a pulse at the User Time Epoch as shown on the top line. In some receivers this time pulse is also aligned with the UTC epoch. The actual output of the GPS parameters may precede this time. It is desirable that the time between the measurement and the time of output be as small as possible so that the position can be used before the estimate gets stale.

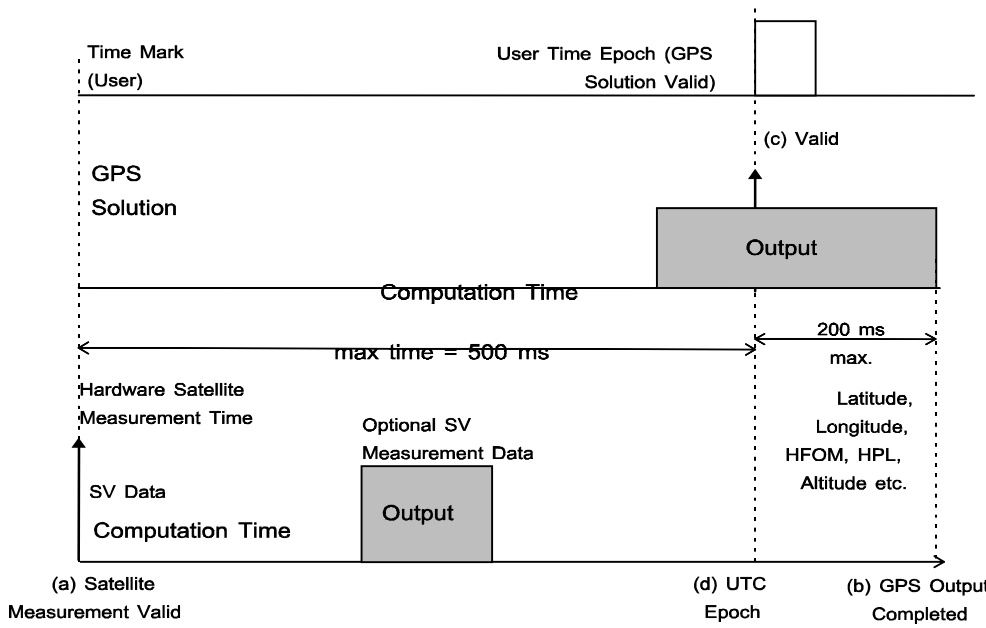

FIGURE H-1 GPS TIMING RELATIONSHIPS

In addition to the above, there is a very good reason for asking that the time of validity (User Time Epoch) be made as close to the UTC Epoch as possible. When external users such as Air Traffic surveillance or TCAS units on other aircraft want to compute the distance between aircraft, they need to compute positions at a common time such as the UTC Epoch. In order to minimize the extrapolation errors, it is desirable to have the GPS output time and valid time (User Time Epoch) as close to the UTC Epoch as possible. It is therefore recommended that the User Time Epoch be aligned with the UTC Epoch as close as possible. This will have the benefit of not only reducing the extrapolation and latency errors, but will also cause the lower order time bits to be zero. If the receiver is unable to align the User Time Epoch and the UTC Epoch then the external application would have to extrapolate the solution to the nearest UTC Epoch using the velocity data, with the attendant degradation in position accuracy.

In order to keep the total time between the SV measurement and the GPS output/ User/ UTC Time Epoch as short as possible it is desirable that the time required for the GPS output to take place be small. Typical output data rates (e.g., ARINC 429) are 100,000 bps.

Thus it takes only 5.1 ms to output fifteen ARINC 429 data words, which is not very significant compared to the total time available.

It is required that the GPS output period be once per UTC second (Section 2.1.2.6.1). Options for higher rates may be desirable, particularly for applications involving the approach phase of flight (Section 2.1.4.6.1).

H.3 Other Desirable GPS Outputs

The above basic set of parameters is a recommended minimum which will assure that the GPS set provides at least a minimal level of interoperability with other avionics applications. In addition to this basic data, some applications (e.g., inertial navigation system) may need to have access to the underlying satellite measurements (e.g., ARINC 743A). Class Gamma equipment, containing a navigator, may perform flight following functions analogous to a flight management system (FMS). In this case, data normally provided by the FMS (e.g., ARINC 702, 704, 738) may optionally be provided by the GPS set. This data may include waypoints on the planned flight path as used in the ADS Predicted Route Group (RTCA/DO-212).

H.4 Summary

This appendix recommends that basic GPS outputs be provided for use by on-board and external systems. Basic position and velocity data should be provided with a one second period aligned to the UTC Epoch. Associated accuracy and integrity assessments will allow the position data to be properly used regardless of the details of the equipment configuration or mode of operation.

Appendix I

EXAMPLE STEP DETECTOR

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Appendix I—EXAMPLE STEP DETECTOR

I.1 Step Detector

This example step detector has the following performance characteristics:

1. The step detector is able to detect and exclude a satellite that has a pseudorange step error of 700 meters or more from one measurement to the next. It is noted that the equipment should not act on smaller step errors to avoid interference with the FDE algorithm.
2. The step detector calculations precedes the FDE algorithm calculations.
3. The operation of the step detector is equivalent to the flow diagrams provided in Figures I-1 and I-2.

FIGURE I-1 STEP DETECTOR FLOW DIAGRAM FOR FAULT DETECTION AVAILABLE

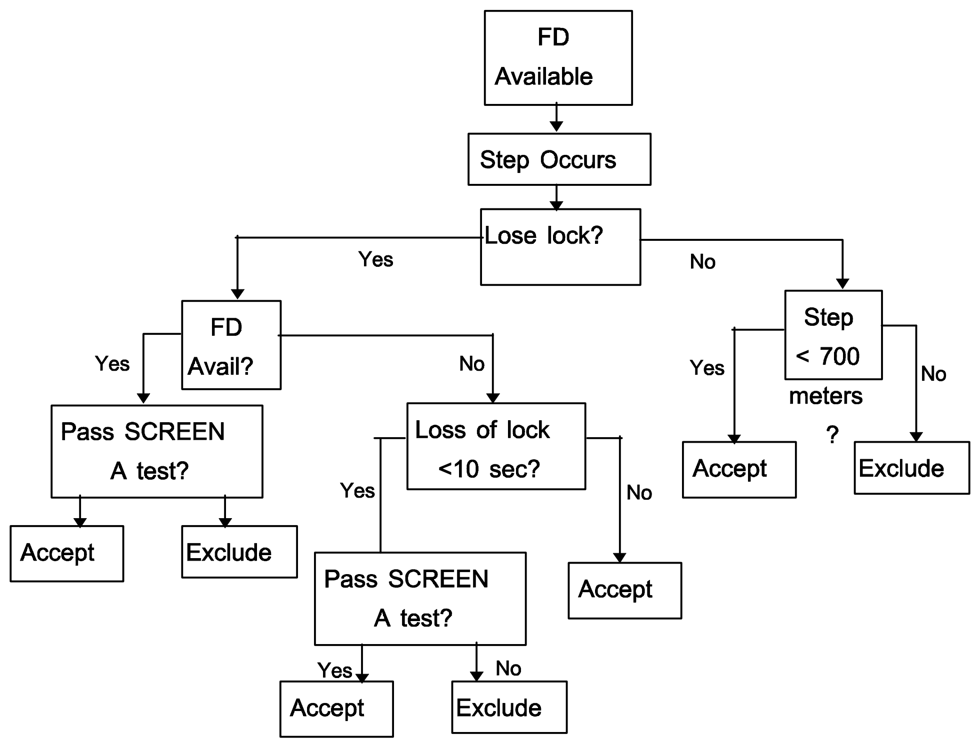
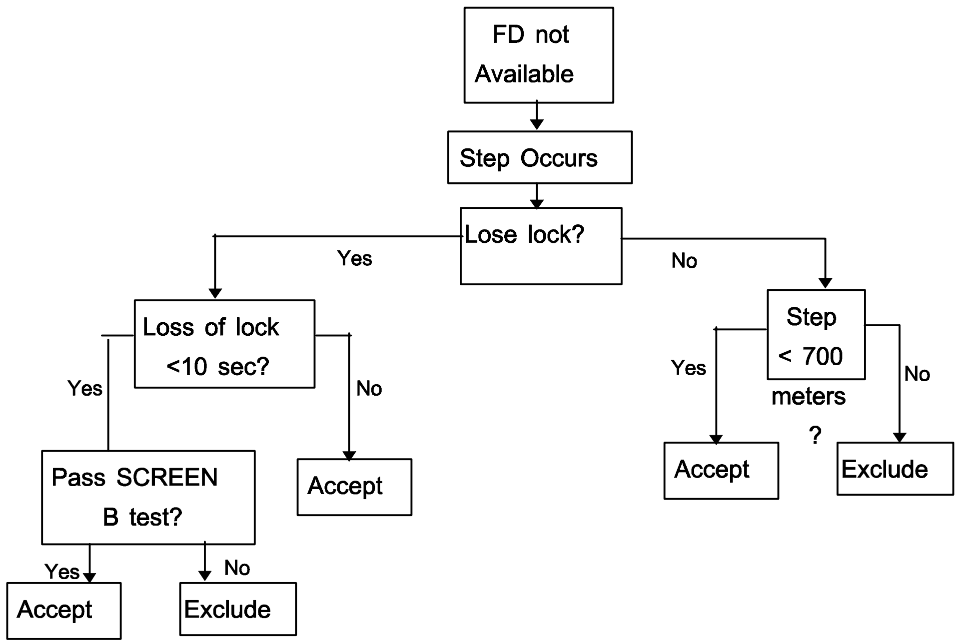


FIGURE I-2 STEP DETECTOR FLOW DIAGRAM FOR FAULT DETECTION NOT AVAILABLE



4. A screen test is performed upon satellite acquisition or re-acquisition (except in the case where the loss-of-lock time is greater than 10 seconds and fault detection is not available). The probability of accepting a satellite with a pseudorange bias of greater than 700 meters is less than 0.001 for each GDOP less than 6 (calculated without the new satellite). In the case that fault detection is not available due to lack of redundancy and loss-of-lock occurs for less than 10 seconds, the screen test in Figure 2-2 (SCREEN B) is different from the screen tests in Figure 2-1 (SCREEN A). Screen test B uses a larger threshold to account for aircraft dynamics.
5. Excluded satellites are monitored for possible future inclusion into the position solution. However, after a satellite has been excluded without loss-of-lock, it remains excluded until positive integrity is available through autonomous fault detection.

Fault detection is considered available if there is measurement redundancy and if the HPL is less than 16 nmi. Following a step error which causes loss-of-lock, the receiver is expected to re-acquire and provide measurements within 10 seconds. Therefore, the screen test is not performed if the loss-of-lock time in the absence of fault detection is greater than 10 seconds, because this would indicate a loss-of-lock due to other conditions such as signal shielding. Loss-of-lock due to aircraft maneuvers is considered more likely than due to the occurrence of a step error.

An example implementation of the screen test follows. Calculate the pseudorange measurement innovation of the new satellite by subtracting the predicted pseudorange from the measured pseudorange. The predicted pseudorange is based on the satellites that are already in the position solution-. The noise on the measurement innovation is the root-sum-square combination of the ranging noise and the noise on the predicted pseudorange

$$\textit{innovation standard deviation} = \sigma_{GDOP} = \sqrt{\sigma^2 + (\sigma GDOP)^2} = \sigma\sqrt{1 + GDOP^2}$$

The standard deviation of noise(σ) is assumed to be 33.3 meters.

To obtain a probability of less than 0.001 of accepting a satellite with a pseudorange bias of greater than 700 meters, the screen threshold is set as follows:

$$\text{screen threshold} = 700 - \sigma_{GDOP}\sqrt{2}\,\text{erfc}^{-1}(2\,P_{MD}) = 73.8 \text{ m}$$

$$\text{where: } \sigma_{GDOP} = 33.3\sqrt{1+6^2} \text{ m}$$

A special case of the screen test occurs if fault detection is not available due to lack of redundancy and loss-of-lock occurs for less than 10 seconds (SCREEN B in Figure I-2). In this case, the threshold for the measurement innovation accounts for aircraft dynamics. The screen threshold is now calculated using a constant altitude assumption allowing for up to 2 g of aircraft acceleration in the horizontal plane. The screen threshold is increased by $0.5 * a * t^2 = 0.5 * 20 * 6^2 = 360$ meters. Thus, the screen threshold for this case is 360 + 73.8 = 433.8 meters.

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Appendix J

WAAS-BASED PROTECTION LEVELS FOR EN ROUTE THROUGH PRECISION APPROACH MODE

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Appendix J—WAAS-BASED PROTECTION LEVELS FOR EN ROUTE THROUGH PRECISION APPROACH MODE

J.1 WAAS Protection Level Equations — General Least Squares Solutions

The equipment shall use the following equations for computing the protection levels. The parameters in these equations shall be used as defined in Section J.2.

$$HPL_{WAAS} = \begin{cases} K_{H,NPA} \cdot d_{major} & \text{for en route through NPA modes} \\ K_{H,PA} \cdot d_{major} & \text{for precision approach mode} \end{cases}$$

$$VPL_{WAAS} = K_{V,PA} d_U$$

where:

$$d_{major} \equiv \sqrt{\frac{d_{east}^2 + d_{north}^2}{2} + \sqrt{\left(\frac{d_{east}^2 - d_{north}^2}{2}\right)^2 + d_{EN}^2}}$$

$d_{east}^2 = \sum_{i=1}^{N} s_{east,i}^2 \sigma_i^2$ = variance of model distribution that overbounds the true error distribution in the east axis.

$d_{north}^2 = \sum_{i=1}^{N} s_{north,i}^2 \sigma_i^2$ = variance of model distribution that overbounds the true error distribution in the north axis.

$d_{EN} = \sum_{i=1}^{N} s_{east,i} s_{north,i} \sigma_i^2$ = covariance of model distribution in the east and north axis.

$d_U^2 = \sum_{i=1}^{N} s_{U,i}^2 \sigma_i^2$ = variance of model distribution that overbounds the true error distribution in the vertical axis.

s_{east} = the partial derivative of position error in the east direction with respect to the pseudorange error on the i^{th} satellite

s_{north} = the partial derivative of position error in the north direction with respect to the pseudorange error on the i^{th} satellite

s_U = the partial derivative of position error in the vertical direction with respect to the pseudorange error on the i^{th} satellite

$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,UIRE}^2 + \sigma_{i,air}^2 + \sigma_{i,tropo}^2$$

Note 1: *dmajor corresponds to the error uncertainty along the semimajor axis of the error ellipse.*

For a general least squares position solution, the projection matrix **S** is defined as:

$$\mathbf{S} = \begin{bmatrix} s_{east,1} & s_{east,2} & \cdots & s_{east,N} \\ s_{north,1} & s_{north,2} & \cdots & s_{north,N} \\ s_{U,1} & s_{U,2} & \cdots & s_{U,N} \\ s_{t,1} & s_{t,2} & \cdots & s_{t,N} \end{bmatrix} = \left(\mathbf{G}^{\mathbf{T}} \cdot \mathbf{W} \cdot \mathbf{G}\right)^{-1} \cdot \mathbf{G}^{\mathbf{T}} \cdot \mathbf{W}$$

where

the i[th] row of the geometry matrix **G** is defined as follows:

$$\mathbf{G_i} = \begin{bmatrix} \cos El_i \cos Az_i & \cos El_i \sin Az_i & \sin El_i & 1 \end{bmatrix} = i^{th} \text{ row of } \mathbf{G}$$

when positive azimuth is defined clockwise from North.

$$\mathbf{W}^{-1} = \begin{bmatrix} \sigma_1^2 & 0 & \cdots & 0 \\ 0 & \sigma_2^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_N^2 \end{bmatrix}$$

For precision approach mode,

$$w_i = \sigma_i^2$$

Note 2: *For modes other than precision approach, the weights are undefined. For an unweighted least-squares solution, the weighting matrix is a unity diagonal matrix ($w_i = 1$).*

Note 3: *When the weights are equal to σ_i^2, the matrix*

$$\begin{bmatrix} d_{east}^2 & d_{EN} & d_{EU} & d_{ET} \\ d_{EN} & d_{north}^2 & d_{NU} & d_{NT} \\ d_{EU} & d_{NU} & d_U^2 & d_{UT} \\ d_{ET} & d_{NT} & d_{UT} & d_T^2 \end{bmatrix} = \left(\mathbf{G}^T \mathbf{W} \mathbf{G}\right)^{-1}$$

.

J.2 HPL_{WAAS} Parameters

J.2.1 K

The value of K_H for computing HPL is:

$$K_H = \begin{cases} 6.18 & \text{for en route through NPA modes} \\ 6.0 & \text{for precision approach mode} \end{cases}$$

The value of K_V for computing VPL is:

$K_V = 5.33$

J.2.2 Variance of Fast and Long Term Correction Residuals

When long term, fast and range rate corrections are applied to a satellite and the degradation model is used (type 7 and 10 message data):

$\sigma_{i,flt}^2$ is the model variance for the residual error as defined in Appendix A, Section A.4.5.1.

When long term, fast and range-rate corrections are applied to a satellite and the degradation model is not used or an active type 7 or 10 message data is not available:

$$\sigma_{i,flt}^2 = \left[\left(\sigma_{i,UDRE}\right) \cdot \left(\delta UDRE\right) + 8m\right]^2$$

Note 1: *δ_{UDRE} is included if Type 27 or Type 28 messages are received, otherwise $\delta UDRE$ is equal to 1.*

When long term, fast, or range-rate corrections are not applied to a satellite, or if an ephemeris covariance type 28 message has not been received for the satellite but an active type 28 message has been received for a different satellite:

$$\sigma^2_{i,flt} = (60)^2 \text{ m}^2$$

Note 2: *All equipment is required to apply long-term and fast corrections when they are available. However, future systems may support an integrity-only mode where Type 6 messages are broadcast to provide integrity monitoring without corrections.*

Note 3: *The $\sigma^2_{i,flt} = (60)^2 \text{ m}^2$ does not override an active "Don't Use" or a "Not Monitored". A "Not Monitored" can result from a UDREI = 14 or when all UDREI data times out.*

J.2.3 Variance of Ionospheric Delay

When WAAS-based ionospheric corrections are applied:

$\sigma^2_{i,UIRE}$ is the model variance for the slant range ionospheric error, as defined in Section A.4.4.10 and A.4.5.2.

When GPS-based ionospheric corrections are applied:

$$\sigma^2_{i,UIRE} = MAX\left\{\left(\frac{cT_{iono}}{5}\right)^2, \left(F_{pp} \cdot \tau_{vert}\right)^2\right\}$$

c = the speed of light in a vacuum

T_{iono} = ionospheric correction (see Section 20.3.3.5.2.6 of ICD-GPS-200, "Navstar GPS Space Segment / Navigation User Interfaces")

F_{pp} = obliquity factor (Section A.4.4.10.4)

$$\tau_{vert} = \begin{cases} 9\ m, & 0 \le |\phi_m| \le 20 \\ 4.5\ m, & 20 < |\phi_m| \le 55 \\ 6\ m, & 55 < |\phi_m| \end{cases}$$

ϕ_m is the magnetic latitude as defined in Section 20.3.3.5.2.6 of ICD-GPS-200, "Navstar GPS Space Segment / Navigation User Interfaces".

Notes:

1. *User equipment must convert ϕ_m from semicircles to degrees. One semicircle is defined as 180 degrees or π radians.*
2. *The GPS-based ionospheric correction model may only be used for en route, terminal, and nonprecision approach operations. It has not been validated with the rigor that is required for any type of approach procedure with vertical guidance.*

J.2.4 Variance of Airborne Receiver Errors

The parameter, $\sigma_{i,air}$, shall be as follows:

For Class 1 equipment:

$$\sigma^2_{i,air} = 25m^2$$

For Class 2, 3 and 4 equipment:

$$\sigma_{air}[i] = \left(\sigma^2_{noise}[i] + \sigma^2_{multipath}[i] + \sigma^2_{divg}[i]\right)^{1/2}$$

The installed multipath error for the airborne equipment is described by the distribution, $N(0,\sigma^2_{multipath})$ where:

$$\sigma_{multipath}[i] = 0.13 + 0.53e^{(-\theta[i]/10\,\mathrm{deg})} \qquad \text{(in meters)}$$

$\theta[i]$ = elevation angle of satellite (in degrees)

$\sigma_{divg}[i]$ (in meters) shall be greater than or equal to the differentially-corrected pseudorange error induced by the steady-state effects of the airborne smoothing filter relative to the steady-state response of the filter defined in Section 2.1.4.1.1, given an ionospheric divergence that is defined to have a constant rate of 0.018 m/s.

Note 1: *If the airborne smoothing filter converges to a different steady-state bias than the standard filter, a steady-state error will remain which must be accounted for in σ_{divg}. When the smoothing filter is initialized or re-initialized the difference between the steady-state response of the standard filter and the initial response of the filter does not need to be included due to the nature in which WAAS corrections are generated.*

$\sigma_{noise}[i]$ (in meters) shall be the standard deviation of a normal distribution that bounds the errors in the tails of the distribution associated with the GNSS receiver for satellite i, including receiver noise, thermal noise, interference, inter-channel biases, extrapolation, time since smoothing filter initialization, and processing errors.

The parameter σ_{noise} must change to reflect current signal conditions. For example, degradation to system accuracy due to interference must be accounted for in the value of RMS_{pr_air} (defined in sections 2.1.4.1.3.1 and 2.1.4.1.3.2) that is used in the protection level computations, within the time to alert.

Note 2: *The test procedures of Section 2.5.8.1 are sufficient to show compliance with the both the accuracy requirement in Section 2.1.4.1 and the σ_{noise} requirement for integrity. The σ_{noise} validated through those tests can be used as the standard deviation of a normal distribution that bounds the tails of the error distribution associated with the receiver tracking performance.*

The steady-state value of $\left(\sigma^2_{noise}[i] + \sigma^2_{divg}[i]\right)^{1/2}$ at the minimum and maximum signal levels (Section 2.1.4.1.3) shall be as follows:

GPS Satellites Minimum signal level:

a. $\left(\sigma^2_{noise}[i] + \sigma^2_{divg}[i]\right)^{1/2} \le 0.36$ meters for Airborne Accuracy Designator A, and

b. $\left(\sigma^2_{noise}[i] + \sigma^2_{divg}[i]\right)^{1/2} \le 0.15$ meters for Airborne Accuracy Designator B

GPS Satellites, Maximum signal level:

a. $\left(\sigma^2_{noise}[i] + \sigma^2_{divg}[i]\right)^{1/2} \le 0.15$ meters for Airborne Accuracy Designator A, and

b. $\left(\sigma^2_{noise}[i] + \sigma^2_{divg}[i]\right)^{1/2} \le 0.11$ meters for Airborne Accuracy Designator B

SBAS Satellites, Minimum signal level:

$$\left(\sigma^2_{noise}[i]+\sigma^2_{divg}[i]\right)^{1/2} \leq 1.8$$

SBAS Satellites, Maximum signal level:

$$\left(\sigma^2_{noise}[i]+\sigma^2_{divg}[i]\right)^{1/2} \leq 1.0$$

Note 3: *These inequalities are consistent with the accuracy requirement defined in Section 2.1.4.1.*

J.2.5 Variance of Tropospheric Errors

For equipment which applies the tropospheric model described in Section A.4.2.4,

$\sigma_{i,tropo}$ = as defined in Section A.4.2.4.

For equipment which does not apply the tropospheric model described in Section A.4.2.4, the equipment shall include a model of the residual error that overbounds the rare tropospheric delays.

J.3 Rationale for HPL and VPL Parameters

This section provides a brief rationale for why the values described in Section J.2 were selected.

J.3.1 Selection of K Values

For en route through nonprecision approach modes, the value of K_H was chosen to bound the user's position in two dimensions with a probability of $5x10^{-9}$ per independent sample, assuming that the error is characterized by a Rayleigh distribution. A Rayleigh distribution is used because radial error needs to be bounded (both cross-track and along-track errors), using the worst case assumption that the semi-major and semi-minor axes are equal. It has been assumed that there are 10 independent samples per hour, and that half of the total integrity requirement (10^{-7}/hour) has been allocated to the HPL bounding probability.

For precision approach mode, the values of K_H and K_V were selected to bound the user's position in one dimension with a probability of $2x10^{-9}$ and 10^{-7}, respectively, assuming that the error is characterized by a Normal distribution. A Normal distribution is used because the aircraft needs to be protected in the vertical and the lateral axes. Only one dimension is used for the HPL, since the along-track tolerance is so much larger than the cross-track. The worst-case dimension is used. It has been assumed that there is only one independent sample per approach, half of the total integrity requirement ($2x10^{-7}$/approach) has been allocated to the VPL bounding probability, and the HPL bounding probability has been made negligible.

J.3.2 Rationale for Fast and Long-Term Residuals

When applying fast and long-term corrections, the parameter to be used is determined from the broadcast information. If the degradation parameters from Type 10 message are not applied, a conservative bound of 8 m (σ) is used. If no corrections are applied, a conservative estimate of the value of the corrections has been chosen based upon the maximum correction values. The maximum magnitude of the fast correction is 255 m, clock correction is 25 m (calculated over the time-out period of 360 seconds), root-sum-square long-term ephemeris corrections is 222 m (rotated to line-of-sight), long-term clock is 143 m (for a velocity code of 1). Since these quantities are independent, a reasonable maximum can be calculated by the rss of these terms, which is 368 m. Dividing by the en route through NPA K values yields approximately 60 meters for $\sigma_{i.flt}$.

J.3.3 Rationale for Ionospheric Delay Residuals

The ionospheric delay residual is derived from broadcast data when ionospheric corrections are applied. Otherwise, a conservative bound for the vertical delay is used depending on the pierce point latitude. To account for the possibility that erroneous values are broadcast by GPS in the navigation message, a scaled version of the GPS-based ionospheric correction is also used.

J.3.4 Rationale for Receiver Residuals

These values are consistent with the requirements and tests in Section 2.

J.3.5 Rationale for Tropospheric Residuals

The tropospheric delay residual has been based on an assessment of tropospheric errors.

Appendix K

FAULT DETECTION AND EXCLUSION REFERENCES

Appendix K—FAULT DETECTION AND EXCLUSION REFERENCES

The following references provide additional information concerning fault detection and exclusion.

1. Brown, G., RTCA Paper No. 491-94/SC-159-584, November 7, 1994.
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7. Parkinson, B., Axelrad, P., "Autonomous GPS Integrity Monitoring Using the Pseudorange Residual", ION, Vol. 35, No. 2, Summer, 1988.
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9. Van Dyke, K., et al, Summary of RTCA SC-159 GPS Integrity Working Group Activities, Proceedings of ION Technical Meeting, January, 1996.

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Appendix L

THE DIRECT AND INDIRECT GEODETIC PROBLEMS FOR GREAT CIRCLE NAVIGATION

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Appendix L—THE DIRECT AND INDIRECT GEODETIC PROBLEMS FOR GREAT CIRCLE NAVIGATION

L.1 General

One of the most important considerations as the NAS evolves from a station-referenced navigation system to an earth-referenced navigation system is the earth model (datum) used for Aviation Information Publications (AIPs) and air navigation systems. This appendix describes the geometry of the WGS-84 ellipsoid, and defines the geodetic latitude and longitude of a point on that ellipsoid. An example algorithm is then given for solving the following, which is called the inverse problem of geodesy:

Given the geodetic latitude and longitude of two points on the WGS-84 ellipsoid, find the range and bearing of the shortest path between them.

This path is called a geodesic.

A related problem is the direct problem of geodesy:

Given the departure geodetic latitude and longitude, the geodesic path length, and the departure bearing on the WGS-84 ellipsoid, find the arrival latitude, longitude and bearing.

The corresponding problem on the surface of a sphere has the following well-known and elementary solution. Suppose that one is given a pair of distinct, nonantipodal points on the surface of a sphere. (Recall that two (distinct) points on the surface of an ellipsoid are said to be antipodal if they are located symmetrically with respect to the center of the ellipsoid). Then these two points, together with the center of the sphere, determine a plane. This plane intersects the surface of the sphere in two circular arcs which together form a circle called a great circle. The shorter of these two circular arcs is the shortest path on the surface of the sphere which joins the prescribed points.

For two antipodal points on the surface of a sphere, there are infinitely many planes which contain both of those points and which also contain, the center of the sphere. Any of the circular arcs determined by the intersection of one of these planes with the surface of the sphere will be a geodesic. Hence, the problem does not have a unique solution in this case.

On a nonspherical, ellipsoid, the situation is considerably different. (It is therefore inappropriate to refer to geodesics on a nonspherical ellipsoid as "great circles"). In particular, the only geodesics which are plane curves are those which lie along a meridian or along the equator [1]. Furthermore, the geodesic can in general be computed to an arbitrary level of accuracy only iteratively. The iterative algorithms presented here were published in [2], and will yield accuracy to within fractions of a millimeter if the termination criterion ε is taken to be 10^{-12} (unless the two points are antipodal, or nearly antipodal. The geodesic is nonunique or highly sensitive to small changes in the problem data, respectively, in that case). This accuracy is generally obtained in no more than six iterations. Compared to "closed-form" approximate solutions, such as that in [3], the algorithm presented here is simpler to implement in software. Further discussion of various algorithms may be found in [4].

L.2 Definitions of Terms

Throughout this appendix, the term ellipsoid will specifically refer to an ellipsoid of revolution, obtained by rotating an ellipse about its minor axis. The points at which the minor axis intersects the surface of the ellipsoid are called the North and South poles. The plane which passes through the center of the ellipsoid and which is normal to the minor axis is called the equatorial plane. The equatorial plane intersects the surface of the ellipsoid in a circle, called the equator.

The geodetic latitude of a point on an ellipsoid is the angle between the equatorial plane and the outward normal vector at that point on the ellipsoid. This angle is taken to be positive in the Northern Hemisphere and negative in the Southern Hemisphere.

Any plane which is orthogonal to the equatorial plane and which passes through the center of the ellipsoid intersects the surface of the ellipsoid in an ellipse, called a meridian. One of these meridians is arbitrarily selected as a reference, and is called the Greenwich meridian. The longitude of a point on the ellipsoid is determined by the angle between the plane that contains the meridian passing through that point, and the plane which contains the Greenwich meridian. (The longitude of either pole is undefined). Longitude is customarily expressed in degrees, measured Eastward from the Greenwich meridian.

A curve that is traversed in a specified direction is said to be oriented. The bearing of an oriented smooth curve on an ellipsoid describes the direction of the tangent vector to that curve, at a particular point on that curve. Bearing is usually expressed in degrees, measured clockwise from local North. (Local (true) North at a point on an ellipsoid is defined as the direction of the tangent vector to the meridian at that point, where the meridian is oriented toward the North Pole. Note that local North is undefined at either pole, so this description of bearing does not apply there).

L.3 Nomenclature

B_1 = Geodetic latitude of departure point, in degrees.

L_1 = Longitude of departure point, in degrees.

B_2 = Geodetic latitude of arrival point, in degrees.

L_2 = Longitude of arrival point, in degrees.

α_1 = Bearing of the geodesic, at the departure point, in radians

α_2 = Bearing of the geodesic, at the arrival point, in radians

s = Range (arclength along the geodesic) from departure point to arrival point, in meters.

L.4 WGS-84 Parameters (from [5])

a = 6378137 m (WGS-84 semimajor axis)

b = 6356752.3142 m (WGS-84 semiminor axis)

e^2 = $6.694379991013 \times 10^{-3}$ (square of WGS-84 first eccentricity)

= $(a^2 - b^2)/a^2$

$(e')^2$ = $6.73949674227 \times 10^{-3}$ (square of WGS-84 second eccentricity)

= $(a^2 - b^2)/b^2$

f = $3.35281066474 \times 10^{-3}$ (WGS-84 flattening)

= $(a - b)/a$

L.5 The Indirect Problem

The inputs are:

B_1 = Departure geodetic latitude in degrees

L_1 = Departure geodetic longitude in degrees

B_2 = Arrival geodetic latitude in degrees

L_2 = Arrival geodetic longitude in degrees

(B_1, L_1) and (B_2, L_2) are with respect to the WGS-84 ellipsoid.

The outputs are:

s = Geodesic path length on the WGS-84 ellipsoid

α_1 = Departure bearing at (B_1, L_1) in radians

α_2 = Arrival bearing at (B_2, L_2) in radians

The algorithm is specified as follows:

1. Convert geodetic latitude from degrees to radians.

   $\Phi_1 = \pi B_1/180$

   $\Phi_2 = \pi B_2/180$

2. Compute the difference in longitude, in radians.

   $\Delta L = (\pi/180)(L_2 - L_1)$

3. Compute the "reduced latitudes", in radians.

   $\beta_1 = \tan^{-1}[(1 - f)\tan(\Phi_1)]$

   $\beta_2 = \tan^{-1}[(1 - f)\tan(\Phi_2)]$

4. Initialize the iteration.

   $\lambda_k = \Delta L$

5. Perform the following iteration, until

   $|\lambda_{k+1} - \lambda_k| < \varepsilon$,

   where ε is the termination criterion:

$$\sin\sigma = \sqrt{(\cos\beta_2\sin\lambda_k)^2 + (\cos\beta_1\sin\beta_2 - \sin\beta_1\cos\beta_2\cos\lambda_k)^2} \quad ,0$$

$$\cos\sigma = \sin\beta_1\sin\beta_2 + \cos\beta_1\cos\beta_2\cos\lambda_k,$$

$$\sigma = \operatorname{atan2}(\sin\sigma, \cos\sigma),$$

$$\sin\alpha_c = \frac{\cos\beta_1\cos\beta_2\sin\lambda_k}{\sin\sigma} \quad ,0$$

$$\cos^2\alpha_e = 1 - \sin^2\alpha_e,$$

$$\cos 2\sigma_m = \begin{cases} \cos\sigma - \dfrac{2\sin\beta_1\beta_2}{\cos^2\alpha_e}, & if\ \cos^2\alpha_e \neq 0; \\ 0, & otherwise \end{cases} \quad 0$$

$$C = (f/16)\cos^2\alpha_e[4 + f(4 - 3\cos^2\alpha_e)],$$

$$\lambda_{k+1} = \Delta L + (1 - C)\, f \sin\alpha_e \{ \sigma + C \sin \sigma [\cos 2\sigma_m + C \cos\sigma (-1 + 2 \cos^2 2\sigma_m)] \}$$

where the function atan2 has following definition, as in FORTRAN:

$$atan2(Y, X) = \begin{cases} \tan^{-1}(Y / X), & if\ X > 0; \\ \tan^{-1}(Y / X) + \pi, & if\ X < 0; \\ \pi / 2, & if\ X = 0 \wedge Y > 0; \\ -\pi / 2, & if\ X = 0 \wedge Y < 0. \end{cases}$$

6. The range s, and the bearings α_1 and α_2 at the departure point and arrival point, respectively, may now be computed as follows:

$u^2 = (e')^2 \cos^2\alpha,$

$A = 1 + (u^2/16384) \{4096 + u^2 [- 768 + u^2 (320 - 175 u^2)]\},$

$B = (u^2/1024) \{256 + u^2 [-128 + u^2 (74 - 47 u^2)]\},$

$\Delta\sigma = B \sin s \{\cos 2s_m + (1/4) B [(-1 + 2 \cos^2 2\sigma_m) \cos \sigma - (1/6) B (-3 + 4 \sin^2 \sigma) (-3 + 4 \cos^2 2\sigma_m) \cos 2\sigma_m]\},$

$s = bA (\sigma - \Delta\sigma),$

$\alpha_1 = (180/\pi)\, atan\, 2(\cos\beta_2 \sin\lambda_{k+1}, \cos\beta_1 \sin\beta_2 - \sin\beta_1 \cos\beta_2 \cos\lambda_{k+1}),$

$\alpha_2 = (180/\pi)\, atan\, 2(\cos\beta_1 \sin\lambda_{k+1}, -\sin\beta_1 \cos\beta_2 + \cos\beta_1 \sin\beta_2 \cos\lambda_{k+1}),$

Note that α_2 is the bearing at the destination point, of the arriving geodesic which originated at the departure point. The so-called back azimuth, or initial bearing of the geodesic that departs from the arrival point and returns to the departure point, is

$\alpha_2 \pm \pi$

L.6 The Direct Problem

The inputs are:

B_1	Departure geodetic latitude in degrees
L_1	Departure geodetic longitude in degrees
s	Geodesic path length
α_1	Departure bearing at (B_1, L_1) in radians

The outputs are:

B_2	Arrival geodetic latitude in degrees
L_2	Arrival geodetic longitude in degrees
α_2	Arrival bearing at (B_2, L_2)

The algorithm is specified as follows:

1. Convert geodetic latitude and longitude to radians

$\Phi_1 = \pi B_1/180$

$\lambda_1 = \pi L_1/180$positive east, negative west

2. Compute the reduced latitude

$\beta_1 = atan [(1 - f) \tan (\Phi_1)]$ ... 2 quadrant arctan

3. Compute equatorial geodesic angular distance and azimuth

$\tan \sigma_e = \tan\beta_1 / \cos\alpha_1$

$\sin \alpha_e = \cos\beta_1 \sin\alpha_1$

$\cos^2\alpha_e = 1 - \sin^2\alpha_e$

4. Initialize the iteration

$u^2 = (e')^2 \cos^2 \alpha_e$

$A = 1 + (u^2/16384) \{4096 + u^2 [- 768 + u^2 (320 - 175 u^2)]\},$

$B = (u^2/1024) \{256 + u^2 [-128 + u^2 (74 - 47 u^2)]\},$

$\sigma_i = s/bA$

5. Perform the following iteration, until

$| \sigma_{i+1} - \sigma_i | \le \varepsilon$

where ε is the termination criterion:

$2\sigma_m = 2\sigma_e + \sigma_i$

$\Delta\sigma = B \{\cos 2\sigma_m + 1/4 B [(-1 + 2 \cos^2 2\sigma_m) \cos \sigma_i - 1/6 B (-3 + 4 \sin 2\sigma_i) (-3 + 4 \cos^2 2\sigma_m) \cos 2\sigma_m]\} \sin\sigma_i$

$\sigma_{i+1} = s/bA + \Delta\sigma$

6. Compute arrival point and arrival azimuth

$\sigma = \sigma_{i+1}$

$Y = \sin\beta_1 \cos\sigma + \cos\beta_1 \sin\sigma \cos \alpha_1$

$X = (1- f) [\sin^2 \alpha_e + (\sin\beta_1 \sin\sigma - \cos\beta_1 \cos\sigma \cos\alpha_1)^2]^{1/2}$

$\Phi_2 = \text{atan } (Y/X)$... 2 quadrant arctan

$Y = \sin \sigma \sin \alpha_1$

$X = \cos\beta_1 \cos\sigma - \sin\beta_1 \sin\sigma \cos\alpha_1$

$Z = \text{atan2 } (Y, X)$.... 4 quadrant arctan

Z is positive east

$C = f/16 [4 + f(4 - 3\cos^2\alpha_e)]\cos^2\alpha_e$

$\lambda_2 = \lambda_1 + Z - (1 - C) f\{ \sigma + C [\cos 2\sigma_m + C (-1 + 2\cos^2 2\sigma_m) \cos\sigma] \sin\sigma\} \sin\alpha_e$

$Y = \sin \alpha_e$

$X = - \sin\beta_1 \sin\sigma + \cos\beta_1 \cos\sigma \cos \alpha_1$

$\alpha_2 = \text{atan2 } (Y, X)$ ... 4 quadrant arctan

Note that α_2 is the bearing at the arrival point, of the arriving geodesic which originated at the departure point. The so called back azimuth, or initial bearing of the geodesic which departs from the arrival point and returns to the departure point, is

$\alpha_2 \pm \pi$

L.7 Validation

The Indirect Problem algorithm described above was tested by computing the range and bearing of the geodesics between all ordered pairs of distinct locations listed in RTCA DO-208 MOPS Section 2.5.2.5.2.1 above. The value of the termination criterion ε used was 10^{-12}. The maximum number of iterations required in any of these 552 cases was 8, with a mean of 4.92 and a median of 5.

Geodesic curves on an ellipsoid may be computed by solving the following system of nonlinear ordinary differential equations, where the unknown quantities are the geodetic latitude B, longitude L, and bearing α, at each point on the geodesic, and where the independent variable t is arclength along the geodesic divided by a:

$$dB/dt = [(1 - e^2 \sin^2 B)^{3/2} \cos\alpha] (1-e^2)$$

$$dL/dt = [(1 - e^2 \sin^2 B)^{1/2} \sin\alpha] \cos B$$

$$d\alpha/dt = (1 - e^2 \sin^2 B)^{1/2} \sin \alpha \tan B$$

(For a derivation of these equations, see pp. 80-83 of [2]).

For each departure point, range, and bearing (at the departure point), the actual terminal point of the corresponding geodesic curve was computed by numerically integrating these equations, using the Runge-Kutta-Fehlberg algorithm of order (4, 5), and a local truncation error tolerance of 10^{-14}. The distance between the actual terminal point and the desired arrival point was then computed. In every case, this distance was less than two-tenths of one millimeter.

For the convenience of anyone wishing to implement the above algorithm in software, seven test cases are supplied here. (These test cases are suggested in [4]). Table L-1 below lists the geodetic latitude of the departure points, and the geodetic latitude and longitude of the arrival points. (The departure points are all on the Greenwich meridian).

TABLE L-1 TEST CASE INPUT

Case	Departure Latitude	Arrival Latitude	Arrival Longitude
1	37.331931575000	26.128566516667	41.476529802778
2	35.269791283333	67.370771216667	137.791198430556
3	1.000000000000	-0.998286322222	179.296674991667
4	1.000000000000	1.020885977778	179.771622900000
5	41.696077777778	41.696166666667	0.000155555556
6	30.000000000000	37.892351622222	116.321302341667
7	37.000000000000	28.260193152778	-2.627646994444

The results for each of these cases are shown in Table L-2 below. (The value of the termination criterion ε used was again 10^{-12}).

TABLE L-2 TEST CASE OUTPUT

Case	Departure Bearing α_1	Arrival Bearing α_2	Ranges
1	95.4669065012712	118.100037749533	4,085,797.71045745
2	15.7398635998781	144.927624307827	8,084,459.01281178
3	89.0255041313847	90.9762395789926	19,959,214.6261821
4	5.0047450389878	174.995222917504	19,779,362.8384626
5	52.6771685463032	52.6772720198999	16.2833273117916
6	45.0000844826718	129.136526168938	10,002,067.6833720
7	-165.000275690672	-166.421458799296	999,975.508415485

Table L-3 below shows the required number of iterations, and the error (distance between the desired arrival and the actual terminal point), for each test case.

TABLE L-3 NUMBER OF ITERATIONS

Case	Number of Iterations	Error	Significant Decimals α_1	α_2	s
1	5	$1.38189930304136 \times 10^{-5}$	10	10	5
2	4	$5.62351088062680 \times 10^{-5}$	7	9	4
3	5	$1.42575492953545 \times 10^{-4}$	6	5	4
4	18	$1.41770874909204 \times 10^{-4}$	8	7	4
5	3	$6.87589522482552 \times 10^{-8}$	7	6	7
6	4	$4.84762978049413 \times 10^{-5}$	9	9	4
7	5	$7.19785012259682 \times 10^{-6}$	9	9	5

Note that the data shown in Table L-2 are the literal output obtained by running the algorithm on a particular platform, and that not all of the digits shown are significant. The last three columns of Table L-3 give the number of digits to the right of the decimal point which are considered to be significant, for each of the data shown in Table L-2. These were obtained by rounding, in turn, the departure bearing, arrival bearing, and range for each case, to different levels of precision, and computing the actual terminal point of the corresponding geodesic. For the arrival bearing, the departure point and arrival point were exchanged, and the departure bearing was replaced by the arrival bearing minus 180°). The number of decimals considered to be significant was determined by the minimum level of precision which resulted in the error between the actual terminal point and the desired arrival point being within fifty percent of the value shown in Table L-3.

The Direct Problem algorithm was validated with above data as well, with nearly identical results.

As a final validation, it is recommended that random pairs of (B_1, L_1) and (B_2, L_2) be generated. These pairs may then be fed into the Indirect Problem algorithm to produce α_1, α_2 and s. Then, (B_1, L_1), α_1 and s may be fed into the Direct Problem algorithm to obtain (B_2, L_2) and α_2. The differences (B_2 - B_1), (L_2 - L_1), (α_2- α_1) should small, < 10^{-10}. This is the closed form validity check.

L.8 References

1. Frederick Pearson II, Map projections: theory and applications. CRC Press, Boca Raton-Ann Arbor - London - Tokyo, 1990.
2. T. Vicenty, "Direct and inverse solution of geodesics on the ellipsoid with application of nested equations", Survey Review, No. 176 (1975), pp. 88-93.
3. E.M. Sodano, "General non-iterative solution of the inverse and direct geodetic problems", Bulletin Géódésique, No. 75 (1965), pp. 69-89.
4. R.H. Rapp, Geometric Geodesy: Part II. Department of Geodetic Science and Surveying, The Ohio State University, Columbus, Ohio, March 1993.
5. Department of Defense World Geodetic System 1984: Its definition and relationships with local geodetic systems, second edition. Defense Mapping Agency Technical Report TR-8350.2, Defense Mapping Agency, Fairfax, Virginia, September 1991.

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Appendix M

TEST CONSIDERATIONS

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Appendix M—TEST CONSIDERATIONS

M.1 Introduction

This appendix presents the statistical justification for the testing and pass/fail criteria presented in sections 2.5.4, 2.5.6, and 2.5.8. In addition, simulator scenario guidelines for these sections are presented.

M.2 (Initial) Acquisition and Reacquisition Testing Statistical Justification

Tests for (initial) acquisition and reacquisition time can be considered to follow a binomial distribution based on the following assumptions:

1. Each acquisition attempt is an independent trial, i.e., the results of any single trial do not depend on the results of any previous trial, and
2. Only two test states are possible — (re)acquire (within the specified time and accuracy) or not (re)acquire.

The binomial distribution is represented by the following:

$$\sum_{y=0}^{n} P(y) = \sum_{y=0}^{n} \binom{n}{y} p^{y} q^{n-y}$$

where:

$$\binom{n}{y} = \frac{n!}{y!(n-y)!}$$

and

P(y)	=	Probability of failing a test
a	=	Graduated sampling variable (0, 1, or 2)
y	=	Number of failures
n	=	Number of trials
p	=	Probability of failing a single trial
q	=	Probability of passing a single trial

A graduated sampling approach shall be employed in order to keep test times within reason. The graduated sampling variable (a) will be allowed to vary between zero and two, according to the approach shown in Table M-1. The acquisition test is broken out into a series of three segments each composed of ten trials. The “quit-while-ahead” concept will be used. For example, if no failure occurs in the first 10 trials, success would be declared and the test terminated. If one failure occurred in the first 10 trials, at least 10 more trials (after the first 10) would be required prior to declaring the test successful. Therefore let:

α	=	Probability of rejecting a good receiver
β	=	Probability of accepting a bad receiver

Rational for this method of testing is based on achieving an acceptably low β risk with a small number of samples and deferring rejection of a good receiver (low α) until a larger sample is obtained. Such a test concept will, on the average, shorten the duration of the testing. The overall probability of passing the three-segment, 30 trial test is related to the probability of success per individual trial. Receivers that are nominally designed to have a 0.95 probability of passing a single test will have 0.86 probability of passing the overall test. Conversely, the probability of a “bad” receiver, one that has a 0.80 chance of passing a single trial, will only pass the overall test with a probability of 0.16. Thus, this graduated test procedure has a high probability of rejecting a bad receiver. Figure M-1 shows the probability of passing the overall test after each 10-segment trial for receivers of varying quality.

TABLE M-1 GRADUATED SAMPLING PASS/FAIL CRITERIA

Trials	Cumulative Failures within Specified Time	Test Disposition
First Ten (10)Trials	Zero (0) One (1) Two (2) or More	Pass Run Ten (10) More Fail
Second Ten (10) Trials	Zero (0) One (1) or Two (2) Three (3) or More	Pass Run Ten (10) More Fail
Third Ten (10) Trials	Zero (0) One (1) or More	Pass Fail

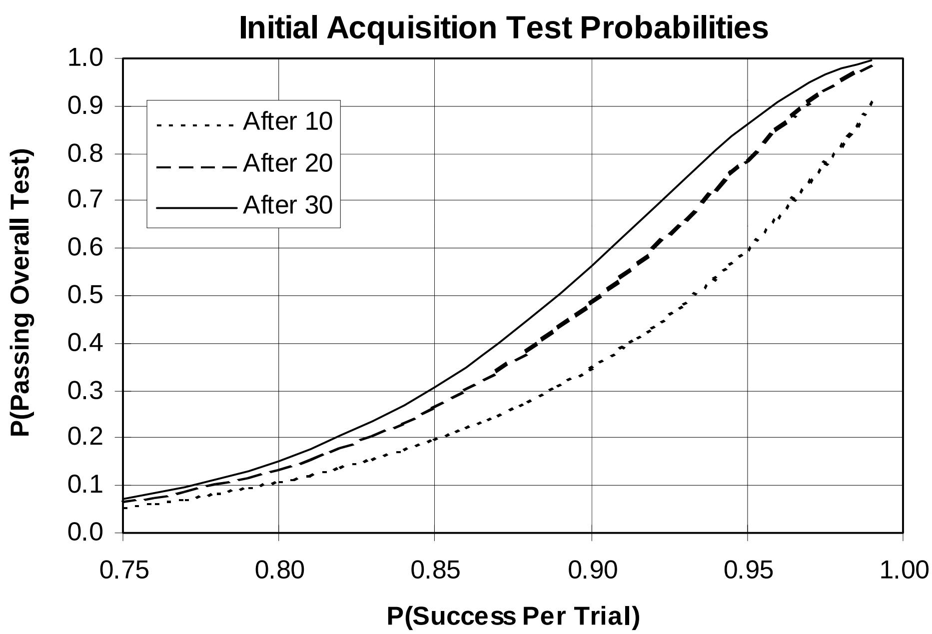

FIGURE M-1 (RE)ACQUISITION TEST PROBABILITY STATISTICS

M.3 Accuracy Statistical Justification

The accuracy test is designed to ensure an acceptably low risk of passing the test for equipment fails to meet its claimed accuracy as represented by its σ_{noise} output. This β_β risk is formally specified as:

$$\beta = \Pr\{\text{test is passed} \mid \sigma > 1.1\sigma_{noise}\} \leq 0.1$$

where σ represents the actual RMS accuracy of the equipment. This risk specification can be used to develop a pass criterion for the normalized accuracy statistic RMS_PR(M). Under the steady-state tracking conditions specified in Section 2.5.8, assuming that the residual pseudo-range errors are zero mean and Gaussian random variables with variance σ^2, it can be shown that the probability distribution of RMS_PR(M) is equal to the Chi distribution with NIS degrees of freedom and with parameter σ/σ_{noise}:

$\Pr\{RMS\_PR(M) \leq X\} = \chi(X, \sigma/\sigma_{noise}, NIS)$

The pass threshold T can be found as a function of NIS by solving the implicit equation:

$\chi(T, 1.1, NIS) = 0.1$

The solution is graphed as a function of NIS in Figure M-2.

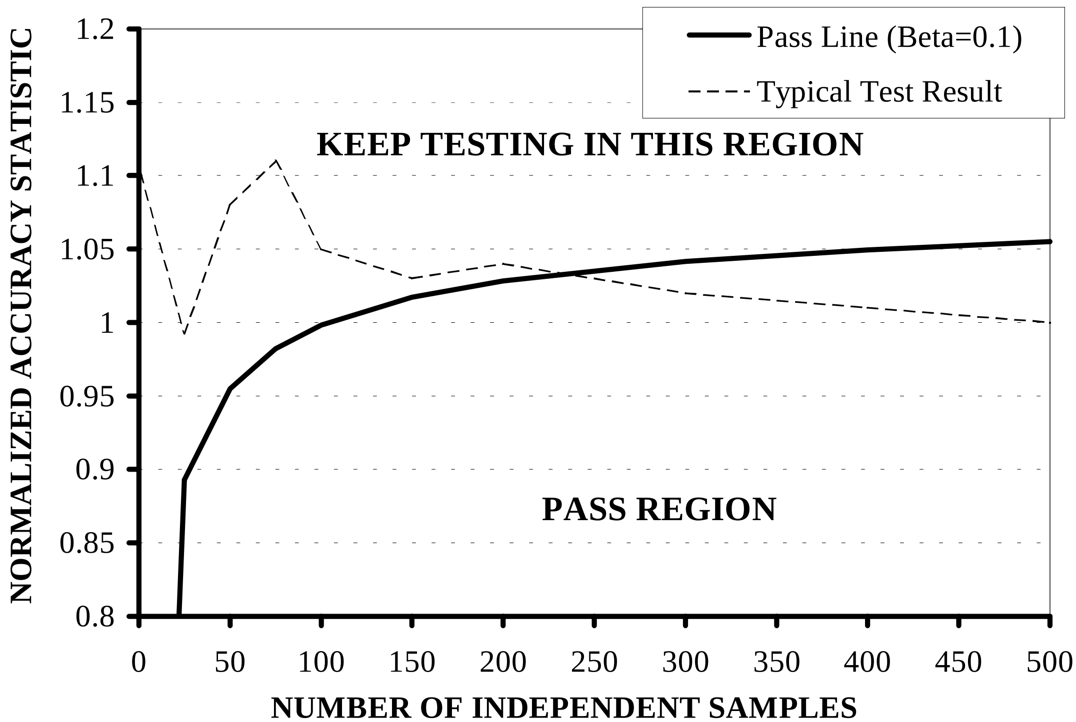

FIGURE M-2 PSEUDORANGE ACCURACY TEST PASS CRITERIA

The probability of passing the test for equipment that meets the requirement, PP(NIS), can be determined by evaluating the following Chi distribution:

$PP(NIS) = \chi(T, 1, NIS)$

The pass probability as a function of NIS is shown in Figure M-3.

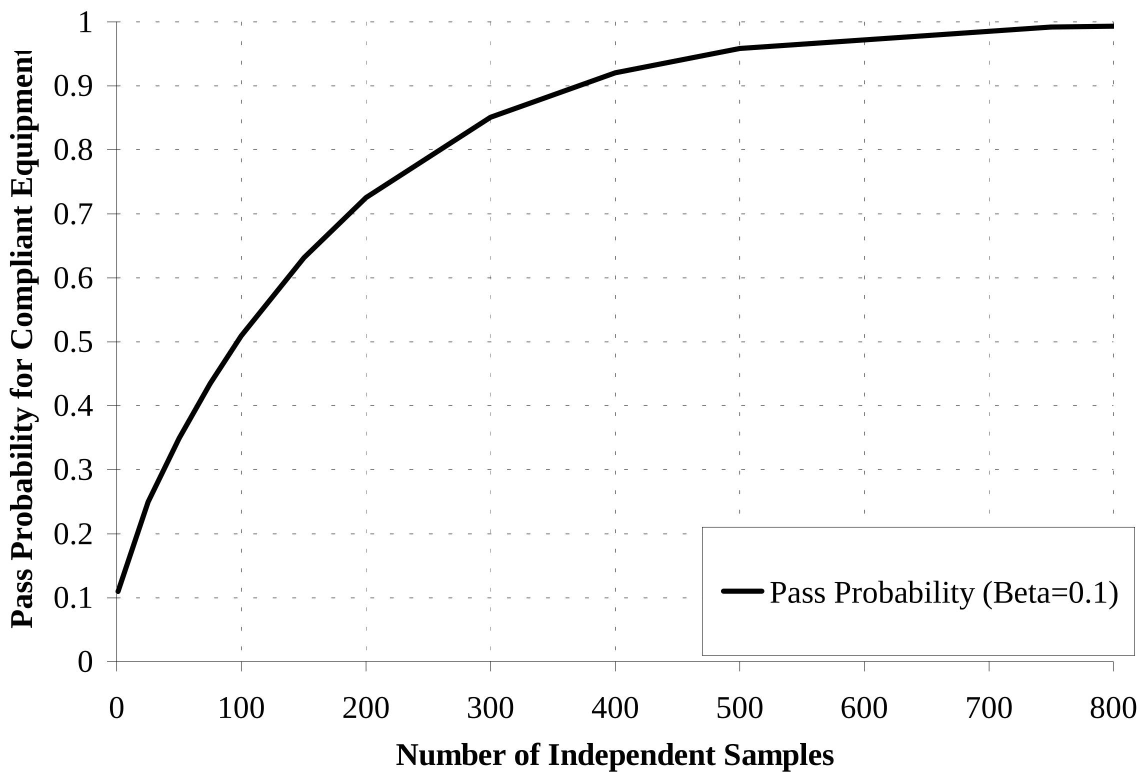

FIGURE M-3 PSEUDORANGE ACCURACY TEST PASS PROBABILITY

M.4 General Simulator Scenario Conditions

Nominal GPS Constellation:	GPS 24 Satellite Constellation (Appendix B)
Starting Coordinates:	Chosen By Manufacturer
Assumed Mask Angle:	5°

Guidelines

Removal of unwanted GPS satellites to meet the required number of satellites for a test can be accomplished by selecting appropriate starting coordinates or by turning the RF off for unwanted satellites. If the RF is turned off, the almanac must reflect the actual satellites simulated (for which RF is on). Time dependent satellite removal (and reapplication) shall be accomplished by turning the satellite of interest on and off (RF control), in a manner approximating satellite blockage or shielding. During the initial acquisition portion of all tests, the same satellites shall be applied throughout, with no satellites rising or setting.

Appendix N

SUMMARY OF REQUIREMENTS

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Appendix N—SUMMARY OF REQUIREMENTS

This standard addresses a variety of equipment architectures, as denoted by the operational and functional classes. As a result, it may be difficult to extract the appropriate requirements from this standard for a specific navigation mode. This appendix provides a complete summary of all of the requirements found in Section 2. The requirements are listed across four columns for the navigation modes. If a requirement is included in a particular column, then it applies to that mode.

TABLE N-1 CLASS BETA AND GAMMA REQUIREMENTS

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Airworthiness (2.1.1.1.1)	Design and manufacture of the airborne equipment shall support installation so as not to impair the airworthiness of the aircraft.			
General Performance (2.1.1.1.2)	The equipment shall perform its intended function, as defined by this MOPS and the manufacturer.			
Fire Resistance (2.1.1.1.3)	Except for small parts (such as knobs, fasteners, seals, grommets and small electrical parts) that would not significantly contribute to the propagation of fire, all materials used shall be self-extinguishing.			
Equipment Interfaces (2.1.1.1.4)	The interfaces with other aircraft equipment shall be designed such that, properly installed with adequately designed other equipment, normal or abnormal GPS/WAAS equipment operation shall not adversely affect the operation of other equipment nor shall normal or abnormal operation of other equipment adversely affect the GPS/WAAS equipment except as specifically allowed.			
Effects of Test (2.1.1.1.5)	The design of the equipment shall be such that the application of the specified test procedures shall not produce a condition detrimental to the performance of the equipment, except as specifically allowed in this MOPS.			
GPS Signal Processing Requirements (2.1.1.2)	GPS/WAAS equipment shall be designed to process the GPS signals and necessary data described in ICD-GPS-200C under interference conditions described in Appendix C and under the minimum signal conditions defined in Section 2.1.1.10.			
(2.1.1.2)	If the ionospheric corrections provided by the WAAS are not applied to a pseudorange, then the equipment shall decode the ionospheric coefficients in the GPS navigation message and apply the ionospheric corrections described in the ICD-GPS-200C.			
(2.1.1.2)	If the ionospheric corrections provided by WAAS are applied to a satellite pseudorange, the GPS ionospheric model shall not be used for that satellite.			
(2.1.1.2)	A tropospheric correction shall be applied.			
(2.1.1.2)	GPS satellite navigation data shall be continuously decoded.			
(2.1.1.2)	Except for "not healthy" information (as defined in Section 2.1.1.5.5), new ephemeris data (subframes 1, 2 and 3 of the GPS navigation message) shall not be used until the data is verified by reception of a second message containing the same data			
(2.1.1.2)	Ionospheric data (subframe 4) shall not be used until the data is verified by reception of a second message, potentially from a different satellite, containing the same data.			
(2.1.1.2)	The WAAS equipment shall apply the satellite clock correction (including relativistic corrections) derived from the clock parameters in subframe 1 of the GPS navigation message after smoothing the pseudorange measurement.			
(2.1.1.2)	In addition, the equipment shall not mistake one GPS satellite for another due to cross-correlation during acquisition or reacquisition.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Acquisition and Track (2.1.1.3.1)	The GPS/WAAS equipment shall be designed to acquire and track the SBAS PRN codes as described in Appendix A, paragraph A.3.3, at power levels as described in A.2.6.5, and under interference conditions described in Appendix C and under the minimum signal conditions defined in Section 2.1.1.10.			
(2.1.1.3.1)	If the ionospheric corrections provided by the WAAS are not applied to a pseudorange, then the equipment shall decode the iono-spheric coefficients in the GPS navigation message and apply the ionospheric corrections described in ICD-GPS-200C .			
(2.1.1.3.1)	If the ionospheric corrections provided by WAAS are applied to a satellite pseudorange, the GPS ionospheric model shall not be used for that satellite.			
(2.1.1.3.1)	A tropospheric correction shall be applied (an acceptable algorithm is described in Appendix A, Section A.4.2.4).			
(2.1.1.3.1)	In addition, when using a WAAS satellite for ranging, the equipment shall not mistake one WAAS satellite for another due to cross-correlation during acquisition or reacquisition.			
(2.1.1.3.1)	The equipment shall not use SBAS PRN codes other than those specified in Table A-1 of Appendix A.			
Demodulation and Forward Error Correction (FEC) Decoding (2.1.1.3.2)	The GPS/WAAS equipment shall be designed to demodulate the signals described in the WAAS Signal Specification, paragraph A.2.3.			
(2.1.1.3.2)	The embedded forward error correction shall be applied in order to minimize data errors in the decoded messages.			
(2.1.1.3.2)	The equipment shall not utilize any message for which the Cyclic Redundancy Check described in Appendix A, paragraph A.4.3.3, does not check.			
(2.1.1.3.2)	The WAAS message loss rate shall be less than 1 message in 10^3 for the interference conditions described in Appendix C and under the minimum signal conditions defined in Section 2.1.1.10.			
WAAS Satellite Pseudorange Determination (2.1.1.3.3)	The GPS/WAAS equipment shall determine the pseudorange to each WAAS satellite that is currently being used in the position computation.			
(2.1.1.3.3)	These pseudoranges shall be referenced to the same time base as that of the GPS satellites.			
(2.1.1.3.3)	The equipment shall account for earth rotation in determining the pseudorange.			
(2.1.1.3.3)	If the ionospheric corrections provided by the WAAS are not applied to the WAAS satellite pseudoranges, then the equipment shall decode the ionospheric coefficients in the GPS navigation message and apply the ionospheric corrections described in the ICD-GPS-200C.			
(2.1.1.3.3)	A tropospheric correction shall be applied.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
WAAS Message Processing (2.1.1.4, 2.1.3.7, 2.1.4.9, 2.1.5.9)	Message Types 0, 1, 2, 3, 4, 5, 6, 7, 9, 17, 24, 25, 27 and 28 shall be utilized in all navigation modes.		The minimum message set to be decoded consists of Message Types 0, 1, 2, 3, 4, 5, 6, 7, 9, 10, 17, 18, 24, 25, 26, 27 and 28.	
(2.1.1.4)	Any such messages may optionally be used in modes for which they are not specifically required, but shall then conform to the relevant requirements.			
(2.1.1.4)	If an optional message is used, the loss of those messages shall not cause loss of function.			
(2.1.1.4)	Message Types the equipment is not specifically designed to decode shall be ignored.			
Message Type 0 — Don't Use for Safety Applications (2.1.1.4.1)	The receipt of a Message Type 0 shall result in the cessation of the use and discarding of any ranging data and all message types 1-7, 9-10, 18, 24-28 obtained from that WAAS signal (PRN code).			
(2.1.1.4.1)	In addition, that WAAS signal (PRN code) shall be deselected for at least one minute.			
Message Type 1 — PRN Mask Assignments (2.1.1.4.2)	The GPS/WAAS equipment shall be able to store and use two PRN masks per GEO PRN signal.			
(2.1.1.4.2)	It shall be able, during the transition period between masks, to use corrections with different IODPs simultaneously.			
Message Types 2-5 and 24 — Fast Clock Corrections (2.1.1.4.3, 2.1.4.9.1, 2.1.5.9.1)	All classes of equipment shall decode Message Types 2, 3, 4, 5 and 24.			
(2.1.1.4.3, 2.1.4.9.1, 2.1.5.9.1)	Neither integrity nor correction data shall be utilized for any satellite unless the IODP matches the IODP obtained from a Type 1 message.			
(2.1.1.4.3, 2.1.4.9.1, 2.1.5.9.1)	The equipment shall determine and apply the fast clock corrections for all WAAS HEALTHY satellites being used in the position solution.			
Message Types 2-5, 6 and 24 — Fast Clock Corrections (2.1.4.9.1, 2.1.5.9.1)			Message Types 2-5 and 24 shall be processed in accordance with Section 2.1.1.4.3 and Message Type 6 shall be processed in accordance with Section 2.1.1.4.4.	

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.4.9.1, 2.1.5.9.1)			In addition, a satellite shall not be used for LNAV/VNAV or precision approach if the $UDREI_i$ associated with that satellite is 12 or greater. (See Appendix A, Sections A.4.4.3 and A.4.4.8.)	In addition, a satellite shall not be used for GLS or APV-II if the $UDREI_i$ associated with that satellite is 12 or greater. (See Appendix A, Sections A.4.4.3 and A.4.4.8.)
Message Type 6 — Integrity Information (2.1.1.4.4)	All classes of equipment shall decode Message Type 6.			
(2.1.1.4.4)	The GPS/WAAS equipment shall decode the UDREI for use in determining the integrity of the corrected position.			
(2.1.1.4.4)	If an $IODF_j$ is equal to 3 in an integrity (type 6) message, the equipment shall utilize the UDREs regardless of the $IODF_j$ in the associated type 2-5, 24 message.			
(2.1.1.4.4)	If the $IODF_j$ is less than 3 in an integrity message, the equipment shall use the σ_{UDRE}s only if the $IODF_j$ matches the IODF in the associated fast corrections message (type 2-5, 24).			
(2.1.1.4.4)	When interpreting a type 6 message, the user equipment shall use the most recently received PRN mask for which corrections have been received.			
Message Type 7 — Fast Correction Degradation (2.1.1.4.5)	The GPS/WAAS equipment shall decode Message Type 7 and determine the timeout interval for fast corrections. (See Appendix A, Section A.4.4.5.)			
(2.1.4.9.5)			The equipment shall decode Message Types 7 and 10 as described in Appendix A, Section A.4.4.5 and A.4.4.6.	
Message Type 9 — WAAS Satellite Navigation Message (2.1.1.4.6)	The GPS/WAAS equipment shall utilize the navigation information contained in Message Type 9, which contains WAAS satellite orbit information, to determine the location of each WAAS satellite being tracked.			
(2.1.1.4.6)	The equipment shall always use the most recent Message Type 9.			
Message Type 17 — WAAS Satellite Almanac (2.1.1.4.7)	The most recent almanac data for at least two WAAS satellites above the minimum mask angle, if available, shall be stored in order to support rapid acquisition of a new WAAS satellite.			
Message Type 27 — WAAS Service Message (2.1.1.4.8)	The GPS/WAAS equipment shall examine the information contained in all Type 27 messages, if broadcast, to determine the δUDRE factor applicable to the user location.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.1.4.8)	The GPS/WAAS equipment shall use the applicable δUDRE factor to inflate the fast and long-term correction residuals variances (σ^2_{flt}) as described in Appendix J (J.2.2). (Reference: A.4.4.13, A.4.5.1, and J.2.2.)			
(2.1.1.4.8)	The data in a Type 27 message shall be retained for the time-out interval in Table 2-1, even after power-off.			
(2.1.1.4.8)	If a Type 27 message with a new IODS indicates a higher δUDRE for the user location, the higher δUDRE shall be applied immediately.			
(2.1.1.4.8)	A lower δUDRE in a new Type 27 message shall not be used until the complete set of messages with the new IODS has been received.			
(2.1.1.4.8)	Once the complete set of Type 27 messages with a given IODS has been received, all previously received Type 27 messages with different IODS shall be discarded.			
Message Type 28 - Clock-Ephemeris Covariance Matrix Message (2.1.1.4.13)	The GPS/WAAS equipment shall examine the information contained in all Type 28 message to determine the δUDRE factor applicable to the user location.			
(2.1.1.4.13)	The GPS/WAAS equipment shall use the applicable δUDRE factor to calculate the fast and long-term residual variances (σ^2_{flt}) as described in Appendix J (J.2.2). (Reference: A.4.4.16, A.4.5.1, and J.2.2.)			
(2.1.1.4.13)	If a Type 28 message has been received for any satellite, and is still active, then UDREIs for satellite without an active Type 28 message shall not be used (therefore the variance of the residual error is defined in Appendix J.2.2), unless the UDREs indicate “Don’t Use” or “Not Monitored”.			
(2.1.1.4.13)	The Type 28 message data shall not be utilized for any satellite unless the IODP matches the IODP obtained from a Type 1 message. (See Appendix A, Section A.4.4.3.)			
Message Type 24 and 25 Long-Term Corrections and Message Type 9 GEO Navigation Data (2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	The GPS/WAAS equipment shall decode Message Types 24 and 25 and determine and apply the long-term clock corrections for all satellites being used in the position solution or FDE algorithm, except for the SBAS satellites operated by the same service provider as the satellite providing corrections.			
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	When using SBAS satellites operated by the same service provider as the satellite providing corrections, the GPS/WAAS equipment shall decode Message Type 9 and determine and apply the GEO navigation data, in lieu of long-term corrections, to the SBAS geostationary satellite.			
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	When using other SBAS satellites operated by a different service provider, the equipment shall decode the Message Type 9 from that satellite and a Message Type 24 or 25 long term correction from the satellite providing corrections and apply both.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	Long term correction data shall not be utilized for any satellite unless the IODP matches the IODP obtained from a Type 1 message. For SBAS satellites, the IOD of message type 9 does not have to match the IOD in Type 24 or 25.			
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	For GPS satellites, the equipment shall compare the Issue of Data (WAAS IOD) in the WAAS Type 24 or 25 message for each GPS satellite with the IODE of that GPS satellite being utilized by the equipment.			
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	There are three possible outcomes: (a) The WAAS IOD and GPS IODE match (the normal condition), in which case the WAAS correction shall be applied using the current GPS IODE to compute satellite position;;			
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	There are three possible outcomes: (b) The WAAS IOD and GPS IODE do not match, but the WAAS IOD matches the previous GPS IODE (a condition which will happen for a few minutes each hour), in which case the WAAS corrections shall be applied using the previous GPS IODE to compute satellite position			
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	There are three possible outcomes: (c) They do not match, nor does the WAAS IOD match the previous GPS IODE (a rare condition), then the equipment shall not apply the fast or long-term correction.			
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	The equipment shall retain old ephemeris information for at least 5 minutes, or until a match between WAAS IOD and GPS IODE is obtained.			
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	Long term corrections shall not be applied without active fast corrections.			
(2.1.1.4.11, 2.1.4.9.2, 2.1.5.9.2)	The airborne equipment shall use the active long term correction with latest time of applicability which is less (earlier) than the current time whenever possible.			
Message Type 18 — Ionospheric Grid Point Masks (2.1.4.9.3, 2.1.5.9.4)			The GPS/WAAS equipment shall decode the information in Message Type 18 to accurately and unambiguously identify the grid point latitude and longitude for each correction in the associated Message Type 26.	
(2.1.4.9.3, 2.1.5.9.4)			The GPS/WAAS equipment shall be able to store and use two IGP masks per GEO PRN signal.	
(2.1.4.9.3, 2.1.5.9.4)			It shall be able, during the transition period between masks, to use corrections with different IODIs simultaneously.	
Message Type 26 — Ionospheric Grid Point Delays (2.1.4.9.3, 2.1.5.9.4)			The GPS/WAAS equipment shall decode the Message Type 26 and store the vertical delay and Grid Ionospheric Vertical Error Indicator (GIVEI) at each grid point needed to compute ionospheric corrections for which information is provided by the WAAS.	

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.4.9.3, 2.1.5.9.4)			If the Issue Of Data Ionospheric (IODI) in Message Type 26 does not match that of the applicable previous Message Type 18, the equipment shall continue to use previous estimates until a match is achieved.	
Message Timeout Periods (2.1.1.4.9)	WAAS equipment shall only use data until it has timed out.			
(2.1.1.4.9)	The most recently decoded a_{ij} shall apply.			
(2.1.1.4.9)	Those data items which do not timeout shall continue to be used until replaced.			
Combining Data from Separate Broadcasts (2.1.1.4.10)	In precision approach mode, corrections and integrity data for all satellites shall be obtained from the same WAAS signal (PRN code).			
(2.1.1.4.10)	If data from multiple WAAS satellites are used, then the equipment shall account for differences in the time reference used to generate corrections.			
(2.1.1.4.10)	For each individual GPS or WAAS satellite, the fast correction, σ2UDRE, long term corrections, ionospheric correction, σ2GIVE, fast correction degradation factor δUDRE, and any Type 10 message degradation factors used shall be derived from a single WAAS signal (PRN code).			
Application of Differential Correction Terms (2.1.1.4.12, 2.1.3.8, 2.1.4.10, 2.1.5.10)	If the equipment filters code or Doppler measurements in developing a pseudorange estimate, the differential corrections shall be applied after filtering, and immediately before computing a position.			
(2.1.1.4.12, 2.1.3.8, 2.1.4.10, 2.1.5.10)	Long term, fast and range rate corrections shall be applied when available.			
(2.1.1.4.12, 2.1.3.8, 2.1.4.10, 2.1.5.10)	When any of these corrections are not available (during data initialization), the model variance of the residual error shall be as defined in Section J.2.2.			
(2.1.1.4.12, 2.1.3.8, 2.1.4.10, 2.1.5.10)	Since there are no Range-Rate Corrections (RRCs) broadcast directly by the WAAS, each equipment shall compute these from the WAAS Message Type 2-5 and 24 data.			
(2.1.1.4.12, 2.1.3.8)	The equipment shall correct the pseudorange as: $PR_{i,corrected}(t) = PR_{i,measured}(t) + PRC_i(t_{i,of}) + RRC_i(t_{i,of}) \times (t - t_{i,of})$			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.4.10, 2.1.5.10)			The equipment shall correct the pseudorange as: $PR_{i,corrected}(t) = PR_{i,measured}(t) + PRC_i(t_{i,of}) + (t - t_{i,of}) \times RRC_i(t_{i,of}) + TC_i + IC_i$	
(2.1.1.4.12, 2.1.3.8, 2.1.4.10, 2.1.5.10)	The clock offset error correction and clock drift error correction shall be computed from the information in Message Types 24 and 25 in accordance with Appendix A, Section 4.4.7, and added to the t_{SV} term obtained from the satellite navigation data message.			
Application of Ionospheric Corrections (2.1.4.10.2, 2.1.5.10.2)			The GPS/WAAS equipment shall first compute an ionospheric pierce point and obliquity angle for each satellite used in the position computation.	
(2.1.4.10.2, 2.1.5.10.2)			The equipment shall compute the ionospheric slant range delay as defined in Appendix A, Section A.4.4.10.4.	
(2.1.4.10.2, 2.1.5.10.2)			Satellites for which this correction cannot be computed shall not be used in the position computation for LNAV/VNAV.	Satellites for which this correction cannot be computed shall not be used in the position computation for GLS or APV-II.
Application of Tropospheric Corrections (2.1.4.10.3)			Equipment shall apply the tropospheric delay correction specified in Section A.4.2.4.	
Satellite Integrity Status (2.1.1.5)	The GPS/WAAS equipment shall designate each GPS and WAAS satellite as WAAS UNHEALTHY, WAAS UNMONITORED, or WAAS HEALTHY as defined in Sections 2.1.1.5.2 through 2.1.1.5.4.			
(2.1.1.5)	The GPS/WAAS equipment shall also designate each satellite as GPS HEALTHY or GPS UNHEALTHY, as defined in Sections 2.1.1.5.5 and 2.1.1.5.6.			
Step Detector (2.1.1.5.1)	The GPS/WAAS equipment shall detect a pseudorange step greater than 700 meters on any satellite used in the position solution, including steps which cause loss of lock for less than 10 seconds.			
(2.1.1.5.1)	The equipment shall falsely declare a pseudorange step less frequently than 10^{-5}/flight hour.			
(2.1.1.5.1)	If the equipment is capable of recovering a satellite after a step error has been declared, the declaration of a pseudorange step shall only be cleared if it is verified through autonomous fault detection.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
WAAS UNHEALTHY Designation (2.1.1.5.2)	The GPS/WAAS equipment shall designate any GPS or WAAS satellite as WAAS UNHEALTHY for that navigation mode upon the occurrence of any of the following conditions: the equipment has successfully decoded a UDREI of 15, indicating that the WAAS has assessed the satellites signal as unusable; the step detection function has declared a step error; for WAAS satellites, user range accuracy index of 8 or more; for WAAS satellites, failure of parity on 4 successive messages.			
(2.1.1.5.2)	The WAAS UNHEALTHY status for that satellite shall be changed only after the condition has cleared and none of the above conditions exist.			
WAAS UNMONITORED Designation (2.1.1.5.3)	The GPS/WAAS equipment shall designate any GPS or WAAS satellite as WAAS UNMONITORED upon the occurrence of any of the following conditions (if not designated as WAAS UNHEALTHY): WAAS UDREI=14 ("Not Monitored"); WAAS data is not provided (satellite not in mask); WAAS signals are not being received (affects all satellites); WAAS data has timed out; If using long-term corrections, WAAS IOD and GPS IODE cannot be reconciled, as described in 2.1.1.4.11.			
(2.1.1.5.3)	The WAAS UNMONITORED status for that satellite shall be changed only after the condition has cleared and none of the above conditions exist.			
WAAS HEALTHY Designation (2.1.1.5.4)	A GPS or WAAS satellite shall be designated as WAAS HEALTHY if the following conditions are both met and if not designated as WAAS UNHEALTHY or WAAS UNMONITORED: the step detection function has not declared a step error; the equipment has not received a UDREI of 14 or 15 for the satellite;			
GPS UNHEALTHY Designation (2.1.1.5.5)	The GPS/WAAS equipment shall designate any GPS satellite as GPS UNHEALTHY if the GPS satellite navigation message meets any of the following conditions: 6 bit health word in subframe 1: all cases where MSB="1" except when other bits are "11101", indicating that the satellite will be out of service but is not at this time; failure of parity on 5 successive words (3 seconds); broadcast IODE does not match 8 least-significant bits of broadcast IODC; user range accuracy index of 8 or more; bit 18 of the HOW set to 1; all bits in subframe 1, 2, or 3 are 0's; default navigation data is being transmitted in subframes 1, 2, or 3 (ref. 20.3.3.3.1.4 and 20.3.3.5.1.3 of ICD-GPS-200C); the preamble does not equal 8B (hexadecimal) or 139 (decimal).			
(2.1.1.5.5)	The GPS UNHEALTHY status for a satellite shall be changed only after the condition has cleared.			
GPS HEALTHY (2.1.1.5.6)	The GPS/WAAS equipment shall designate any GPS satellite as GPS HEALTHY if it does not satisfy any of the criteria listed under Section 2.1.1.5.5 (if not designated as GPS UNHEALTHY).			
Satellite Selection (2.1.1.6)	The equipment shall monitor the data broadcast of at least one WAAS satellite that is providing valid integrity information, if one is available.			
(2.1.1.6)	GPS/WAAS equipment shall automatically select satellites for use in the navigational computation, and, if the FDE algorithm is being applied, for use in the FDE algorithm itself.			
(2.1.1.6)	The equipment shall not utilize any satellite designated WAAS UNHEALTHY.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.1.6)	A WAAS HEALTHY designation shall override a GPS UNHEALTHY designation, except that a GPS satellite designated as GPS UNHEALTHY due to failure of parity on five successive words or due to default navigation data shall not be used.			
(2.1.1.6)	The GPS/WAAS equipment shall either select a set of satellites that can satisfy the performance requirements of the navigation mode, select the set that provides the smallest HPL or VPL, or select satellites as shown in Figure 2-1.			
(2.1.1.6)	When a change to the selected set of satellites is necessary, the GPS/WAAS equipment shall accomplish this change within the time-to-alert (6 seconds for precision approach, or as specified in section 2.1.2.2.2.2.1 or 2.1.3.2.2.2.1 for other operations).			
(2.1.1.6)	If manual deselection is implemented, the manufacturer shall address these issues.			
(2.1.1.6)	The equipment shall clear all previous manual deselections at power-up.			
(2.1.1.6)	Manual selection of satellites which have been designated WAAS UNHEALTHY or GPS UNHEALTHY shall be prohibited.			
(2.1.3.9)		In addition to the general requirements of Section 2.1.1.6, the equipment shall select at least two WAAS satellites, if they are available.		
(2.1.4.11, 2.1.5.11)			In addition to the general requirements of Section 2.1.1.6, the equipment shall select at least two WAAS satellites that are broadcasting correction data (including ionosphere) for the user's location, if they are available.	
(2.1.3.9, 2.1.4.11, 2.1.5.11)		When two WAAS satellites are available, the equipment shall be capable of switching between WAAS data streams to maximize continuity of function.		
(2.1.4.11, 2.1.5.11)			For procedures defined by a FAS data block, (see Appendix D), the equipment shall only use data from satellites for which the service provider ID in the Type 17 message matches the service provider ID in the FAS data block unless any service provider may be used (ID=15).	
(2.1.4.11, 2.1.5.11)			The position determination shall not include satellites (GPS or WAAS) with elevation angles below 5 degrees.	

MOPS Requirement	**En Route / Terminal Mode**	**NPA Mode**	**LNAV/VNAV**	**APV-II / GLS**
(2.1.4.11, 2.1.5.11)			For LNAV/VNAV, only satellites designated WAAS HEALTHY shall be used for the position solution.	For GLS or APV-II, only satellites designated WAAS HEALTHY shall be used for the position solution.
Initial Acquisition Time (2.1.1.7)	The equipment shall be capable of acquiring satellites and determining a position without any initialization information, including time, position, and GPS and WAAS almanac data.			
(2.1.1.7)	In addition, with latitude and longitude initialized within 60 nautical miles, with time and date within 1 minute, with valid almanac data and unobstructed satellite visibility, and under interference conditions of Appendix C and under the minimum signal conditions defined in Section 2.1.1.10, the time from application of power to the first valid position fix shall be less than 5 minutes.			
GPS Satellite Acquisition Time (2.1.1.8.1)	After steady state accuracy has been established, i.e., at least one minute of accurate navigation, the equipment shall be capable of incorporating a new GPS satellite signal into the position within 80 seconds.			
WAAS Satellite Acquisition Time (2.1.1.8.2)	After steady state accuracy has been established, i.e., at least one minute of accurate navigation, the equipment shall be capable of acquiring a new WAAS satellite signal, applying the WAAS integrity information, and incorporating that satellite signal into the position solution within 134 seconds.			
Satellite Reacquisition Time (2.1.1.9)	For satellite signal outages of 30 seconds or less when the remaining satellites provide a GDOP of 6 or less, the equipment shall reincorporate the satellite into the position solution within 10 seconds from the time the signal is reintroduced.			
Sensitivity and Dynamic Range (2.1.1.10) Equipment either meets first three requirements or next five requirements.	If the manufacturer chooses to be interoperable with a standard GPS antenna without preamplifier, as specified in RTCA/DO-228, the GPS/WAAS equipment shall be capable of tracking GPS satellites with a minimum input signal power of -136 dBm at the receiver port (see Figure 2-2) in the presence of background thermal noise density of -176.6 dBm/Hz.			
(2.1.1.10)	The equipment shall be capable of tracking WAAS satellites with a minimum input signal power of -137 dBm at the receiver port in the presence of background thermal noise density of -176.6 dBm/Hz.			
(2.1.1.10)	The equipment shall have the capability of tracking GPS and WAAS satellites with a maximum power of at least -116 dBm at the receiver port.			
(2.1.1.10)	If the manufacturer does not choose to be interoperable with a RTCA/DO-228 antenna without preamplifier as a component in his equipment, the GPS/WAAS equipment sensitivity and dynamic range depends on the RF amplifier design. The antenna shall satisfy the performance requirements of RTCA/DO-228.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.1.10)	The preamplifier shall accommodate GPS signals with a minimum input signal power of -134.5 dBm, and WAAS signals with a minimum input signal power of -135.5 dBm, in the presence of background thermal noise density of -178.6 dBm/Hz.			
(2.1.1.10)	The equipment shall have the capability of tracking GPS and WAAS satellites with a maximum power of at least -116 dBm at the input of the preamplifier.			
(2.1.1.10)	In addition, the maximum tolerable loss (L_{max} in Figure 2-2) between the preamplifier and the receiver port shall be determined in order to support testing of the minimum signal power at the receiver port.			
(2.1.1.10)	Finally, the minimum loss (L_{min}) shall be determined in order to support testing of the maximum signal power at the receiver port. See Figures 2-21 and 2-22.			
Equipment Burnout Protection (2.1.1.11)	GPS/WAAS equipment shall withstand, without damage, an in-band CW signal of +20 dBm input to the preamplifier (at the receiver port or antenna port, as applicable).			
Integrity in the Presence of Interference (2.1.1.12)	The GPS/WAAS equipment shall satisfy the applicable integrity requirement within the time-to-alert (See section 2.1.2.2.2.2.1, 2.1.3.2.2.2.1, and 6 seconds for precision approach operations) for the output of misleading information in the presence of interfering signals higher in power than the values specified in Appendix C.			
(2.1.1.12)	The equipment shall autonomously return to steady-state accuracy (according to the conditions in Section 2.1.1.7) within 5 minutes after the interference conditions return to those specified in Appendix C for initial acquisition.			
Protection Level (2.1.1.13.1)	Class Beta equipment shall output the Horizontal Protection Level (HPL_{WAAS} or HPL_{FD} as described in Sections 2.1.2.2.2, 2.1.3.2.2, 2.1.4.2.2, and 2.1.5.2.2).			
(2.1.1.13.1)	Class Gamma and Delta equipment intended to support an external ADS-B function shall output HPL.			
(2.1.1.13.1)	The latency of the WAAS-based protection levels shall not exceed 4.8 seconds, from the arrival at the antenna port of the last bit of a message, which affects the horizontal protection level.			
(2.1.1.13.1)	The GPS/WAAS equipment shall indicate if the HPL cannot be calculated.			
(2.1.4.12.1, 2.1.5.12.1)			Class Beta-2 equipment shall output WAAS-based protection levels (HPL_{WAAS} and VPL_{WAAS}) once per second.	Class Beta-3 equipment shall output WAAS-based protection levels (HPL_{WAAS} and VPL_{WAAS}) once per second.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.4.12.1, 2.1.5.12.1)			The latency of the output of the WAAS-based protection levels shall not exceed 0.7 seconds, from the arrival at the antenna port of the last bit of a message, which affects the horizontal or vertical protection levels to output of the last bit of a message containing the protection levels.	
(2.1.4.12.1, 2.1.5.12.1)			The GPS/WAAS equipment shall indicate if the HPL_{WAAS} and VPL_{WAAS} cannot be calculated (insufficient number of WAAS HEALTHY satellites).	
Navigation Alert (2.1.1.13.2, 2.1.4.12.2, 2.1.5.12.2)	Class Beta equipment shall provide an indication or output of the loss of navigation capability within one second of the onset of any of the following conditions: a) The absence of power; b) Probable equipment malfunction or failure; c) The presence of a condition lasting five seconds or more where there are an inadequate number of usable satellites to compute a position solution; d) The presence of a condition where fault detection detects a position failure which cannot be excluded within the time-to-alert.		Class Beta-2 equipment shall provide an indication or output of the loss of navigation capability within one second of the onset of any of the following conditions: a) The absence of power; b) Probable equipment malfunction or failure; c) The presence of a condition where fault detection detects a position failure; or d) when no valid WAAS message has been received for 4 seconds or more.	Class Beta-3 equipment shall provide an indication or output of the loss of navigation capability within one second of the onset of any of the following conditions: a) The absence of power; b) Probable equipment malfunction or failure; c) The presence of a condition where fault detection detects a position failure; or d) when no valid WAAS message has been received for 4 seconds or more.
(2.1.4.12.2, 2.1.5.12.2)			Class Beta-2 equipment shall also provide an indication or output of the loss of navigation capability within 0.6 seconds of the onset of any of the following conditions: e) there are fewer than 4 WAAS HEALTHY satellites.	Class Beta-3 equipment shall also provide an indication or output of the loss of navigation capability within 0.6 seconds of the onset of any of the following conditions: e) there are fewer than 4 WAAS HEALTHY satellites.

MOPS Requirement	**En Route / Terminal Mode**	**NPA Mode**	**LNAV/VNAV**	**APV-II / GLS**
(2.1.1.13.2, 2.1.4.12.2, 2.1.5.12.2)	The alert shall be returned to its normal state immediately upon termination of the responsible condition.			
Accuracy (2.1.2.1, 2.1.3.1, 2.1.4.1, 2.1.5.1)	This requirement shall be met under the minimum signal conditions defined in Section 2.1.1.10 and interference conditions defined in Appendix C.			
(2.1.2.1, 2.1.3.1, 2.1.4.1, 2.1.5.1)	The horizontal radial position fixing error for en route (domestic and oceanic) and terminal area navigation shall not exceed 100 m, 95th percentile, when HDOP is normalized to 1.5.	The horizontal radial position fixing error for nonprecision approach navigation shall not exceed 100 m, 95th percentile, when HDOP is normalized to 1.5.		
(2.1.2.1)	If a time output is provided, it shall be within 1 second of coordinated universal time (UTC).			
Smoothing (2.1.4.1.1, 2.1.5.1.1)			The equipment shall perform carrier smoothing.	
(2.1.4.1.1, 2.1.5.1.1)			In the presence of a code-carrier divergence rate of up to 0.018 m/s, the smoothing filter output shall achieve an error less than 0.25 m within 200 seconds after initialization, relative to the steady-state response of the following filter (shown in 2.1.4.1.1).	
Measurement Quality Monitoring (2.1.4.1.2, 2.1.5.1.2)			The satellite signal tracking quality shall be monitored such that the allocated integrity risk due to undetected cycle slip or other undetected measurement faults is within the manufacturer's allocation.	

MOPS Requirement	**En Route / Terminal Mode**	**NPA Mode**	**LNAV/VNAV**	**APV-II / GLS**
GPS Satellites (2.1.4.1.3.1, 2.1.5.1.3.1)			The RMS of the total steady-state equipment contribution to the error in the corrected pseudorange for a GPS satellite ($RMS_{pr\_air,GPS}$) at the minimum and maximum signal levels (Section 2.1.1.10) shall be as follows: Minimum signal level: a) $RMS_{pr\_air,GPS} \leq 0.36$ meters for airborne Accuracy Designator A, and b) $RMS_{pr\_air,GPS} \leq 0.15$ meters for airborne Accuracy Designator B Maximum signal level: a) $RMS_{pr\_air,GPS} \leq 0.15$ meters for airborne Accuracy Designator A, and b) $RMS_{pr\_air,GPS} \leq 0.11$ meters for airborne Accuracy Designator B.	
WAAS Satellites (2.1.4.1.3.2, 2.1.5.1.3.2)			The RMS of the total steady-state equipment contribution to the error in the corrected pseudorange for a WAAS satellite ($RMS_{pr\_air\_GEO}$) at the minimum and maximum signal levels (Section 2.1.1.10) shall be as follows: Minimum signal level: $RMS_{pr\_air,GEO} \leq 1.8$ Maximum signal level: $RMS_{pr\_air,GEO} \leq 1.0$.	
Position Solution (2.1.4.1.4, 2.1.5.1.4)			The equipment shall compute three-dimensional position using a linearized, weighted least-squares solution as defined in Appendix J.	
Development Assurance (2.1.2.2.1, 2.1.3.2.1, 2.1.4.2.1, 2.1.5.2.1)	The hardware and software shall be designed such that the output of misleading information, considered to be a major failure condition, shall be improbable.			The hardware and software shall be designed such that the output of misleading information, considered to be a severe-major/hazardous failure condition, shall be extremely remote during a 150-second approach.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Integrity Monitoring (2.1.2.2.2, 2.1.3.2.2, 2.1.4.2.2, 2.1.5.2.2)	The equipment shall be capable of computing HPL_{WAAS} and HPL_{FD}.		When in LNAV/VNAV, the equipment shall compute WAAS-based protection levels (HPL_{WAAS} and VPL_{WAAS}).	When in GLS or APV-II, the equipment shall compute WAAS-based protection levels (HPL_{WAAS} and VPL_{WAAS}).
(2.1.2.2.2, 2.1.3.2.2, 2.1.4.2.2 2.1.5.2.2)	At a minimum, the equipment shall compute HPL_{WAAS} when it is available; otherwise it shall compute HPL_{FD}.		The equipment shall also perform fault detection, if more than four satellites are available.	
(2.1.2.2.2, 2.1.3.2.2)	If the equipment uses integrated GPS/inertial and does not use the WAAS integrity and correction data, it shall meet the requirements and accomplish the test procedures in Appendix R.			
(2.1.2.2.2, 2.1.3.2.2)	If the equipment uses integrated GPS/inertial and does not use the WAAS integrity and correction data, it shall meet the requirements and accomplish the test procedures in Appendix R.			
WAAS-Provided Integrity Monitoring (2.1.2.2.2.1, 2.1.3.2.2.1, 2.1.4.2.2.1, 2.1.5.2.2.1)	The equipment shall compute a horizontal protection level HPL_{WAAS} as defined in Appendix J.		The equipment shall compute Horizontal and Vertical Protection Levels HPL_{WAAS} and VPL_{WAAS} as described in Appendix J.	
FDE-Provided Integrity Monitoring (2.1.2.2.2.2, 2.1.3.2.2.2, 2.1.4.2.2.2, 2.1.5.2.2.2)	GPS/WAAS equipment shall have a fault detection and exclusion (FDE) capability that utilizes redundant GPS and WAAS ranging measurements to provide independent integrity monitoring.		GPS/WAAS equipment shall have a fault detection integrity monitoring capability that utilizes redundant GPS and WAAS ranging measurements to provide independent integrity monitoring.	
(2.1.2.2.2.2, 2.1.3.2.2.2)	This algorithm shall be used to monitor the navigation solution whenever WAAS integrity is not available.			
(2.1.2.2.2.2, 2.1.3.2.2.2)	The FDE algorithm shall use the URA broadcast to modify the modes for alerting.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.2.2.2.2, 2.1.3.2.2.2)	At a minimum, the FDE algorithm shall set: (1) an SA mode, if any satellite URA's are greater than 16 meters; (2) an SA off mode, if the URA for every satellite being used is less than or equal to 16 meters.			
(2.1.2.2.2.2, 2.1.3.2.2.2)	Equipment which utilizes barometric altitude to improve the performance of this algorithm shall meet the requirements specified in Appendix G.			
(2.1.2.2.2.2, 2.1.3.2.2.2)	Equipment which utilizes inertial information to improve the performance of this algorithm shall meet the requirements specified in Appendix R.			
(2.1.2.2.2.2, 2.1.3.2.2.2)	The equipment shall compute a horizontal protection level HPL_{FD}.			
(2.1.2.2.2.2, 2.1.3.2.2.2)	The FDE algorithm shall meet the following requirements under the standard assumptions of GPS performance specified in Appendix B.			
(2.1.2.2.2.2, 2.1.3.2.2.2)	If the equipment uses a mixture of corrected and uncorrected satellites, the FDE algorithm shall account for the difference between WNT and GPS time.			
Missed Alert Probability (2.1.2.2.2.2.2, 2.1.3.2.2.2.2)	The probability of missed alert shall be less than or equal to 0.001 for every geometry and every navigation mode, regardless of which satellite is causing the positioning failure.			
False Alert Probability (2.1.2.2.2.2.3, 2.1.3.2.2.2.3, 2.1.4.2.2.2.3, 2.1.5.2.2.2.3)	The probability of false alert shall be less than or equal to 10^{-5}/flight hour.		The probability of false alert shall be less than or equal to 2 x 10^{-5} per approach.	
(2.1.2.2.2.2.3, 2.1.3.2.2.2.3, 2.1.4.2.2.2.3, 2.1.5.2.2.2.3)	The product of the average duration of a false alert and the probability of a false alert shall be less than $3.33x10^{-7}$.		This requirement shall be met for every geometry.	
Failed Exclusion Probability (2.1.2.2.2.2.4, 2.1.3.2.2.2.4)	The probability of failed exclusion shall be less than or equal to 10^{-3} for every geometry and every navigation mode, regardless of which satellite is causing the positioning failure.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Frequency of Fault Detection (2.1.4.2.2.2.1, 2.1.5.2.2.2.1)			For LNAV/VNAV, the fault detection algorithm shall be performed at a rate of at least once per minute or within 6 seconds of a change in the set of satellites that are being used in the navigation solution.	For GLS or APV-II, the fault detection algorithm shall be performed at a rate of at least once per minute or within 6 seconds of a change in the set of satellites that are being used in the navigation solution.
Availability (2.1.2.2.2.2.5, 2.1.3.2.2.2.5, 2.1.4.2.2.2.4, 2.1.5.2.2.2.4)	The availability of the FDE algorithm to meet the above requirements with an HAL of 1 nm, when evaluated over the constellations and grids specified in the test procedures for Case 1 of Section 2.5.9 (i.e., S/A on), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to the following: Availability of detection: 99.80% Availability of exclusion: 94.55%	The availability of the FDE algorithm to meet the above requirements with an horizontal alert limit (HAL) of 0.3 nm, when evaluated over the constellations and grids specified in the test procedures for Case 1 (Section 2.5.9), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to the following: Availability of detection: 97.06% Availability of exclusion: 57.30%	The availability of the fault detection function algorithm for the LNAV/VNAV mode to meet the above requirements assuming a missed alert rate of 0.1 and a vertical alert limit of 50 m, when evaluated over the constellations and grids specified in the test procedures (Section 2.5.10), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to 95 percent.	The availability of the fault detection function algorithm for GLS or APV-II to meet the above requirements assuming a missed alert rate of 0.1 and a vertical alert limit of 15 m, when evaluated over the constellations and grids specified in the test procedures (Section 2.5.10), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to 95 percent.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.2.2.2.2.5, 2.1.3.2.2.2.5)	The availability of the FDE algorithm to meet the above requirements with an HAL of 1 nm, when evaluated over the constellations and grids specified in the test procedures for Case 2 (Section 2.5.9), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to the following: Availability of detection: 99.9% Availability of exclusion: 98.0%	The availability of the FDE algorithm to meet the above requirements with an HAL of 0.3 nm, when evaluated over the constellations and grids specified in the test procedures for Case 2 (Section 2.5.9), using the same satellite selection algorithm used by the equipment, and using a mask angle of 5 degrees, shall be greater than or equal to the following: Availability of detection: 99.7% Availability of exclusion: 92.0%		
Satellite Tracking Capability (2.1.2.4, 2.1.3.4, 2.1.4.4, 2.1.5.4)	The GPS/WAAS equipment shall be capable of simultaneously tracking a minimum of 8 GPS satellites and no WAAS satellites.			
(2.1.2.4, 2.1.3.4, 2.1.4.4, 2.1.5.4)	It shall also be capable of simultaneously tracking at least 6 GPS satellites and two WAAS satellites, including demodulating and storing WAAS data from both satellites.			
Tracking Constraints (2.1.4.5, 2.1.5.5)			Depending on the pre-correlation bandwidth of the equipment, the correlator spacing, d, and the differential group delay shall be within the range as defined in Table 2-3A-C.	

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
GPS Satellites (2.1.4.3.1, 2.1.5.3.1)			The RMS of the total steady-state equipment contribution to the error in the corrected pseudorange for a GPS satellite ($RMS_{pr\_air,GPS}$) at the minimum and maximum signal levels (Section 2.1.1.10) shall be as follows: Minimum signal level: a) $RMS_{pr\_air,GPS} \leq 0.36$ meters for airborne Accuracy Designator A, and b) $RMS_{pr\_air,GPS} \leq 0.15$ meters for airborne Accuracy Designator B. Maximum signal level: a) $RMS_{pr\_air,GPS} \leq 0.15$ meters for airborne Accuracy Designator A, and b) $RMS_{pr\_air,GPS} \leq 0.11$ meters for airborne Accuracy Designator B.	
WAAS Satellites (2.1.4.3.2, 2.1.5.3.2)			The RMS of the total steady-state equipment contribution to the error in the corrected pseudorange for a WAAS satellite ($RMS_{pr\_air\_GEO}$) at the minimum and maximum signal levels (Section 2.1.1.10) shall be as follows: Minimum signal level: $RMS_{pr\_air,GEO} \leq 1.8$ Maximum signal level: $RMS_{pr\_air,GEO} \leq 1.0$	
GPS Tracking Constraints (2.1.4.5.1, 2.1.5.5.1)			For early-minus-late (E-L) DLL discriminator tracking GPS satellites, the pre-correlation bandwidth of the installation, correlator spacing, d, and the differential group delay shall be within the ranged as defined in Table 2-3A.	
(2.1.4.5.1, 2.1.5.5.1)			The discriminator (Δ) shall be based upon an average of correlator spacings within the specified range.	
(2.1.4.5.1, 2.1.5.5.1)			For the Double Delta (DD) DLL discriminators of the type $\Delta = 2\Delta_{d1} - \Delta_{2d1}$ tracking GPS satellites, the pre-correlation bandwidth of the installation, correlator spacings (d_1 and $2d_1$) and the differential group delay shall be within the range as defined in Table 2-3B.	
(2.1.4.5.1, 2.1.5.5.1)			For the DD DLL Discriminators, the pre-correlation filter shall roll-off by at least 30 dB per octave in the transition band.	

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
SBAS Tracking Constraints (2.1.4.5.2, 2.1.5.5.2)			For the E-L and DD DLL discriminator tracking SBAS satellites, the pre-correlation bandwidth of the installation, correlator spacing, (d, d_1 and $2d_1$) and the differential group delay shall be within the range as defined in Table 2-3C.	
(2.1.4.5.2, 2.1.5.5.2)			For the DD DLL Discriminators, the pre-correlation filter shall roll-off by at least 30 dB per octave in the transition band.	
Correlation Peak Validation (2.1.4.6, 2.1.5.6)			The equipment shall acquire the main C/A code correlation peak for each GPS and WAAS ranging source used for the navigation solution.	
(2.1.4.6, 2.1.5.6)			For Double Delta DLL discriminators, the equipment shall operate at the correct tracking point corresponding to the strongest peak within the main C/A code correlation peak.For Double Delta DLL discriminators, the equipment shall ensure that it is operating at the correct tracking point corresponding to the strongest correlation peak in the presence of faulted satellite signals.	
Dynamic Tracking (2.1.2.5, 2.1.3.5, 2.1.4.7, 2.1.5.7)	When the aircraft has dynamics within normal maneuvers defined by the maximum ground speeds and accelerations shown below, the equipment shall meet the accuracy requirements of 2.1.2.1 and the satellite acquisition time requirements of 2.1.1.8 and the satellite reacquisition requirements of 2.1.1.9.	When the aircraft has dynamics within normal maneuvers defined by the maximum ground speeds and accelerations shown below, the equipment shall meet the accuracy requirements of 2.1.3.1 and the satellite acquisition time requirements of 2.1.1.8 and the satellite reacquisition requirements of 2.1.1.9.	When the aircraft has dynamics within normal maneuvers defined by the maximum ground speeds and accelerations shown below, the equipment shall output positions meeting the accuracy requirements of Section 2.1.4.1 and the satellite acquisition time requirements of 2.1.1.8 and the satellite reacquisition requirements of 2.1.1.9.	
(2.1.2.5, 2.1.3.5, 2.1.4.7, 2.1.5.7)	During abnormal maneuvers, the equipment shall not output misleading information.			
(2.1.2.5, 2.1.3.5, 2.1.4.7, 2.1.5.7)	When the aircraft returns to normal maneuvers from abnormal maneuvers, the equipment shall meet the steady-state reacquisition requirements of Section 2.1.1.9.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.2.5, 2.1.3.5, 2.1.4.7, 2.1.5.7)	During the abnormal maneuver period, loss-of-navigation capability and loss-of-integrity monitoring alerts and outputs shall function as specified.			
Position Output (2.1.2.6, 2.1.3.6, 2.1.4.8, 2.1.5.8)	The GPS/WAAS equipment shall determine a position for navigation.			
(2.1.2.6, 2.1.3.6, 2.1.4.8, 2.1.5.8)	This position shall represent the WGS-84 position of the aircraft antenna (or center of navigation) at the time of applicability.			
(2.1.2.6, 2.1.3.6, 2.1.4.8)	The equipment shall provide an electronic data interface capable of transmitting digital data containing position, velocity, integrity and other pertinent data.			
(2.1.5.8)				Class Beta-3 shall output this position (latitude, longitude, and height above WGS-84 ellipsoid).
Position Output Update Rate (2.1.2.6.1, 2.1.3.6.1, 2.1.4.8.1, 2.1.5.8.1)	The minimum update rate of position outputs used for navigation shall be once per second.			The GPS/WAAS Class Beta 3 equipment shall compute and output position at a 5 Hz rate to support an unaugmented GLS and APV-II navigator.
(2.1.5.8.1)				The equipment shall compute and output at a 1 Hz rate to support a GLS and APV-II navigator that is augmented by a separate sensor providing at least 5 Hz data (e.g., inertial).

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.1.5.8.1)				Each computed position shall be dynamically independent of the previous position.
Position Output Latency (2.1.2.6.2, 2.1.3.6.2, 2.1.4.8.2, 2.1.5.8.2)	The latency of the position output, defined as the interval between the time of the measurement and the time of applicability of the position, shall be less than or equal to 500 milliseconds.			For Class Beta-3 equipment that supports an unaided GLS and APV-II navigator, the overall latency, defined as the interval between the time of measurement and time of applicability of the measurement, shall not exceed 300 msec.
(2.1.5.8.2)				The output of the data defining the position shall also be completed prior to 300 milliseconds after the time of the measurement.
(2.1.2.6.2, 2.1.3.6.2, 2.1.4.8.2, 2.1.5.8.2)	The data defining the position shall be output prior to 200 milliseconds after the time of applicability.			Class Beta-3 equipment that supports a GLS and APV-II navigator that is aided by a separate sensor shall have overall latency that does not exceed 400 milliseconds, and the output of data defining the position shall also be completed prior to 400 milliseconds after the time of the measurement.

TABLE N-2 CLASS GAMMA REQUIREMENTS

MOPS Requirement	**En Route / Terminal Mode**	**NPA Mode**	**LNAV/VNAV**	**APV-II / GLS**
General Human Factors (2.2.1.1)	Where multiple actions are necessary to accomplish a function, the equipment shall provide contextual information of the active subfunction or mode (e.g., NAV, FPL).			
Operation (2.2.1.1.1.1)	Controls that are normally adjusted in flight shall be accessible without interfering with the visibility of critical displays.			
(2.2.1.1.1.1)	Controls shall provide clear tactile or visual feedback when operated.			
(2.2.1.1.1.1)	The controls shall be movable without excessive effort and detents shall be well defined.			
(2.2.1.1.1.1)	Control spacing, physical size, and control logic shall be sufficient to avoid inadvertent activation.			
(2.2.1.1.1.1)	Controls shall be operable with the use of only one hand.			
Control Labels (2.2.1.1.1.2)	Labels shall be readable from viewing distances of 30 inches, under anticipated lighting conditions (Section 2.5.11.3.2).			
Equipment Operating Procedures (2.2.1.1.2)	Use of prompting cues shall be consistent.			
Minimum Workload Functions (2.2.1.1.3)	The tasks shown in Table 2-4 shall be capable of being accomplished within the indicated time (as a bench test without distraction).			
Discriminability (2.2.1.1.4.1)	Alert and symbols shall be distinctive and discriminable from one another.			
(2.2.1.1.4.1)	If a control is used to perform multiple functions, the functionality shall be clearly distinguished.			
Brightness, contrast, and color (2.2.1.1.4.2)	Displays shall be readable and colors shall be discriminable under anticipated lighting conditions (Section 2.5.11.3.2).			
(2.2.1.1.4.2)	When color is used to distinguish between functions and indications, red shall not be used other than for warning indications (hazards which may require immediate corrective action).			
(2.2.1.1.4.2)	Amber (yellow) shall be reserved for caution indicators.			
Angle of Regard (2.2.1.1.4.3)	All displays shall be fully readable up to a horizontal viewing angle of 35 degrees from normal to the face of the display screen.			
(2.2.1.1.4.3)	They shall be fully readable up to a vertical viewing angle of 20 degrees from normal to the face of the display screen.			
Alphanumerics (2.2.1.1.4.5)	Display of letters and numbers depicting primary data shall be readable from viewing distances of 30 inches under anticipated lighting conditions (Section 2.5.10.2.2).			
(2.2.1.1.4.5)	Except on map displays, the initial approach, final approach, missed approach and missed approach holding waypoints shall be labeled clearly when used as part of an approach procedure.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Moving Map (2.2.1.1.4.6)	Map scale shall be appropriate and clear.			
(2.2.1.1.4.6)	Map update rates shall be appropriate for approach, terminal and en route operations.			
(2.2.1.1.4.6)	Map orientation, such as north-up or track-up, shall be capable of being displayed on the map page and shall be pilot selectable, if multiple orientations are available.			
(2.2.1.1.4.6)	Location and track of the aircraft shall be shown on the plan view and on the profile view if available.			
(2.2.1.1.4.6)	The display of obstructions shall reflect database precision.			
Primary Navigation Display (2.2.1.1.4.7)	If a selectable display is used for this purpose, reconfiguring the display to access the primary navigation information shall require a maximum of two operator actions.			
Bearing Labels (2.2.1.1.4.8)	All bearing data fields shall be labeled as “°” to the right of the bearing value.			
(2.2.1.1.4.8)	All true bearing data fields shall be labeled as “°T” to the right of the bearing value.			
Annunciations (2.2.1.1.5)	Visual annunciations shall be consistent with the criticality of the annunciation and shall be readable under all cockpit illumination conditions (See Section 2.5.11.3.2).			
(2.2.1.1.5)	Visual annunciations shall not be so bright or startling as to reduce pilot dark adaptation.			
Annunciators (2.2.1.1.5.1)	Brightness shall be controllable, which does not preclude automatic adjustment.			
(2.2.1.1.5.1)	The equipment shall provide the capability to test all external annunciators.			
Messages (2.2.1.1.5.2)	All current messages shall be retrievable.			
(2.2.1.1.5.2)	An indication shall be provided to identify new messages.			
Set of Standard Function Labels (2.2.1.1.6)	If a function is implemented as a discrete action, the equipment shall use the labels or messages in the Table.			
(2.2.1.1.6)	If several of the following functions are accomplished as a discrete action, one of the applicable labels in Table 2-4 shall be used (e.g., suspend automatic sequencing and accessing the ability to select a course to or from a waypoint would be labeled “DCRS”).			
(2.2.1.1.6)	Except for waypoint identifiers, these abbreviations shall not be used to represent a different term.			
(2.2.1.1.6)	[1] If this function is accomplished using a button, it shall be labeled “OBS” to avoid confusion with “CRSR”.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Set of Standard Abbreviations (2.2.1.1.7)	These abbreviations should not be used to represent a different term, and they shall be used consistently in the design of the pilot handbook supplements, quick reference checklists and the controls and displays of the equipment.			
Flight Plan Selection (2.2.1.2.1)	The equipment shall be capable of accommodating an active flight plan of at least twenty discrete waypoints.			
(2.2.1.2.1)	The equipment shall also be capable of maintaining at least one alternate flight plan.			
(2.2.1.2.1)	The equipment shall be capable of creating these flight plans, consisting of at least the following items, strung together in any order: (a) The ability to select a procedure by name, and automatically include the series of waypoints and paths that define the procedure (refer to database requirements in Sections 2.2.3.5 and 2.2.4.5, for a discussion of the appropriate procedures); (b) The ability to individually select waypoints by name as part of the flight plan. Waypoint names shall be consistent with published names. The equipment shall provide a minimum 5-character field for input and display of database fix identifiers. Airport identifiers shall be accessible using standard ICAO nomenclature when available (e.g., KJFK); (c) The ability to manually select user-defined waypoints as part of the flight plan. (The equipment must provide the capability to manually enter user-defined waypoints as required in Section 2.2.1.2.6.)			
(2.2.1.2.1)	The equipment shall provide a means for the operator to differentiate between duplicate waypoint identifiers in the database, including waypoints in the navigation database and user defined waypoints.			
Flight Plan Review (2.2.1.2.2)	The equipment shall provide a means to readily display each waypoint of any flight plan for review.			
(2.2.1.2.2)	The active leg or waypoint shall be identified as such.			
(2.2.1.2.2)	The equipment shall provide the ability to edit the flight plan, including the ability to insert or delete any waypoint in the flight plan other than those waypoints which are part of a published procedure (departure, arrival, approach).			
(2.2.1.2.2)	For those waypoints, which are part of a published procedure, the equipment shall provide the capability to bypass waypoints or proceed to a waypoint not part of the published procedure.			
(2.2.1.2.2)	Modifying the final approach segment (i.e., inserting a waypoint between the FAWP and MAWP or bypassing the FAWP or MAWP) shall disable the approach mode.			
(2.2.1.2.2)	The equipment shall allow the operator to replace a procedure (i.e., departure, arrival or approach) with a different procedure without first deleting the procedure.			
(2.2.1.2.2)	The equipment shall prompt the operator before replacing a procedure.			
(2.2.1.2.2)	When a flight plan is being reviewed or edited, any change shall not be incorporated into the flight plan until that change has been accepted.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.1.2.2)	The time lag between accepting changes to an active flight plan and outputting navigation guidance derived from the modified flight plan shall not exceed five seconds.			
Flight Plan Activation (2.2.1.2.3)	Means shall be provided for the pilot to select and activate a flight plan.			
(2.2.1.2.3)	Prior to activating the flight plan, the equipment shall ensure that the data in the flight plan or obtained from the database is valid.			
(2.2.1.2.3)	If the database is not available or fails a verification check, the equipment shall continue to function, preventing access to the invalid data (but still providing access to valid data, including user-defined waypoint functions).			
Waypoint Sequencing (2.2.1.2.4)	For To-To navigation, the equipment shall automatically sequence waypoints in the active flight plan.			
(2.2.1.2.4)	If automatic sequencing is suspended for any reason, the equipment shall retain the active flight plan for later selection.			
(2.2.1.2.4)	If the equipment provides the capability to suspend and unsuspend automatic sequencing as a discrete action (SUSP), the equipment shall continuously annunciate when waypoint sequencing has been suspended.			
(2.2.1.2.4)	When the pilot deselects SUSP mode, automatic sequencing of waypoints shall resume upon reaching the current waypoint if the current waypoint is in the flight plan.			
Direct To (2.2.1.2.5.1)	The equipment shall provide the capability to fly from the present position Direct To any designated waypoint.			
TO/FROM Course Selection (2.2.1.2.5.2)	The equipment shall provide a means of selecting and displaying an active waypoint and a desired course TO or FROM that way-point.			
(2.2.1.2.5.2)	The minimum entry and display resolution of such a selected course shall be 1 degree.			
(2.2.1.2.5.2)	The equipment shall provide the capability to intercept any course to a designated waypoint (CF path).			
(2.2.1.2.5.2)	The equipment shall provide an indication, capable of installation in the normal field of view, of whether the equipment is in TO or FROM operation.			
Manually-Selected Waypoint and Waypoint Sequencing (2.2.1.2.5.3)	If the desired "TO" waypoint is selected from the active flight plan, automatic sequencing of the remaining waypoints in the active flight plan shall continue following the "TO" waypoint.			
(2.2.1.2.5.3)	If the desired "TO" waypoint is **not** selected from the active flight plan, the waypoints in that flight plan shall be retained.			
(2.2.1.2.5.3)	When the manually selected waypoint is crossed, the equipment shall automatically enter FROM operation, maintaining the prior track.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.1.2.5.3)	The equipment shall remain in FROM operation until the pilot manually selects another TO waypoint, either on the active flight plan or not.			
User-Defined Waypoints (2.2.1.2.6)	The equipment shall provide the capability to manually enter and display (prior to its utilization in the flight plan) the coordinates of a waypoint in terms of latitude and longitude with a resolution of 0.1 minute or better.			
(2.2.1.2.6)	The equipment shall also provide the capability to create a waypoint at the present position.			
(2.2.1.2.6)	The equipment shall provide the ability to enter a waypoint as a range and bearing from another waypoint, with range resolution of 0.1 nm and bearing resolution of 1 degree or better.			
Emergency Procedures (2.2.1.2.7)	The equipment shall provide the capability to determine at least the nearest (NRST) 9 airports, and shall provide the capability to fly directly to any of them.			
Approach Selection (2.2.3.2.1)		For procedures with multiple IAWPs, the system shall present all IAWPs and provide the capability for pilot selection of the desired IAWP.		
(2.2.3.2.1)		After selection and entry of the desired IAWP into the flight plan, the remaining waypoints for the approach and missed approach shall automatically be inserted in the flight plan in the proper sequence.		
(2.2.3.2.1)		The equipment shall provide the capability for the pilot to manually select a VTF approach, indicating that the pilot does not intend to fly the entire procedure.		

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.3.2.1)		Until the FAWP has been sequenced, the equipment shall indicate, either continuously or on the primary navigation display, that a VTF approach has been selected.		
Path Selection (2.2.4.2, 2.2.5.2)			The equipment shall enable the pilot to select the approach path of the aircraft through either of two means: (1) by selecting a 5-digit channel number, then selecting the desired initial approach fix or VTF; or (2) by selecting the airport, runway, approach identifier and initial approach fix.	
(2.2.4.2, 2.2.5.2)			Both methods shall be implemented by WAAS Gamma equipment.	
(2.2.4.2, 2.2.5.2)			Once the approach has been selected, the approach name (airport, runway, route indicator) and Reference Path Identifier shall be accessible for display.	
5-Digit Channel Selection (2.2.4.2.1, 2.2.5.2.1)			For procedures defined by a FAS data block (see Section 2.2.4.3.1), entry of the channel number shall result in the database providing to the navigation equipment the FAS data block.	
(2.2.4.2.1, 2.2.5.2.1)			Subsequent selection of the initial approach fix shall result in selection of the entire approach procedure including missed approach.	
(2.2.4.2.1, 2.2.5.2.1)			The equipment shall provide a means for the operator to differentiate between duplicate channel numbers (approaches) in the database.	
Approach Name Selection (2.2.4.2.2, 2.2.5.2.2)			WAAS equipment shall provide the capability to select approaches as defined in Section 2.2.3.2.1.	
(2.2.4.2.2, 2.2.5.2.2)			Once a procedure has been selected, the equipment shall automatically obtain the appropriate Final Approach Segment data for those approaches where it is defined.	

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Missed Approach Sequencing (2.2.3.2.2, 2.2.4.2.3, 2.2.5.2.3)		The equipment shall allow the pilot to initiate the missed approach with manual action.	The equipment shall allow the pilot to initiate the missed approach in accordance with Section 2.2.3.2.2.	
(2.2.3.2.2, 2.2.4.2.3, 2.2.5.2.3)		It shall be possible to take this action before crossing the MAWP, in which case the equipment shall automatically initiate the missed approach procedure at the MAWP.	If the aircraft is past the FPAP - (length offset), and the pilot has not already activated the missed approach, the receiver shall automatically transition to missed approach guidance.	
Selection of the Type of Approach with Vertical Guidance (2.2.4.2.4, 2.2.5.2.4)			The equipment shall provide a means to select which type of approach with vertical guidance will be conducted.	
Path Definition (2.2.1.3)	The GPS/WAAS equipment shall define a desired flight path based upon the active flight plan.			
(2.2.1.3)	The current position of the aircraft shall be determined relative to that desired path in order to determine cross-track deviation.			
(2.2.1.3)	Except as specifically noted, the equipment shall auto-sequence from one waypoint to the next, in accordance with the flight plan, along the flight path.			
(2.2.1.3)	The desired path shall be defined according to the leg type: TF leg: straight segment between two waypoints; CF leg: straight segment following a course to a waypoint; FROM leg: straight line following a course from a waypoint.			
(2.2.1.3)	In defining any leg that is predicated on course guidance, the local declination (if available from the database) shall be used; otherwise the mag-var model shall be used			
(2.2.1.3)	If the equipment is designed to perform DME arcs or RF legs (constant radius turn segment), it shall meet the requirements in Section 2.2.1.3.3.			
(2.2.1.3)	The equipment shall not permit the flight crew to select a procedure or route that is not supported by the equipment, either manually or automatically (e.g., a procedure is not supported if it incorporates an RF leg if the equipment does not provide RF leg capability).			
Fixed Waypoint to a Fixed Waypoint (TF) (2.2.1.3.2)	A TF leg shall be defined by a WGS-84 geodesic path between two fixed waypoints (Figure 2-4).			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
DME Arcs (AF) Constant Radius to a Fix (RF) (2.2.1.3.3)	If the ability to perform DME arcs is provided, the equipment shall permit the pilot to readily accomplish such procedures in accordance with published non-precision approach procedures utilizing piloting techniques similar to those applicable to use of the reference DME facility.			
(2.2.1.3.3)	If the equipment is designed to perform RF legs, an RF leg shall be defined by a constant radius circular arc path about a defined turn center that terminates at a fixed waypoint.			
(2.2.1.3.3)	The radius shall be computed as the distance from the turn center to the termination waypoint by the navigation computer.			
(2.2.1.3.3)	The beginning of the leg shall be defined by the termination waypoint of the previous leg, which must also lie on the arc.			
Direct-To (2.2.1.3.4)	The navigation system shall have a Direct-To function that has the following characteristics: a. The Direct-To function shall be able to be activated at any time by the flight crew, when required. The Direct-To function shall be available to any fix, b. The system shall be capable of generating a geodesic path to the designated "To" fix. The aircraft shall capture this path without "S-turning" and without undue delay.			
Course to a Fix Waypoint (CF) (2.2.1.3.5)	A CF leg shall be defined by a WGS-84 geodesic path that terminates at a fixed waypoint with a defined course.			
FROM Leg (2.2.1.3.6)	The equipment shall provide the capability to define a desired course from a waypoint.			
(2.2.1.3.6)	That course shall define a WGS-84 geodesic path that passes through the FROM waypoint with the desired course.			
Fly-By Turns (2.2.1.3.7)	The equipment shall provide fly-by turn capability.			
(2.2.1.3.7)	Unless otherwise designated by a procedure, all turns with heading changes of less than or equal to120 degrees shall be accomplished as fly-by turns.			
Fly-By Turn Indications (2.2.1.3.7.1)	The equipment shall provide an indication at the start of a defined turn, to indicate to the pilot that the turn has begun. (See Figure 2-10.)			
(2.2.1.3.7.1)	The equipment shall provide an indication prior to the start of a defined turn, to indicate to the pilot that a turn is anticipated.			
(2.2.1.3.7.1)	The equipment shall provide an indication of the desired course of the next active leg no later than the onset of the turn anticipation indication.			
Fly-By Theoretical Transition Area (2.2.1.3.7.2)	The defined path shall ensure that the turn is accomplished within the theoretical transition area defined below.			
Fly Over Turns (2.2.1.3.8)	The equipment shall define a path to accomplish fly-over turns that passes through the transition waypoint.			

MOPS Requirement	**En Route / Terminal Mode**	**NPA Mode**	**LNAV/VNAV**	**APV-II / GLS**
Waypoint Sequencing (2.2.1.3.10)	The equipment shall provide an indication when a waypoint is sequenced (crossed).			
(2.2.1.3.10)	If cross-track deviations are provided relative to a curved path through the turn at a waypoint and the estimated position is within the theoretical transition area, the waypoint shall be sequenced when the estimated position crosses the bisector of the angle defined by the leg on either side of the waypoint. (See Figure 2-10.)			
(2.2.1.3.10)	If cross-track deviations are not provided relative to a curved path through the turn at a waypoint, the waypoint shall be sequenced at the turn initiation point and deviations provided relative to the extension of the next leg.			
(2.2.1.3.10)	After sequencing past a waypoint, the equipment shall be capable of recalling it if necessary.			
(2.2.1.3.10)	When the final waypoint in the flight plan is the active waypoint, the equipment shall automatically switch to FROM operation at the active waypoint.			
Holding Patterns/ Procedure Turns (2.2.1.3.11)	The equipment shall provide the capability for accomplishment of holding patterns at any waypoint.			
(2.2.1.3.11)	The equipment shall provide the capability to accomplish procedure turns in accordance with published procedures.			
(2.2.1.3.11)	If automatic sequencing of the flight plan has been suspended, the equipment shall indicate the condition.			
(2.2.1.3.11)	Automatic sequencing of flight plan waypoints shall resume upon completion or cancellation of the suspended mode.			
Magnetic Course (2.2.1.3.12)	The source of the magnetic variation used for paths which are defined using magnetic course shall be in accordance with the following: (a) If the leg is part of a database terminal area procedure and the magnetic variation is specified by the State for that procedure, the magnetic variation to be used is the value specified for that procedure; (b) If the leg is not part of a procedure and the active fix is a VOR ,the magnetic variation to be used is the published station declination for the VOR; (c) If the leg is not part of a procedure and the terminating fix is not a VOR, the magnetic variation to be used shall be defined by the system using an internal model.			
(2.2.1.3.12)	The navigation system shall have the capability of assigning a magnetic variation at any location within the region that flight operations may be conducted using Magnetic North reference.			
(2.2.1.3.12)	The assigned magnetic variation shall be within two degrees of the value determined at the same location and time by an internationally recognized magnetic model that is valid for the time of computation (e.g., USGS, IGRF).			
Dead Reckoning (2.2.1.3.13)	The equipment shall provide a Dead Reckoning capability.			
(2.2.1.3.13)	The Dead Reckoning capability shall be active whenever no position can be obtained from GPS/WAAS.			
(2.2.1.3.13)	Dead Reckoning shall be clearly indicated to the pilot.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.1.3.13)	If automatic input of TAS or heading is not available, the equipment shall project the last known GPS/WAAS position forward using last known position, groundspeed and desired track.			
(2.2.1.3.13)	The equipment shall continue to navigate relative to the active flight plan.			
(2.2.1.3.13)	The equipment shall change its assumed track in accordance with the flight plan (i.e., if the flight requires out for a track change, the equipment assumes that the pilot performs the track change as displayed by the equipment).			
(2.2.1.3.13)	The equipment shall provide the capability to determine bearing to an airport, based upon the dead reckoning position (e.g., accessible via the nearest airport function described in Section 2.2.1.2.7).			
(2.2.1.3.13)	If this capability is provided and this information is available, the equipment shall project the last known GPS/WAAS position forward using TAS and heading, corrected for last known wind.			
(2.2.1.3.13)	The equipment shall continue to navigate using this position and the active flight plan.			
Geodesic Path Computation Accuracy (2.2.1.3.15)	The cross-track path deviation error between the computed path used to determine cross-track deviations and the true geodesic shall be less than 10% of the horizontal alert limit of the navigation mode applicable to the leg containing the path.			
Parallel Offsets (2.2.1.3.16)	The parallel offset function shall be available for enroute TF and the geodesic portion of DF leg types at a minimum.			
(2.2.1.3.16)	The system shall have the capability to fly parallel tracks at a selected offset distance.			
(2.2.1.3.16)	When executing a parallel offset, the navigation mode and all performance requirements of the original route in the active flight plan shall be applicable to the offset route.			
(2.2.1.3.16)	The system shall provide for entry of offset distance in increments of 1 nm, left or right of course.			
(2.2.1.3.16)	The system shall be capable of offsets of at least 20 nm.			
(2.2.1.3.16)	The fact that the system is operating in offset mode shall be clearly indicated to the flight crew.			
(2.2.1.3.16)	When in offset mode, the system shall provide reference parameters (e.g., cross-track deviation, distance-to-go, time-to-go) relative to the offset path and offset reference points.			
(2.2.1.3.16)	An offset shall not be propagated through route discontinuities, unreasonable path geometries, or beyond the initial approach fix.			
(2.2.1.3.16)	Annunciation shall be given to the flight crew prior to the end of the offset path, with sufficient time to return to the original path.			
(2.2.1.3.16)	Once a parallel offset is activated, the offset shall remain active for all flight plan route segments until removed automatically, until the flight crew enters a Direct-To routing, or until flight crew (manual) cancellation.			
Approach Path Definition (2.2.3.3.1, 2.2.4.3.1, 2.2.5.3.1)		If the pilot has not selected a VTF approach, deviations shall be provided with respect to the active leg of the approach procedure.		

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.3.3.1, 2.2.4.3.1, 2.2.5.3.1)		If the pilot has selected a VTF approach, deviations shall be provided relative to the inbound course to the FAF.		
(2.2.3.3.1, 2.2.4.3.1, 2.2.5.3.1)		The active waypoint shall initially be the FAWP.		
(2.2.3.3.1, 2.2.4.3.1, 2.2.5.3.1)		If the pilot has selected Direct-To the FAWP, and the difference between the desired track and the desired track of the final approach segment is greater than 45 degrees, the equipment shall indicate that the FAWP will not be sequenced (the intercept angle at the FAWP is too sharp).		
(2.2.3.3.1, 2.2.4.3.1, 2.2.5.3.1)		In this case, the equipment shall suspend automatic sequencing.		
(2.2.3.3.1, 2.2.4.3.1, 2.2.5.3.1)		The missed approach waypoint shall be a fly-over waypoint unless otherwise designated (see Section 2.2.1.3.7).		
(2.2.4.3.1, 2.2.5.3.1)			For procedures defined by a FAS data block, the final approach path shall be defined by the Flight Path Alignment Point (FPAP) and Landing Threshold Point/Fictitious Threshold Point (LTP/FTP), and by the Threshold Crossing Height (TCH) and glide-path angle.	
(2.2.5.3.1)				APV-II and GLS approaches shall only be available for procedures defined by a FAS data block.
Missed Approach Path Definition (2.2.3.3.2, 2.2.4.3.2, 2.2.5.3.2)		If a missed approach is not initiated prior to crossing the MAWP, the equipment shall automatically switch to FROM mode at the MAWP and continue on the same course.		
(2.2.3.3.2, 2.2.4.3.2, 2.2.5.3.2)		If the pilot initiates the missed approach, then the equipment shall provide guidance relative to the procedure.		
(2.2.3.3.2, 2.2.4.3.2, 2.2.5.3.2)		If a missed approach is initiated prior to crossing the MAWP, the desired path to and after the MAWP shall be defined by the procedure.		
(2.2.3.3.2, 2.2.4.3.2, 2.2.5.3.2)		The equipment shall be capable of using at least the following legs in defining missed approach procedures: TF, CF, and Direct-To.		
Departure Path Definition (2.2.3.3.3)	Class 1, 2 and 3 equipment shall provide guidance for departure procedures.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Vertical Path for NPA Procedures (2.2.3.3.4) When this capability is provided, then:		The vertical path shall be defined as described in Section 2.2.4.2.1 for LVAV/VNAV approaches.		
(2.2.3.3.4)		The vertical path shall be selected automatically when the lateral path is selected (Section 2.2.3.2).		
(2.2.3.3.4)		The equipment shall meet the requirements of Section 2.2.4.4.4 for non-numeric vertical deviation display.		
(2.2.3.3.4)		The equipment shall meet the requirements of Section 2.2.4.4.9 for display of vertical accuracy.		
(2.2.3.3.4)		The equipment shall meet the requirements of Section 2.2.4.6 for LVAV/VNAV alerts.		
Navigation Center Offset (2.2.4.3.3, 2.2.5.3.3)			The equipment shall provide a means for compensating for the navigation center offset for each installation.	
(2.2.4.3.3, 2.2.5.3.3)			The equipment shall not provide the flight crew with a means of changing information associated with this compensation during flight.	
Primary Navigation Display (2.2.1.4.1)	At a minimum, the non-numeric cross-track deviation shall be continuously displayed in all navigation modes (either on an internal or on an external display).			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.1.4.1)	At a minimum, the following navigation parameters shall be displayed, either continuously or on the selectable display, in all navigation modes (either on an internal or an external display): (a) Active waypoint distance or estimated time en route to the active waypoint; (b) Active waypoint name; (c) Active waypoint bearing; (d) (Desired track and actual track) or track angle error; e) Indication of navigation TO or FROM the active waypoint.			
(2.2.1.4.1)	Distance, bearing, desired track, actual track, and track angle error shall be distinguishable.			
(2.2.4.4.1, 2.2.5.4.1)			Nonnumeric vertical deviation shall be continuously displayed when in LNAV/VNAV.	Nonnumeric vertical deviation shall be continuously displayed when in GLS or APV-II
Electrical Output (2.2.1.4.2.1)	If the equipment does not include a non-numeric cross-track (and vertical deviation for precision approach) display, or intends to drive other displays, it shall provide an electrical output capable of driving a display.			
(2.2.1.4.2.1)	The electrical output shall have the following characteristics shown in Table 2-6.			
Display (2.2.1.4.2.2)	If the equipment provides a non-numeric display of cross-track deviation (or vertical deviation for precision approach) that is intended to substitute for an external display, the GPS/WAAS equipment display shall have the following characteristics shown in Table 2-7.			
Active Waypoint Distance Display (2.2.1.4.3)	When in TO operation, the distance to the active waypoint shall be displayed.			
(2.2.1.4.3)	When in FROM operation, the distance from the active waypoint shall be displayed.			
(2.2.1.4.3)	The distance shall be displayed with a resolution of 0.1 nm up to a range of 99.9 nm from the waypoint, and 1 nm between 100 nm and 9999 nm.			
Active Waypoint Bearing Display (2.2.1.4.4)	The equipment shall provide the capability to display bearing to the active waypoint.			
(2.2.1.4.4)	If this capability is provided, there shall be an indication of whether the displayed bearing is to the waypoint or from the waypoint.			
(2.2.1.4.4)	The bearing shall be displayed with a resolution of 1 degree.			
(2.2.1.4.4)	The equipment shall be capable of displaying the bearing in true or magnetic bearing as selected.			
Desired Track (2.2.1.4.5.1)	The equipment shall display the desired track (DTK) of the active leg expressed as a course in units of degrees with 1° resolution.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Track Angle (2.2.1.4.5.2)	The track angle shall be displayed with 1° resolution.			
Track Angle Error (2.2.1.4.5.3)	The track angle error shall be displayed with 1° resolution.			
Display of TO or FROM Operation (2.2.1.4.6)	The equipment shall provide a continuous indication of whether it is in TO or FROM operation (either integrated or on a separate display).			
Waypoint Bearing/ Distance Display (2.2.1.4.7)	The equipment shall be capable of displaying the distance and bearing to any selected waypoint.			
(2.2.1.4.7)	For waypoints in the active flight plan, the equipment shall be capable of displaying the estimated time to arrive at the waypoint (this calculation may assume current groundspeed).			
Magnetic Course (2.2.1.4.9)	For the display of navigation data in magnetic degrees, the following conventions shall be used: (a) DTK: The desired track is based on true-to-magnetic conversion at the user location, using the magnetic model; (b) BRG to or from a waypoint other than a VOR: The bearing is based on true-to-magnetic conversion at the user location, using the magnetic model; (c) BRG to or from a VOR: The bearing is based on the true-to-magnetic conversion at the waypoint location, using the same magnetic conversion as used to define the path; (d) CRS (OBS): The magnetic course is based on the true-to-magnetic conversion at the waypoint location, using the same magnetic conversion as used to define the path.			
Ground Speed (2.2.1.4.10)	The equipment shall provide a display of ground speed with one knot resolution.			
Aircraft Present Position (2.2.1.4.11)	The equipment shall provide a display of the aircraft present position in latitude and longitude with 0.1 minute resolution.			
Non-Numeric Cross-Track Deviation (2.2.2.4.2)	Full-scale deflection (FSD) in oceanic/remote mode shall not exceed ± 5 nm.			
(2.2.2.4.2)	Full-scale deflection in en route mode shall be ± 2 nm.			
(2.2.2.4.2)	Full-scale deflection in terminal mode shall be ± 1 nm.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.3.4.2)		The full-scale deflection for nonprecision approach mode shall either be identical to the precision approach mode as defined in 2.2.4.4.2 (only possible for procedures with FAS path definition records); or shall be as follows:		
(2.2.3.4.2)		If a VTF approach has not been selected: Prior to 2nm from the FAWP, the FSD shall be ±1 nm;		
(2.2.3.4.2)		If a VTF approach has not been selected: Between 2 nm from the FAWP and the FAWP, the FSD shall gradually change to the FSD specified in (c) below at the FAWP;		
(2.2.3.4.2)		If a VTF approach has not been selected: At and beyond the FAWP, but before initiating a missed approach, the full-scale deflection shall be the minimum of: constant FSD of ± 0.3 Nautical Miles (NM); or angular Full-Scale Deflection (FSD) defined by a ± 2.0 degree wedge with origin located 10,000 feet past the MAWP.		

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.3.4.2)		The FSD shall continue to decrease or shall reach a minimum of ± 350 feet.		
(2.2.3.4.2)		If a Vector-to-Final (Approach) (VTF) has been selected, the FSD shall be the minimum of: constant FSD of ± 1 nm; or angular FSD defined by a ± 2.0 degree wedge with origin located 10,000 feet past the Missed Approach Waypoint (MAWP).		
(2.2.3.4.2)		The FSD shall continue to decrease or shall reach a minimum of ± 350 feet.		
(2.2.3.4.2)		The full-scale deflection shall change to ±0.3 nm when a missed approach is initiated.		
(2.2.4.4.2, 2.2.5.4.2)			Positive lateral deviation shall correspond to aircraft positions to the left of the lateral deviation reference plane, as observed from the LTP/FTP facing toward the FPAP.	

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.4.2, 2.2.5.4.2)			If in LNAV/VNAV and a VTF has not been selected, the lateral deviation shall be as follows: a) Prior to the FAWP, the deviation shall be either: (i) Prior to 2 nm from the FAWP, the deviation shall be linear, with FSD for a cross-track error of ±1 nm. Between 2 nm from the FAWP and the FAWP, the deviation sensitivity shall gradually change to the final approach segment lateral deviation sensitivity (Figure 2-16a); or (ii) The deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$ (Figure 2-16b). b) Between the FAWP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$; c) Between the LTP/FTP and the length offset distance to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ±(Course Width at LTP/FTP).	If in GLS or APV-II and a VTF has not been selected, the lateral deviation shall be as follows: a) Prior to the FAWP, the deviation shall be either: (i) Prior to 2 nm from the FAWP, the deviation shall be linear, with FSD for a cross-track error of ±1 nm. Between 2 nm from the FAWP and the FAWP, the deviation sensitivity shall gradually change to the final approach segment lateral deviation sensitivity (Figure 2-16a); or (ii) The deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$ (Figure 2-16b); b) Between the FAWP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$; c) Between the LTP/FTP and the length offset distance to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ±(Course Width at LTP/FTP).

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.4.2, 2.2.5.4.2)			If in LNAV/VNAV and a VTF has been selected, the lateral deviation shall be as follows: a) Prior to the LTP/FTP, the deviation shall be either: (i) At a distance greater than $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP, the deviation shall be linear with FSD for a cross-track error of ±1 nm. Between $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation (Figure 2-16a); or (ii) The deviation shall be the final approach segment lateral deviation with FSD for a cross-track error of $\alpha_{lat,FS}$ (Figure 2-16b). b) Between the LTP/FTP and the length offset distance to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ±(Course Width at LTP/FTP); c) Beyond the length offset distance to the FPAP, the deviation shall be linear with FSD for a cross-track displacement of ±0.3 nm.	If in GLS or APV-II and a VTF has been selected, the lateral deviation shall be as follows: (a)At a distance greater than $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP, the deviation shall be linear with FSD for a cross-track error of ±1 nm; (b) Between $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation; (c) Between the LTP/FTP and the length offset distance to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ±(Course Width at LTP/FTP); (d) Beyond the length offset distance to the FPAP, the deviation shall be linear with FSD for a cross-track displacement of ±0.3 nm.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.4.2, 2.2.5.4.2)			When a missed approach is initiated, the deviation shall be linear with FSD for a cross-track error of ± 0.3 nm.	
Numeric Cross-Track Deviation (2.2.2.4.3, 2.2.3.4.3, 2.2.4.4.3, 2.2.5.4.3)	When in oceanic/remote, en route, or terminal mode, the equipment shall provide either a display or electrical output of cross-track deviation with a range of at least ± 20 nm (left and right).	When in nonprecision approach, LNA/VNAV, APV-II or GLS, the equipment shall provide either a display or electrical output of cross-track deviation with a range of at least ± 9.99 nm (left and right).		
(2.2.2.4.3, 2.2.3.4.3, 2.2.4.4.3, 2.2.5.4.3)	The equipment shall provide a resolution of 0.1 nm for deviations up to 9.9 nm, and a resolution of 1 nm for deviations greater than 9.9 nm.	The equipment shall provide a resolution of 0.01 nm for deviations up to 9.99 nm, and a resolution 0.1 nm for deviations greater than 9.99 nm (if provided).		
Displayed Data Update Rate (2.2.2.4.4, 2.2.3.4.6, 2.2.4.4.7, 2.2.5.4.7)	The equipment shall update required data presented by a display at a rate of 1 Hz or more.		The equipment shall update non-numeric deviation data presented by a display at a rate of 5 Hz or more.	
(2.2.4.4.7)			The deviation update shall be based on a dynamically independent position (reference 2.1.5.8.1) at a minimum of 1 Hz.	
(2.2.5.4.7)				Each deviation update shall be dynamically independent (Reference Section 2.1.4.6.1)

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Display Update Latency (2.2.2.4.5, 2.2.3.4.7, 2.2.4.4.8, 2.2.4.5.8)	Latency of the display or electrical output shall not exceed 1 second for required data, from the time of applicability of the position solution to the time the corresponding information is displayed/output.		For the LNAV/VNAV navigator, the overall latency, defined as the interval between the time of measurement and time of applicability of the measurement, shall not exceed 400 milliseconds.	For the GLS or APV-II navigator, the overall latency, defined as the interval between the time of measurement and time of applicability of the measurement, shall not exceed 400 milliseconds.
(2.2.4.4.8, 2.2.4.5.8)			The output of the data defining the position shall also be completed prior to 400 milliseconds after the time of the measurement.	
Missed Approach Waypoint Distance Display (2.2.3.4.4, 2.2.4.4.5, 2.2.5.4.5)	When in terminal or nonprecision approach mode, the distance to the missed approach waypoint shall be available for display until the MAWP is sequenced.		When in terminal and approach modes, prior to crossing the LTP/FTP when an approach procedure is selected in the active flight plan, the distance to the LTP/FTP shall be available for display.	
(2.2.3.4.4, 2.2.4.4.5, 2.2.5.4.5)	The distance shall be displayed with a resolution of 0.1 nm up to a range of 99.9 nm.			
Missed Approach Waypoint Bearing Display (2.2.3.4.5, 2.2.4.4.6, 2.2.5.4.6)	When in terminal or nonprecision approach mode, the bearing to the missed approach waypoint shall be available for display until the MAWP is sequenced.		When in terminal and approach modes, prior to crossing the LTP/FTP when an approach procedure is selected in the active flight plan, the bearing to the LTP/FTP shall be available for display.	
(2.2.3.4.5, 2.2.4.4.6, 2.2.5.4.6)	The bearing shall be displayed with a resolution of 1 degree.			
(2.2.3.4.5, 2.2.4.4.6, 2.2.5.4.6)	The equipment shall be capable of displaying the bearing in true or magnetic bearing as selected.			
Non-Numeric Vertical Deviation (2.2.4.4.4, 2.2.5.4.4)			When in LNAV/VNAV, the equipment shall continuously provide guidance in the form of an analog or digital output with signals meeting the requirements of Section 2.2.1.4.2.	When in GLS or APV-II, the equipment shall continuously provide guidance in the form of an analog or digital output with signals meeting the requirements of Section 2.2.1.4.2.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.4.4, 2.2.5.4.4)			The vertical deviation shall be as follows: a)At a distance greater than $\frac{45m}{\tan(\alpha_{vert,FS})}$, the vertical deviation shall be either: (i) At a distance greater than $\frac{150m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be linear with FSD for a vertical error of 150 m. Between $\frac{150m}{\tan(\alpha_{vert,FS})}$ and $\frac{45m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be the final approach segment vertical deviation (Figure 2-17a); or (ii) The deviation shall be the final approach segment vertical deviation with FSD for a vertical error of $\alpha_{vert,FS}$ (Figure 2-17b). b) Closer than $\frac{45m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be linear with FSD for a vertical error of ±45 m.	The vertical deviation shall be as follows: a) At a distance greater than $\frac{15m}{\tan(\alpha_{vert,FS})}$, the vertical deviation shall be either: (i) At a distance greater than $\frac{150m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be linear with FSD for a vertical error of 150 m. Between $\frac{150m}{\tan(\alpha_{vert,FS})}$ and $\frac{15m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be the final approach segment vertical deviation (Figure 2-17a); or (ii) The deviation shall be the final approach segment vertical deviation with FSD for a vertical error of αvert,FS (Figure 2-17b) b) Closer than $\frac{15m}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be either the final approach segment vertical deviation or linear with FSD for a vertical error of ±15 m.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.4.4, 2.2.5.4.4)			Vertical deviations shall be flagged as invalid if: a) The lateral position of the aircraft is outside of a ± 35 degree wedge with origin at the GARP, centered on the FAS; and b) The aircraft is not on the approach side of the GPIP.	
(2.2.4.4.4, 2.2.5.4.4)			When a missed approach is initiated, the vertical deviations for approach shall be flagged as invalid.	
Display of Vertical Accuracy (2.2.4.4.9, 2.2.5.4.9)			The equipment shall make available for display the 95%-confidence vertical accuracy.	
Database Access (2.2.1.5.1)	Manual entry/update of the navigation database data defined in Sections 2.2.1.5.2, 2.2.3.5 and 2.2.4.5.1 shall not be possible.			
(2.2.1.5.1)	When data are recalled from storage they shall also be retained in storage.			
(2.2.1.5.1)	Updating of the navigation database shall be accomplished using a high-integrity data validation technique such as a cyclic redundancy check (CRC).			
(2.2.1.5.1)	The system shall provide a means to identify the navigation data base version and valid operating period.			
(2.2.1.5.1)	The equipment shall indicate if the database is not yet effective or out of date.			
Database Content (2.2.1.5.2)	The equipment shall provide an updatable navigation database containing at least the following location and path information, referenced to WGS-84 or equivalent, with a resolution of 0.01 minute (latitude/longitude) and 0. 1° (for course information) or better at all of the following for the area(s) in which IFR operations are intended: (a) Airports; (b) VORs, DMEs (including DMEs collocated with localizers), collocated VOR/DME's, VORTACs, and NDBs (including NDBs used as locator outer marker); (c) All named waypoints and intersections shown on en route and terminal area charts; and (d) RNAV departure procedures and arrival routes (STARs), including all waypoints and intersections.			
(2.2.1.5.2)	Departures and arrivals shall be retrievable as a procedure (so that selecting the procedure by name results in loading the appropriate waypoints and legs into the flight plan).			
(2.2.1.5.2)	Waypoints shall be identified as "fly-over" or "fly-by" in accordance with the published procedure.			
Content (2.2.4.5.1, 2.2.5.5.1)			In addition to the requirements of paragraph 2.2.1.5.2, the equipment shall store the LNAV/VNAV procedures in the area(s) in which IFR operation is intended.	In addition to the requirements of paragraph 2.2.1.5.2, the equipment shall store the GLS and APV-II procedures in the area(s) in which IFR operation is intended.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.5.1)			The equipment shall also store data necessary to support stand-alone LNAV/VNAV approaches (i.e., LNAV/VNAV approaches to runway ends that do not also have a GLS or APV-II approach).	
(2.2.5.5.1)				For each procedure, the equipment shall also identify the types of approach with vertical guidance that are published (i.e., GLS, APV-II, and/or LNAV/VNAV), and the naming convention associated with the types of approach (e.g., “GLS”, “LNAV/VNAV”).
(2.2.4.5.1, 2.2.5.5.1)			Waypoints utilized as a final approach waypoint (FAWP) and LTP/FTP in a LNAV/VNAV procedure shall be uniquely identified as such to provide proper approach mode operation.	Waypoints utilized as a final approach waypoint (FAWP) and LTP/FTP in a GLS or APV-II, procedure shall be uniquely identified as such to provide proper approach mode operation.
(2.2.5.5.1)				In addition to the above requirements, the equipment shall store the VAL for each GLS and APV-II approach.
Data Integrity (2.2.4.5.2, 2.2.5.5.2)			Once the FAS data block has been decoded, the GPS/WAAS equipment shall apply the CRC to the data block as defined in Appendix D to determine if the data is valid.	

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.5.2, 2.2.5.5.2)			If the FAS data block does not pass the CRC test, the equipment shall not allow activation of LNAV/VNAV for that approach.	If the FAS data block does not pass the CRC test, the equipment shall not allow activation of GLS or APV-II for that approach.
Database Standard (2.2.1.5.3)	The equipment navigation databases shall meet the standards specified in Sections 3, 4, and 5 of RTCA/DO-200A, "Standards for Processing Aeronautical Data."			
Incorporation of Conversion Algorithms (2.2.1.5.4.1)	When designing equipment, which can display and enter latitude/longitude information in datums other than WGS-84 or NAD83, an annunciation shall be made to the pilot of the selection of a datum other than WGS-84 or NAD83.			
(2.2.1.5.4.1)	This annunciation shall be designed to prevent errors in the latitude/longitude information entered by the pilot, as well as misinterpretation of displayed latitude/ longitude, because of accidental selection of the wrong datum.			
Alert Limits (2.2.2.6.1, 2.2.3.6.1, 2.2.4.6.1, 2.2.5.6.1)	The HAL for the navigation modes shall be: Oceanic/Remote 4 nm En Route 2 nm Terminal 1 nm	The horizontal alert limit for nonprecision approach mode shall be 0.3 nm.	Prior to sequencing the FAWP, the HAL shall be 0.3 nm. There is no VAL.	
(2.2.4.6.1, 2.2.5.6.1)			After sequencing the FAWP, the alert limits shall be as follows: a) LNAV/VNAV: HAL and VAL as stored in the database.	After sequencing the FAWP, the alert limits for LNAV/ VNAV, APV-II and GLS shall be as follows: a) APV-II: HAL = 40 m, VAL = 20 m, b) GLS: HAL = 40 m, VAL as stored in the database for each GLS per Section 2.2.5.5.1 (range at least 10 to 20 m).
(2.2.4.6.1, 2.2.5.6.1)			The equipment shall not provide the flight crew a means of changing the alert limit.	
(2.2.4.6.1, 2.2.5.6.1)			Once that advisory is provided, the level of service shall not change unless the missed approach is initiated or the pilot changes the desired level of service.	

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.6.1, 2.2.5.6.1)			The equipment shall use the alert limits for the monitoring described in Sections 2.2.4.6.2 and 2.2.4.6.3.	The equipment shall use the alert limits associated with the selected level of service for the monitoring described in Sections 2.2.5.6.2 and 2.2.5.6.3.
Caution Associated with Loss of Integrity Monitoring (2.2.1.6.1)	Class Gamma equipment shall provide a caution, independent of any operator action, when the equipment has a loss of integrity monitoring.			
(2.2.1.6.1)	This caution shall be capable of installation in the pilot's normal field of view (ref. Section 3.3.1.1.1).			
(2.2.1.6.1)	The equipment shall also provide an indication when integrity monitoring capability is restored.			
(2.2.2.6.2, 2.2.3.6.2, 2.2.4.6.2, 2.2.5.6.2)	The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within 30 seconds if the current HPL (HPL_{WAAS} if available, otherwise HPL_{FD}) exceeds the HAL.	The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within 30 seconds if the current HPL_{FD} exceeds the HAL.		
(2.2.2.6.2, 2.2.3.6.2, 2.2.4.6.2, 2.2.5.6.2)	The GPS/WAAS equipment shall provide a loss of integrity monitoring caution (see Section 2.2.1.6.1) within two seconds if the current HPL_{WAAS} exceeds the HAL.			
Caution Associated with Loss of Navigation (2.2.1.6.2)	Class Gamma equipment shall continuously provide a caution, independent of any operator action, which indicates the loss of navigation capability.			
(2.2.1.6.2)	This caution shall be a unique annunciator capable of installation in the pilot's primary field of view.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.2.6.2)	The loss of navigation caution shall be output/displayed within one second of the onset of any of the following conditions: (a) The absence of power (loss of function is an acceptable indicator); (b) Probable equipment malfunction or failure (must consider all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5}/hour); (c) The presence of a condition lasting five seconds or more where there are an inadequate number of satellites to compute a position solution; (d) Fault detection detects a position failure, which cannot be excluded within the time-to-alert.			
(2.2.2.6.2)	The fault detection function shall detect positioning failures within the following times-to-alert.			
(2.2.2.6.2)	The equipment shall distinguish between these different causes of the loss of navigation capability.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.2.6.2)	The caution shall be returned to its normal state immediately upon termination of the responsible condition.			
(2.2.3.6.3)		Class Gamma nonprecision approach equipment shall provide an indication when the navigation system is no longer adequate to conduct or continue the nonprecision approach by means of a navigation warning flag on the navigation display.		

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.3.6.3)		The flag shall be displayed within one second of the onset of any of the following conditions: (a) The absence of power (loss of function is an acceptable indicator); (b) Probable equipment malfunction or failure (must consider all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5}/hour); (c) The presence of a condition lasting five seconds or more where there are an inadequate number of satellites to compute a position solution; (d) Fault detection detects a position failure which cannot be excluded within the time to alert. When in NPA mode, the fault detection function shall detect positioning failures within 10 seconds after the onset of the positioning failure; (e) HPL > HAL at any point on the final approach segment.		

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.3.6.3)		After sequencing the FAWP, this indication (flag) shall be latched until the equipment is no longer in the nonprecision approach mode.		
(2.2.4.6.3, 2.2.5.6.3)			Class Gamma-2 equipment shall provide an indication that the navigation system is no longer adequate to conduct or continue the LNAV/VNAV approach by means of a warning flag or equivalent indicator on the vertical or lateral navigation display.	Class Gamma-3 equipment shall provide an indication that the navigation system is no longer adequate to conduct or continue the GLS or APV-II approach by means of a warning flag or equivalent indicator on the vertical or lateral navigation display.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.6.3, 2.2.5.6.3)			Both lateral and vertical flags or equivalent indicators shall be displayed within one second of the onset of any of the following conditions when in LNAV/VNAV (a-c): (a) The absence of power (loss of function is an acceptable indicator); (b) Probable equipment malfunction or failure (all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5} per approach must be considered); or (c) The presence of a condition where fault detection detects a position failure which cannot be excluded (Section 2.1.4.2.2.2.).	Both lateral and vertical flags or equivalent indicators shall be displayed within one second of the onset of any of the following conditions when in GLS or APV-II (a-c): (a) The absence of power (loss of function is an acceptable indicator); (b) Probable equipment malfunction or failure (all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5} per approach must be considered); or (c) The presence of a condition where fault detection detects a position failure which cannot be excluded (Section 2.1.4.2.2.2.).

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.4.6.3, 2.2.5.6.3)			Both lateral and vertical flags or equivalent indicators shall be displayed within one second of the onset of any of the following conditions (d-f) when the reference point, defined as the point on the desired path to which deviations are referenced, is between the FAWP and the LTP/FTP and heading toward the runway, or when the aircraft is below 1000 feet HAT, whichever occurs first: (d) When no valid WAAS message has been received for 4 seconds or more (this indicates a probable communications link problem or WAAS signal blockage); (e) There are an insufficient number of WAAS HEALTHY satellites (onset of condition is either (1) when a satellite is blocked or (2) when the last bit of a WAAS message indicating "Don't Use" arrives at the antenna port); (f) The horizontal protection level exceeds the alert limit as defined in Section 2.2.4.6.1.	
(2.2.4.6.3, 2.2.5.6.3)			In addition, the vertical flag or equivalent indicator shall be displayed within 0.8 seconds of the onset of the following condition: (g) The vertical protection level exceeds the alert limit as defined in Section 2.2.4.6.1.	In addition, the vertical flag or equivalent indicator shall be displayed within 0.8 seconds of the onset of the following condition: (g) The vertical protection level exceeds the alert limit as defined in Section 2.2.5.6.1.
(2.2.4.6.3, 2.2.5.6.3)			After sequencing the FAWP, this indication (flag) shall be latched until the equipment is no longer in LNAV/VNAV.	After sequencing the FAWP, this indication (flag) shall be latched until the equipment is no longer in GLS or APV-II.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Low Altitude Alert (2.2.4.6.4, 2.2.5.6.4)			When in LNAV/VNAV and before sequencing the FAWP, the equipment shall provide an altitude alert if the estimated position is lower than the desired FAWP height by more than 50 m + VPL.	When in GLS or APV-II and before sequencing the FAWP, the equipment shall provide an altitude alert if the estimated position is lower than the desired FAWP height by more than 20 m + (APV-II), or the applicable VAL for GLS.
Example Alerting Scheme (2.2.4.6.5, 2.2.5.6.5)			Under normal operation, when a LNAV/VNAV procedure has been entered into the active flight plan and the equipment is in LNAV/VNAV the vertical and lateral integrity flags shall be out of view, and the guidance displays shall show the deviations from track in vertical and lateral dimensions.	Under normal operation, when a GLS or APV-II procedure has been entered into the active flight plan and the equipment is in GLS or APV-II, the vertical and lateral integrity flags shall be out of view, and the guidance displays shall show the deviations from track in vertical and lateral dimensions.
Mode Switching Requirements (2.2.1.7)	The equipment shall display the current mode upon user request.			
(2.2.1.7)	The equipment shall automatically switch to the default mode upon entering the region defined for that mode.			
(2.2.1.7)	Approach mode shall be annunciated by a unique continuous indication.			

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Entry Criteria (2.2.4.7.1, 2.2.5.7.1)			LNAV/VNAV shall not be allowed to be activated unless all of the following conditions are met: (a) Valid long-term, fast, and ionospheric WAAS corrections are available and being applied to at least 4 satellites; (b) An approach procedure has been selected; and (c) The FAS data associated with the precision approach procedure has been verified using the CRC as described in 2.2.4.5.2.	LNAV/VNAV, APV-II or GLS shall not be allowed to be activated unless all of the following conditions are met: (a) Valid long-term, fast, and ionospheric WAAS corrections are available and being applied to at least 4 satellites; (b) An approach procedure has been selected; and (c) The FAS data associated with the precision approach procedure has been verified using the CRC as described in 2.2.4.5.2.
(2.2.4.7.1, 2.2.5.7.1)			If activation of LNAV/VNAV fails due to any of the conditions above, the equipment shall provide a means to notify the pilot that the selection was attempted and did not succeed.	If activation of APV-II or GLS fails due to any of the conditions above, the equipment shall provide a means to notify the pilot that the selection was attempted and did not succeed.
(2.2.4.7.1, 2.2.5.7.1)			When LNAV/VNAV, is activated, the equipment shall provide an indication of the available service as described in 2.2.4.7.4 or 2.2.5.7.4.	When APV-II or GLS is activated, the equipment shall provide an indication of the available service as described in 2.2.4.7.4 or 2.2.5.7.4.
Exit Criteria (2.2.3.7.1.2, 2.2.4.7.2, 2.2.5.7.2)		When a missed approach is initiated and the first leg in the missed approach procedure is not a TF leg aligned within 3 degrees of the final approach path, the equipment shall automatically switch to terminal mode.		

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.3.7.1.2, 2.2.4.7.2, 2.2.5.7.2)		When a missed approach is initiated and the first leg in the missed approach procedure is a TF leg aligned within 3 degrees of the final approach path, the equipment shall automatically switch to terminal mode at the turn initiation point for the first waypoint in the missed approach procedure.	When a missed approach is initiated and the first leg in the missed approach procedure is a TF leg, the equipment shall automatically switch to terminal mode at the turn initiation point for the first waypoint in the missed approach procedure.	
(2.2.3.7.1.2, 2.2.4.7.2, 2.2.5.7.2)		If the pilot initiates Direct-To any waypoint while in non-precision approach mode, the equipment shall automatically switch to terminal mode.	If the pilot initiates Direct-To any waypoint while in LNAV/VNAV, the equipment shall automatically switch to terminal mode.	If the pilot initiates Direct-To any waypoint while in GLS or APV-II, the equipment shall automatically switch to terminal mode.
Display Transition Requirements (2.2.2.7.1.3, 2.2.3.7.1.3, 2.2.4.7.3, 2.2.5.7.3)	Upon automatic transition to en route mode from terminal mode, the non-numeric cross-track sensitivity shall gradually decrease from ± 1 nm FSD to ±2 nm FSD over a distance of 1 nm.	Upon entering the nonprecision approach mode when a VTF has been selected, the equipment shall immediately transition to the angular/linear guidance relative to the (extended) FAS as defined in Section 2.2.3.4.2.	Upon entering LNAV/VNAV when a VTF has been selected, the equipment shall immediately transition to the angular/linear guidance relative to the (extended) FAS as defined in Section 2.2.4.4.2.	Upon entering APV-II, or GLS when a VTF has been selected, the equipment shall immediately transition to the angular/linear guidance relative to the (extended) FAS as defined in Section 2.2.4.4.2.
(2.2.3.7.1.3, 2.2.4.7.3, 2.2.5.7.3)		The sensitivity shall change from ±0.3nm to ±1 nm when the equipment changes to terminal mode.		
Entry Criteria - Terminal Mode Switching Requirements (2.2.2.7.2.1)	Automatic mode switching to terminal mode shall occur at a distance of 31 nm from the destination airport.			

MOPS Requirement	**En Route / Terminal Mode**	**NPA Mode**	**LNAV/VNAV**	**APV-II / GLS**
Display Transition Requirements (2.2.2.7.2.3)	Upon automatic transition from en route mode to the terminal mode, the non-numeric cross-track sensitivity shall increase from ±2 nm FSD to ±1 nm FSD over a distance of 1 nm.			
Entry Criteria - Departure Requirements (2.2.3.7.2.1)		Once a departure procedure is activated, the equipment shall provide nonprecision approach accuracy and integrity.		
Exit Criteria (2.2.3.7.2.2)		The equipment shall automatically revert to normal terminal mode operation at the turn initiation point of the first waypoint in a departure procedure.		
Display Transition Requirements (2.2.3.7.2.3)		The full-scale deflection shall change from ±0.3 nm to ±1 nm at the turn initiation point of the first waypoint in the departure procedure.		
Advisory of LNAV/VNAV Availability (2.2.4.7.4)			For approach procedures that support GLS or APV-II, equipment supporting only LNAV/VNAV operations shall indicate that the GLS or APV-II approach is not available.	

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Advisory of APV-II or GLS Approach Availability (2.2.5.7.4)				For manual selection of the type of approach with vertical guidance, the equipment shall indicate whether the applica-ble alert limit requirements are met.
(2.2.5.7.4)				This indication shall be pro-vided continuously once the equipment is in GLS or APV-II.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.2.5.7.4)				For automatic selection of the type of approach with vertical guidance, the equipment shall display the level of service that is available when entering precision approach mode (i.e., GLS, APV-II, LNAV/VNAV, or LNAV).
(2.2.5.7.4)				The selected level of service shall be the most accurate level of service for which both the vertical and horizontal alert limits are supported and for which a minimum is published for the selected procedure.
(2.2.5.7.4)				If the most accurate level of service for which a minimum is published is available, the equipment shall indicate that it is available.
(2.2.5.7.4)				If the most accurate level of service for which a minimum is published is not available, the equipment shall indicate that it is not available and shall indicate the level of service that is available (e.g., “GLS not available – Use LNAV/VNAV minima”).

TABLE N-3 CLASS DELTA-4 REQUIREMENTS FOR PRECISION APPROACH OPERATIONS

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Class Delta-4 Requirements for Precision Approach Operations (2.3)				Class Delta-4 equipment shall meet the requirements of this section, as well as all the requirements in Sections 2.1.1 and 2.1.5, except for specific cases described in this section.
Path Definition (2.3.3)				Class Delta-4 equipment shall output deviations relative to the FAS.
Non-Numeric Cross-Track Deviation (2.3.4.1)				The equipment shall provide an output of non-numeric deviations that meets the requirements of Section 2.2.1.4.2.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
(2.3.4.1)				The equipment shall provide an output of non-numeric deviations that meets the requirements of Section 2.2.1.4.2. The lateral deviation shall be as follows: a) At a distance greater than $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP, the deviation shall be linear with FSD for a cross-track error of ±1 nm; b) Between $\frac{1}{\tan(\alpha_{lat,FS})}$ nm to the GARP and the LTP/FTP, the deviation shall be the final approach segment lateral deviation as defined in Section 2.2.5.4.2; c) Between the LTP/FTP and the length offset distance to the FPAP, the deviation shall be either the final approach segment lateral deviation or linear with FSD for a cross-track error of ±(Course Width at LTP/FTP).

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Non-Numeric Vertical Deviation (2.3.4.2)				The equipment shall provide an output of non-numeric deviations that meets the requirements of Section 2.2.1.4.2.
(2.3.4.2)				The equipment shall meet the requirements of Section 2.2.5.4.4.
Landing Threshold Point/ Fictitious Threshold Point Distance Display (2.3.4.3)				Prior to crossing the LTP/FTP, the distance (length of the slant range vector projected onto the plane tangent to the WGS-84 ellipsoid at the LTP/ FTP) to the LTP/FTP shall be output or displayed.
(2.3.4.3)				The distance shall be output or displayed with a resolution of 0.1 nm up to a range of 99.9 nm from the waypoint. If a moving map is provided, the map may obviate the need for a numerical output.
Displayed Data Update Rate (2.3.4.4)				The equipment shall meet the requirements of Section 2.2.5.4.7.

MOPS Requirement	En Route / Terminal Mode	NPA Mode	LNAV/VNAV	APV-II / GLS
Displayed Data Update Latency (2.3.4.5)				The overall latency, defined as the interval between the time of measurement and the completion of transmission of the deviation output reflecting the measurement, shall not exceed 400 msec.
Database Requirements (2.3.5)				The database functions do not reside in the GPS/WAAS Delta-4 equipment. However, the applicable FAS data block is transferred in its entirety, including the CRC, to the GPS/WAAS equipment.
(2.3.5)				The GPS/WAAS equipment shall verify the CRC. If the FAS data block does not pass the CRC, the equipment shall indicate a loss of navigation.
(2.3.5)				The applicable HAL and VAL for the GLS approach also shall be transferred to the GPS/WAAS equipment.
Alerts (2.3.6)				The equipment shall meet the requirements of Section 2.2.5.6 applicable to GLS.
(2.3.6)				The equipment shall accommodate the configuration of horizontal and vertical alert limits.

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Appendix O

GLOSSARY AND ACRONYMS

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Appendix O—GLOSSARY AND ACRONYMS

AC — Advisory Circular

ACARS — Aircraft Communications, Addressing and Reporting System

Active Waypoint — A waypoint to or from which navigational guidance is being provided. For a parallel offset, the active waypoint may or may not be at the same geographical position as the parent waypoint. When not in the parallel offset mode (operating on the parent route), the active and parent waypoints are at the same geographical position.

ADS — Automatic Dependent Surveillance

ADS-B — Automatic Dependant Surveillance-Broadcast

Advisory — An annunciation that is generated when crew awareness is required and subsequent crew action may be required; the associated color is unique but not red or amber/yellow. (Source: Advisory Circular AC 25 - 11).

AGL — Above Ground Level

AIP — Aviation Information Publications

Along-Track Distance — The distance along the desired track from the waypoint to the perpendicular line from the desired track to the aircraft.

Applications — Specific use of systems that address particular user requirements. For the case of GNSS, applications are defined in terms of specific operational scenarios.

APV — Approach operations with Vertical guidance (The terminology CAT-I PA, APV-II, and APV-I has been introduced to describe the three levels of SBAS precision approach service and is consistent with the ICAO GNSS ANNEX 10 SARPs. The FAA plans to label CAT-I PA as “GNSS Landing System (GLS)” and APV-I as “LNAV/VNAV”. The naming convention for APV-II has not been proposed.)

Area Navigation (RNAV) — Application of the navigation process providing the capability to establish and maintain a flight path on any arbitrary chosen course that remains within the coverage area of navigation sources being used. RNAV utilizing capabilities in the horizontal plane only is called 2D RNAV, while RNAV which also incorporates vertical guidance is called 3D RNAV. Time navigation (TNAV) may be added to either 2D or 3D systems. TNAV added to a 3D system is called 4D.

ARINC — Aeronautical Radio

ASIC — Application Specific Integrated Circuit

ATC — Air Traffic Control

Availability — The availability of a navigation system is the ability of the system to provide the required function and performance at the initiation of the intended operation. 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 external sources are available for use. Availability is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

Barometric Altitude — Geopotential altitude in the earth's atmosphere above mean standard sea level pressure datum surface, measured by a pressure (barometric) altimeter.

BCD — Binary Coded Decimal

BER — Bit Error Rate

BNR — Binary Numbers

BPSK — Binary Phase Shift Keying

BW — Bandwidth

C/A — Coarse Acquisition

CAT-I PA — Category I Precision Approach

Caution — An annunciation that is generated when immediate crew awareness is required and subsequent crew action will be required; the associated color is amber/yellow. (Source: Advisory Circular AC25 - 11)

CC — Clock Correction

CDI — Course Deviation Indicator

Center of Navigation — The mathematical point, referenced to the aircraft coordinate frame, associated with the GNSS navigation solution. This point would typically be the phase center of the GNSS antenna, but could also be an offset or translated point (e.g., might be translated vertically to the level of the wheels of a large aircraft).

CF — Course-to-Fix

CFIT — Controlled Flight Into Terrain

Continuity — The continuity of a system is the ability of the total system (comprising all elements necessary to maintain aircraft position within the defined airspace) to perform its function without interruption during the intended operation. More specifically, continuity is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation, and predicted to exist throughout the operation.

Coverage — The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions and other factors which affect signal availability.

CRC — Cyclic Redundancy Check

CW — Continuous Wave

CWI — Continuous Wave Interference

DCH — Datum Crossing Height

DD — Double Delta

DDL — Delay Lock Loop

Desired Course

a. True — A predetermined desired course direction to be followed (measured in degrees from true north).

b. Magnetic — A predetermined desired course direction to be followed (measured in degrees from local magnetic north).

Desired Track — The planned or intended track between two waypoints. It is measured in degrees from either magnetic or true north. The instantaneous angle may change from point to point along the great circle track between waypoints.

DME — Distance Measuring Equipment

DOD — U.S. Department of Defense

DOP — Dilution Of Precision

DP — Datum Point

D.R. — Dead Reckoning

EC — Ephemeris CORRECTION

ECEF — Earth Centered Earth Fixed

EFIS — Electronic Flight Instruments System

EGNOS — European Geostationary Navigation Overlay Service

EL — Glidepath Angle (approach path elevation angle)

E-L — Early minus Late (correlator)

ELT — Emergency Locating Transmitter

En Route — A phase of navigation covering operations between departure and termination phases. En route phase of navigation has two subcategories: en route domestic/continental and en route oceanic.

FAA — Federal Aviation Administration

FAF — Final Approach Fix

FAS — Final Approach Segment

FAWP — Final Approach Waypoint

FD — Fault Detection

FDE — Fault Detection and Exclusion

FEC — Forward Error Correction

Final Approach Fix (FAF) — A point in space used to indicate the position at which an aircraft on a standard approach should be stabilized with appropriate guidance being supplied for the Final Approach Segment. (Source: FAA)

Final Approach Segment (FAS) — The straight line segment which prescribes the three-dimensional geometric path in space that an aircraft is supposed to fly on final approach. This segment is defined by two points in space, the Glide Path Intercept Waypoint (GPIWP) and the Threshold Crossing Waypoint (TCWP).

Flight Technical Error (FTE) — The accuracy with which the aircraft is controlled as measured by the indicated aircraft position with respect to the indicated command or desired position. It does not include blunder errors.

FMS — Flight Management System

FPAP — Flight Path Alignment Point

FSD — Full Scale Deflection

FTE — Flight Technical Error

GARP — GNSS Azimuth Reference Point

GDOP — Geometric Dilution of Precision

GEO — Geostationary

Geocentric — Relative to the earth as a center, measured from the center of the earth.

Geodesy — The science related to the determination of the size and shape of the earth (geoid) by such direct measurements as triangulation, leveling and gravimetric observations; which determines the external gravitational field of the earth and, to a limited degree, the internal structure.

Geometric Dilution of Position (GDOP) — The ratio of position error of a multilateration system. More precisely, it is the ratio of the standard deviation of the position error to the standard deviation of the measurement errors, assuming all measurement errors are statistically independent and have a zero mean and the same standard distribution. GDOP is the measure of the "goodness" of the geometry of the multilateration sources as seen by the observer; a low GDOP is desirable, a high GDOP undesirable. (See also PDOP, HDOP and VDOP.)

Geostationary — An equatorial satellite orbit that results in a constant fixed position of the satellite over a particular earth surface reference point. (GPS and GLONASS satellites are not geostationary.)

GIVE — Grid Ionospheric Vertical Error

GIVEI — Grid Ionospheric Vertical Error Indicator

GL — Ground Level

GLS — GNSS Landing System

Global Navigation Satellite System (GNSS) — GNSS is a world-wide position, velocity, and time determination system, that includes one or more satellite constellations, receivers, and system integrity monitoring, augmented as necessary to support the required navigation performance for the actual phase of operation.

GPIP — Glide Path Intercept Point

Global Positioning System (GPS) — A space-based positioning, velocity and time system composed of space, control and user segments. The space segment, when fully operational, will be composed of 24 satellites in six orbital planes. The control segment consists of five monitor stations, three ground antennas and a master control station. The user segment consists of antennas and receiver-processors that provide positioning, velocity, and precise timing to the user.

GLONASS — Global Orbiting Navigation Satellite System

GNSS — Global Navigation Satellite System

GNSSU — GNSS (Landing) Unit

GPS — Global Positioning System

HAL — Horizontal Alert Limit

HAT — Height Above Touchdown

HDOP — Horizontal Dilution of Position

Height Above Touchdown (HAT) — Specifically, the height above the Runway Intercept Waypoint. In using this term for airborne equipment specifications, care should be taken to define the point on the aircraft (GPS antenna, wheel height, center of mass) that applies.

HF — High Frequency

HIRF — High Intensity Radiation Fields

Horizontal Dilution of Precision (HDOP) — The ratio of user-referenced horizontal position error to measurement error of a multilateration system. (See GDOP for a more detailed description.)

HOW — Hand Over Word

HPL — Horizontal Protection Level

HSI — Horizontal Situation Indicator

HUL — Horizontal Uncertainty Level

Hz — Hertz (cycles per second)

IAWP — Initial Approach Waypoint

IC — Ionospheric Correction

ICAO — International Civil Aviation Organization

ID — Identification

IFR — Instrument Flight Rules

IGP — Ionospheric Grid Point

ILS — Instrument Landing System

IMC — Instrument Meteorological Conditions

INS — Inertial Navigation System

IOD — Issue of Data

IODC — Issue of Data Clock

IODE — Issue of Data Ephemeris

IODF — Issue of Data Fast Correction

IODI — Issue of Data Ionospheric

IODP — Issue of Data PRN mask

IODS — Service Issue of Data

IPP — Ionospheric Pierce Point

IPV — Instrument Procedures with Vertical guidance

I/S — interference-to-signal ratio

IWP — Intermediate Waypoint

L1 — 1575.42 MHz

LAAS — Local Area Augmentation System

LNAV — Lateral Navigation

LORAN — Long Range Navigation

LSB — Least Significant Bit

LSR — Least Squares Residual

LTP/FTP — Landing Threshold Point/ Fictitious Threshold Point

m — Meters

MAHWP — Missed Approach Holding Waypoint

Mask Angle — A fixed elevation angle referenced to the user's horizon below which satellites are ignored by the receiver software. Mask angles are used primarily in the analysis of GNSS performance, and are employed in some receiver designs. 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.

MASPS — Minimum Aviation System Performance Standards

MDA — Minimum Descent Altitude

MAWP — Missed Approach Waypoint

Mcps — Mega-chips/second

Misleading Information — Within this standard, misleading information is defined to be any data which is output to other equipment or displayed to the pilot that has an error larger than the current protection level (HPL/VPL). This includes all output data, such as position, non-numeric cross-track, numeric cross-track, and distance-to-waypoint as applicable.

MLS — Microwave Landing System

MOPS — Minimum Operational Performance Standards

MSAS — MTSAT Satellite-based Augmentation System

MSL — Mean Sea Level

MT — Message Type

MTBF — Mean Time Between Failure

MTSAT — Multifunction Transport Satellite

NAD-83 — North American Datum 1983

NAS — U.S. National Airspace System

NAV — Navigation

NAVAID — Navigation Aid

Navigation Mode — The navigation mode refers to the equipment operating to meet the requirements for a specific phase of flight. The navigation modes are: oceanic/remote, en route, terminal, non-precision approach, and precision approach. The oceanic/remote mode is optional; if it is not provided, the en route mode can be substituted for the oceanic mode.

NDB — Non-Directional Beacon

NIS — Number of Independent Samples

NM — Nautical Mile

Non Precision Approach — A standard instrument approach procedure in which no glideslope/glidepath is provided. (Source: FAA document 7110.65G)

NPA — Non Precision Approach

NSE — Navigation System Error

OBS — Omni Bearing Selector

PA — Precision Approach

PDOP — Position Dilution of precision

Planned Primary Means of Navigation — Planned primary means of navigation refers to the capability of planning an operation around scheduled outages so that the system is available for a particular flight and the operational continuity, integrity and accuracy requirements are met.

Position Dilution of Precision (PDOP) — The ration of user-referenced three-dimensional position error to measurement error of a multilaterial system. PDOP is the root-sum-square of HDOP and VDOP.

Position Fix — A derived location of an entity in a common coordinate system.

Position Fixing Error — The accuracy with which a navigation sensor in combination with a navigation computer can calculate and provide an output of actual location in relation to desired location in an operational environment.

PPOS — Present Position

PR — Pseudo Range

PRC — Pseudo Range Correction

Precision Approach (PA) — A standard instrument approach procedure in which a glideslope/glidepath is provided. (Source: FAA document 7110.65G)

PRN — Pseudo Random Noise

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. If the user clock offset is known, three satellite signals would suffice to compute a position.

Radionavigation — The determination of position, or the obtaining of information relating to position, for the purposes of navigation by means of the propagation properties of radio waves.

RAIM — Receiver Autonomous Integrity Monitoring

RDP — Runway Datum Point

Receiver Autonomous Integrity Monitoring (RAIM) — A technique whereby a civil GNSS receiver/processor determines the integrity of the GNSS navigation signals without reference to sensors or non-DoD integrity systems other than the receiver itself. This determination is achieved by a consistency check among redundant pseudorange measurements.

Reliability — The probability of performing a specified function without failure under given conditions for a specified period of time.

Required Navigation Performance (RNP) — A measure of the navigation system performance within a defined airspace, route, or procedure, including the operating parameters of the navigations systems used within that airspace. (Source: Adapted from the ICAO Separation Panel).

RF — Radio Frequency

RF — Radius-turn-to-Fix

RGCSP — Review of General Concepts of Separation Panel

RMI — Radio Magnetic Indicator

RNAV — Area Navigation

RNP — Required Navigation Performance

RRC — Range Rate Correction

rss — Root-Sum-Square

RTCA — RTCA, Inc. (publishes documents with the RTCA designator)

s — Second

SA — Selective Availability (also written as S/A)

SAE — Standard Aerospace Equipment

SATCOM — Satellite Communications

SBAS — Satellite Based Augmentation System (SBAS) — International name used in the Global Navigation Satellite System Panel (GNSSP) Standards and Recommended Practices (SARPs) for a set of programs that use satellites to transmit GPS and GLONASS integrity and correction data. The U.S. program is the WAAS which currently is planned to provided integrity and corrections to GPS and SBAS satellites only.

Selective Availability (S/A) — A set of techniques for denying the full accuracy and selecting the level of positioning, velocity, and time accuracy of GPS available to users of the Standard Positioning Service (L1 frequency) signal.

SC — Special Committee (RTCA Special Committees)

SNR — Signal to Noise Ratio

SPS — Standard Positioning Service

sps — symbols per second

Standard Positioning Service (SPS) — The standard specified level of positioning, velocity and timing accuracy that is available, without qualifications or restrictions, to any user on a continuous worldwide basis.

STAR — Standard Terminal Arrival Routes

SV — Satellite Vehicle

TC — Trophosperic Correction

TCAS — Traffic Alert and Collision Avoidance System

TCH — Threshold Crossing Height

TCP — Threshold Crossing Point

Terminal Area — A general term used to describe airspace in which approach control service or airport traffic control service is provided.

TERPS — Terminal Instrument Procedures

TF — To-From

Threshold Crossing Height (TCH) — The height of the straight line extension of the glidepath above the runway at the threshold.

TOD — Time of Day; Top of Descent

Total System Error (TSE) — Generic: The root-sum-square of the navigation source error, airborne component error, display error and flight technical error. Specific: The root-sum-square of the position fixing error, display error, course selection error and flight technical error.

TOW — Time of Week

Track Angle — Instantaneous angle measured from either true or magnetic north to the aircraft's track.

TSE — Total System Error

TSO — Technical Standards Order

TTA — Time to Alert

TTFF — Time To First valid position Fix

UDRE — User Differential Range Error

UDREI — User Differential Range Error Indicator

UERE — User Equivalent Range Error

UIVE — User Ionospheric Vertical Error

URA — User Range Accuracy

User Range Accuracy (URA) — The one-sigma estimate of user range errors in the navigation data for each individual satellite. It includes all errors for which the space or control segment is responsible. It does not include any errors introduced at the user set.

UTC — Universal Time Coordinated

VAL — Vertical Alert Limit

VDOP — Vertical Dilution of Position

Vertical Dilution of Precision (VDOP) — The ratio of user-referenced vertical position error to measurement error of a multilateration system (see GDOP for a more detailed description).

Vertical Navigation (VNAV) — A function of RNAV equipment which calculates, displays and provides guidance to a vertical profile or path.

Vertical Profile — A line or curve, or series of connected lines and/or curves in the vertical plane, defining an ascending or descending flight path either emanating from or terminating at a specified waypoint and altitude, or connecting two or more specified waypoints and altitudes. In this sense, a curve may be defined by performance of the airplane relative to the airmass.

VFR — Visual Flight Rules

VHF — Very High Frequency

VNAV — Vertical Navigation

VOR — VHF Omni Range

VORTAC — VHF Omni Range / Tactical Air Navigation

VPL — Vertical Protection Level

VTF — Vector-to-Final (Approach)

VUL — Vertical Uncertainty Level

WAAS — Wide Area Augmentation System

Warning — An annunciation that is generated when immediate recognition and corrective or compensatory action is required; the associated color is red. (Source: Advisory Circular AC25 - 11)

WGS-72 — World Geodetic System 1972

WGS-84 — World Geodetic System 1984

WMS — Wide-area Master Stations (WAAS)

WN — Week Number

WNT — WAAS Network Time

World Geodetic Survey (WGS) — A consistent set of parameters describing the size and shape of the earth, the positions of a network of points with respect to the center of mass of the earth, transformations from major geodetic datums, and the potential of the earth (usually in terms of harmonic coefficients).

WPT — Waypoint

WRS — Wide-area Reference Stations (WAAS)

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Appendix P

IONOSPHERIC GRID POINT (IGP) SELECTION FLOWCHARTS

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Appendix P—IONOSPHERIC GRID POINT (IGP) SELECTION FLOWCHARTS

P.1 Introduction

This appendix provides the flowcharts for IGP selection discussed in Appendix A, Section A.4.4.10.2.

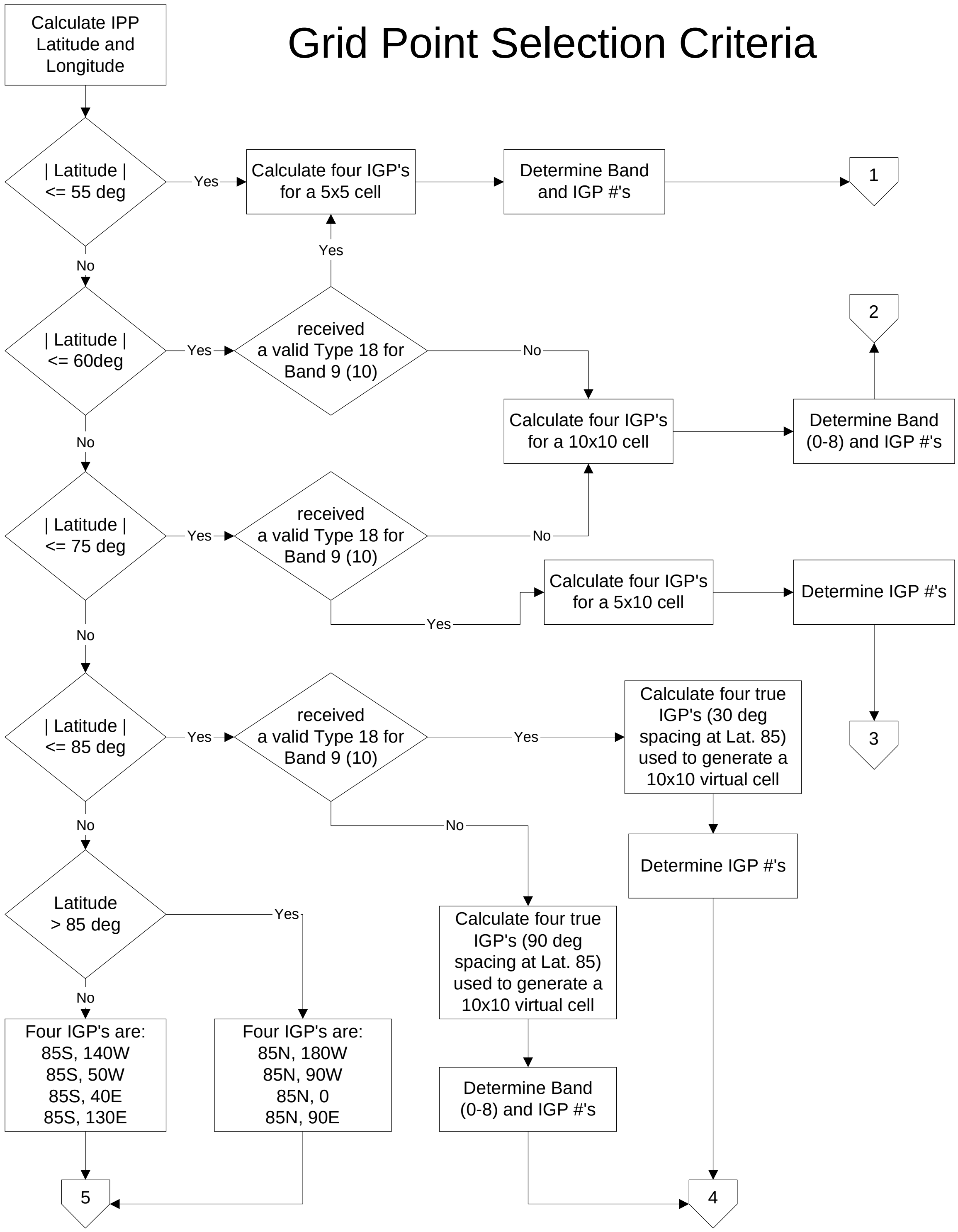
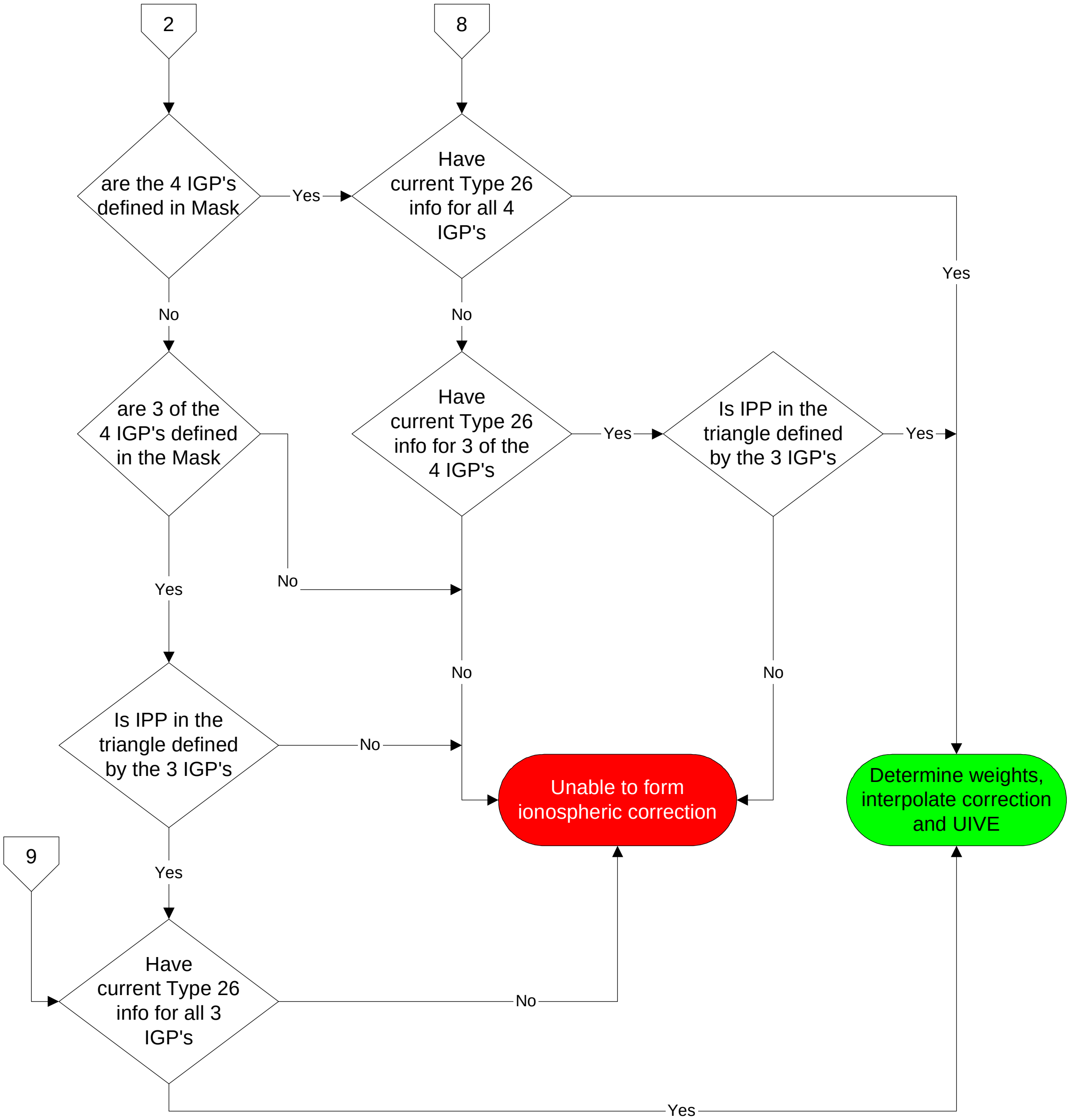


FIGURE P-1 GRID POINT SELECTION CRITERIA

FIGURE P-2 **ABS IPP LATITUDE BELOW 60 DEG (5X5)**



<u>FIGURE P-3</u> ABS IPP LATITUDE BELOW 85 DEG

FIGURE P-4 **ABS IPP LATITUDE BETWEEN 60 & 75 DEG BANDS 9-10**

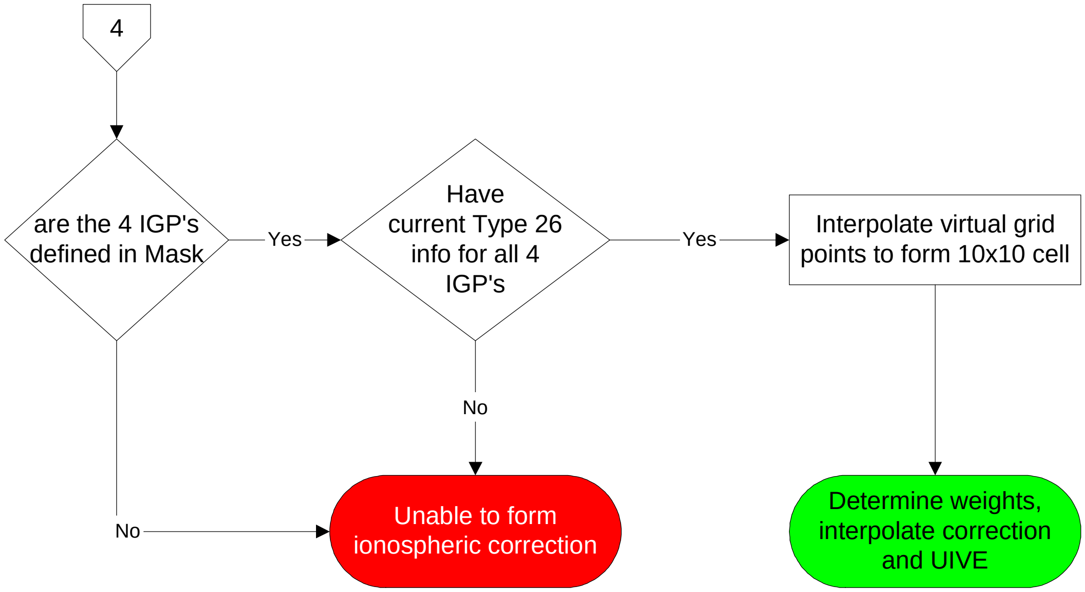


FIGURE P-5 ABS IPP LATITUDE BETWEEN 75 & 85 DEG

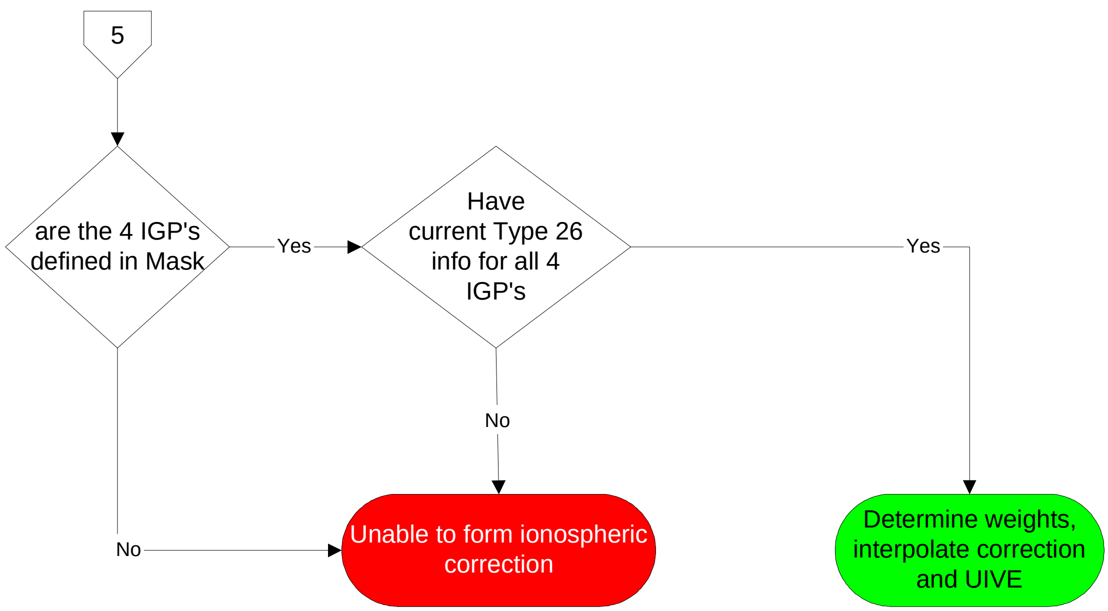


FIGURE P-6 ABS IPP LATITUDE ABOVE 85 DEG

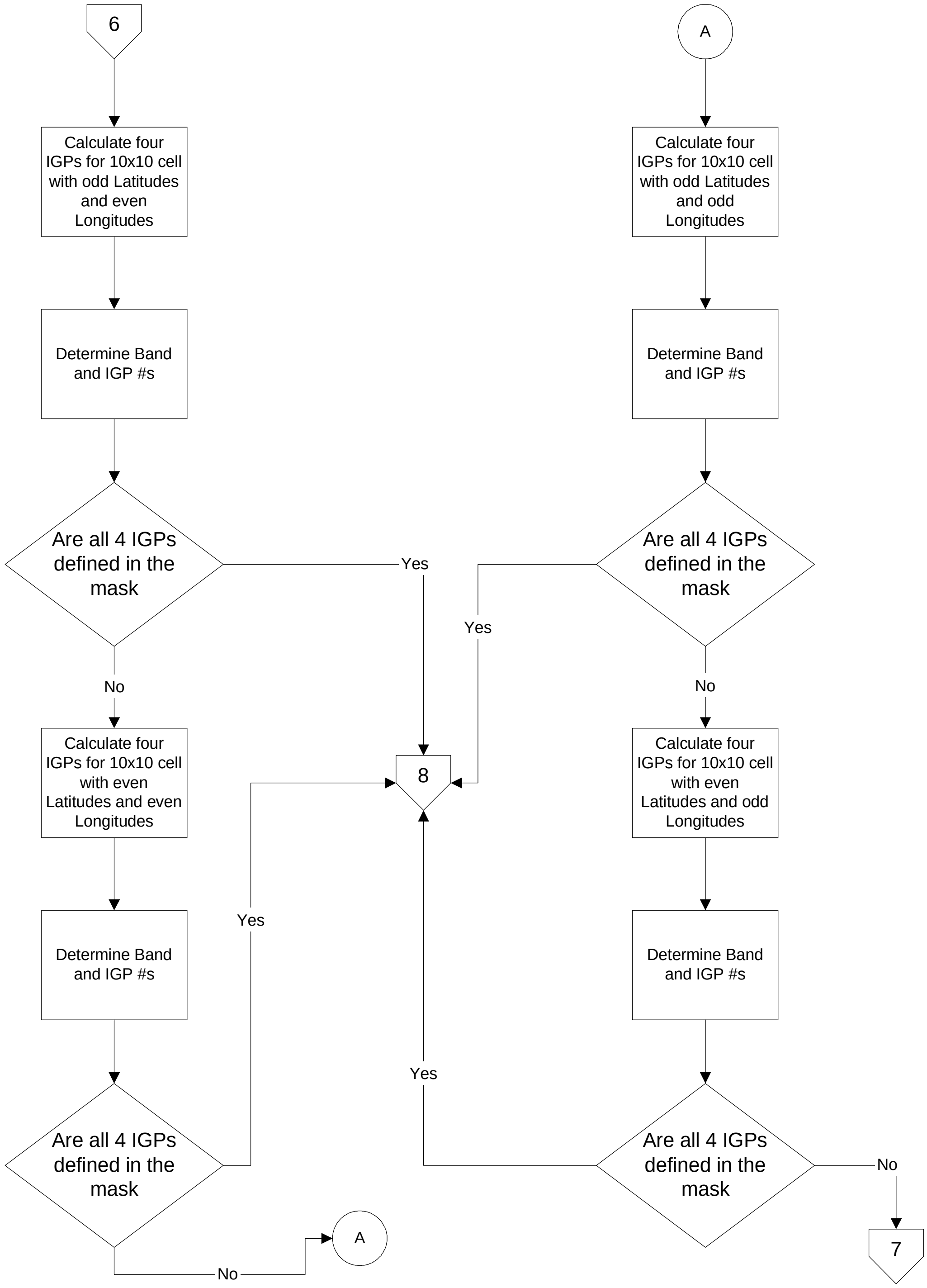


FIGURE P-7 ABS IPP LATITUDE BELOW 60 DEG (10X10 SQUARES)

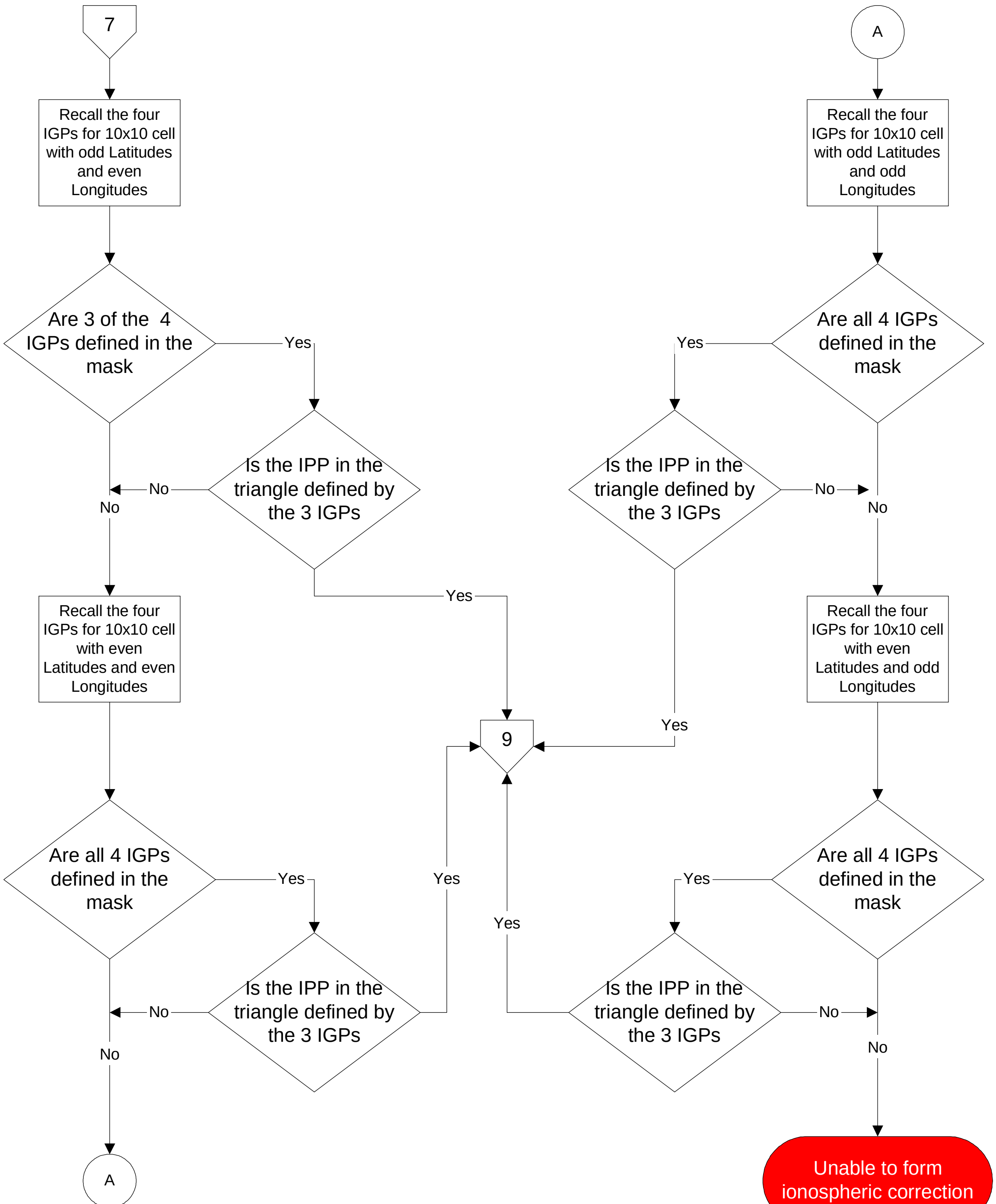


FIGURE P-8 **ABS IPP LATITUDE BELOW 60 DEG (10X10 TRIANGLES)**

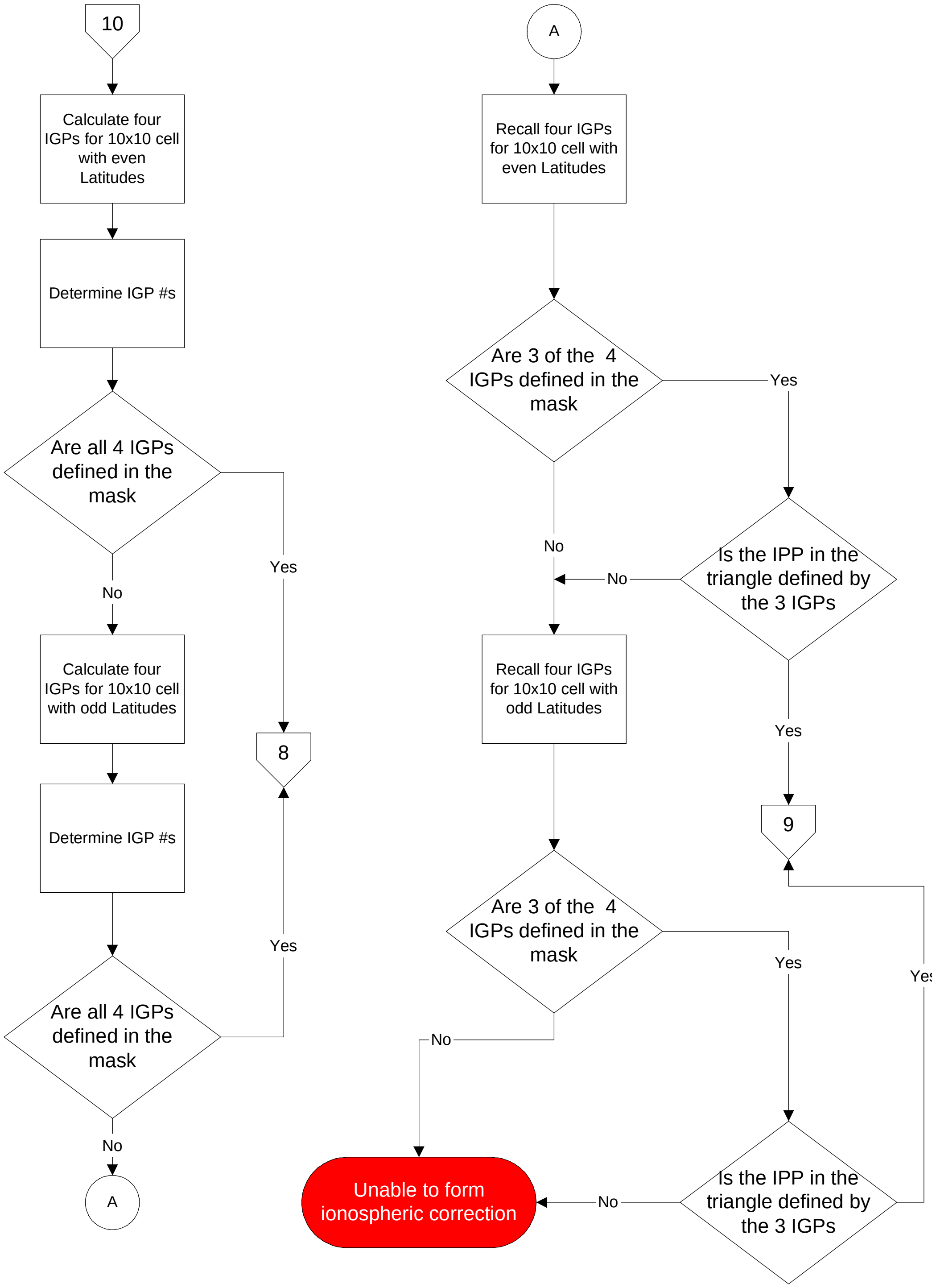


FIGURE P-9 ABS IPP LATITUDE BETWEEN 60 & 75 DEG BANDS 9-10

Appendix Q

WAAS REQUIREMENTS FOR HELICOPTERS

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Appendix Q—WAAS REQUIREMENTS FOR HELICOPTERS

Q.1 General

The material in this appendix applies to helicopter approach operations to heliports only. The specific requirements for these operations can be achieved through various integration techniques without requiring changes to the basic sensor.

Q.2 Non-Numeric Cross-Track Deviation

Previous experience using MLS for precision approach to heliports established full-scale deflection values in angular terms. These values apply to the final approach and intermediate segments and differ from those values described in Section 2.2.4.4.2 and 2.2.5.4.2. Two characteristics of heliport precision approaches are considered with the following display scaling requirements. Softer lateral scaling is required because of closer proximity to the pseudo-lateral guidance radiation point to the heliport than the threshold to localizer distance associated with the ILS. Softer vertical scaling is required when flying glidepath angles steeper than the normal 3°. These full-scale display values are based on manual flight performance.

Q.2.1 Non-Numeric Lateral Cross-Track Deviation

For helicopter-unique approaches (designated by a runway number of “00”), the full-scale deviation shall be in accordance with the requirements in Section 2.2.5.4.2 with the following exceptions: (1) the course width in the FAS data block is ignored and the course width is set to ±38 meters (±125 feet) (ref. Appendix D, Table D-1), and (2) the equipment shall not switch to missed approach deviation until a distance of the length offset *beyond* the FPAP. See Figure Q-1.

Note: *The FTP and FPAP will be cited so that the angular splay on the final approach segment is defined by a ± 3.6° wedge with its origin located 73 meters beyond the helipoint and aligned with the final approach segment.*

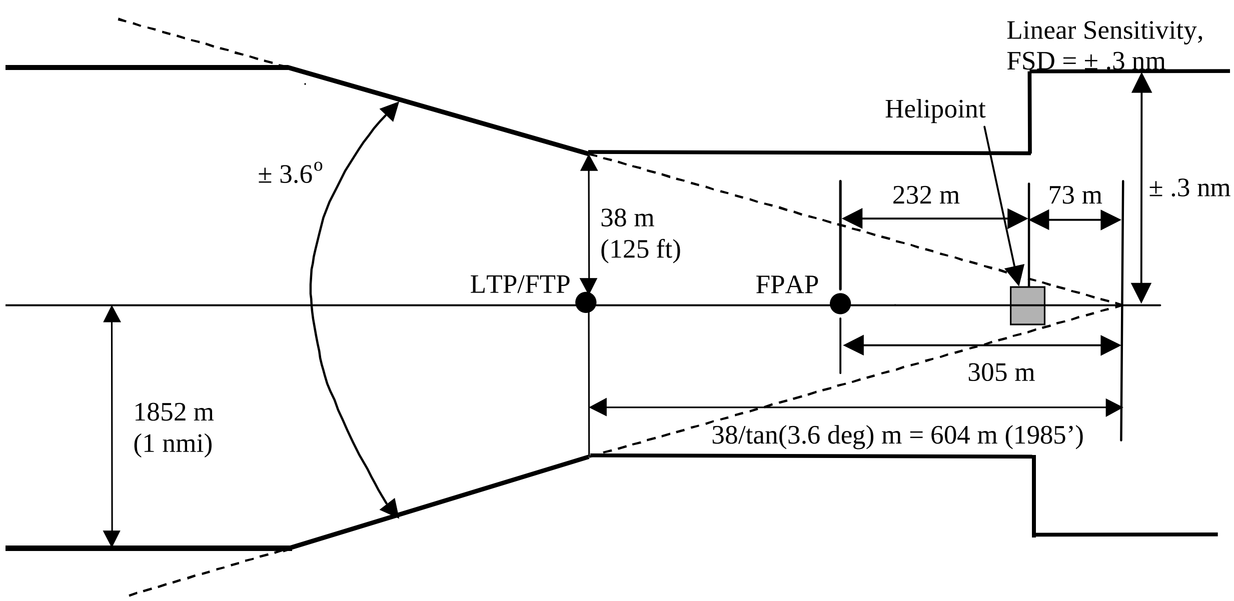

FIGURE Q-1 LATERAL DISPLAY SCALING

Q.2.2 Non-Numeric Vertical Deviation

For helicopter-unique approaches (designated by a runway number of "00"), the ± full-scale deflection shall be in accordance with the requirements in Section 2.2.5.4.4 with the following exceptions:

1. $\alpha_{vert,FS} = \pm$(FAS glidepath angle)/3); and

2. closer than $\dfrac{12\ meters}{\tan(\alpha_{vert,FS})}$ to the origin, the deviation shall be linear with FSD for a vertical error of ±12 meters. See Figure Q-2.

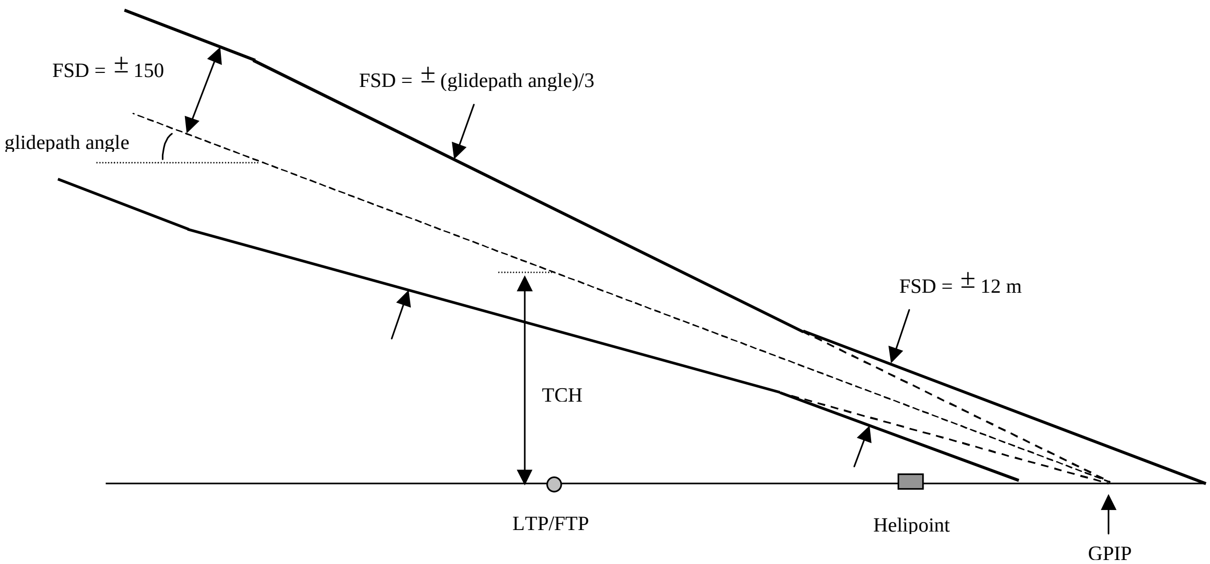

FIGURE Q-2 VERTICAL DISPLAY SCALING

Note: *The TCH is coded in accordance with Table D-1 as the height above the FTP. The helipoint crossing height depends upon the glidepath angle and the TCH.*

Q.2.3 Flight Director and Autopilot Displacement Gains

Flight test results indicate tighter course displacement gains, both horizontal and vertical, may be used whenever the flight director and/or autopilot is used to fly the navigation deviation signals in order to reduce FTE. Horizontal and vertical deviation scaling displayed to the pilots will, however, remain the same as Q.2.1, and Q.2.2, above, whenever increased flight director and autopilot gains are employed.

Q.3 Primary Navigation Display

Q.3.1 Ground Speed

In addition to the primary navigation display in Section 2.2.1.4.1, helicopters shall require the display of ground speed when flying precision approaches to heliports.

Note: *Ground speed is required to aid the crew in establishing the maximum safe approach speed in order to perform the necessary deceleration prior to landing.*

Q.3.2 Active Waypoint Distance

The Active Waypoint Distance, referenced in Section 2.2.1.4.1.a), for helicopter-unique approaches (designated by a runway number of "00") to heliports, following the FAWP will be the distance to the helipoint.

Note: *The helipoint is located a distance of the length offset beyond the FPAP. See Figure Q-1.*

Q.4 Alerts and Advisories

This section is reserved.

Q.5 Protection Level

Q.5.1 Horizontal Protection Level

The same horizontal protection level (HPL) can be used for approaches to runways and heliports.

Q.5.2 Vertical Protection Level

The same vertical protection level (VPL) can be used for approaches to runways and heliports.

Q.5.3 Other Protection Level Considerations

Currently, there are no protection levels identified for the velocity outputs from a WAAS sensor. At helicopter approach speeds, velocity errors could dominate position error in terms of achieved navigation system performance, in particular, when tracking a commanded deceleration profile. Tightly coupled GPS-IRU velocity estimates or inertially aided velocity estimates through an FMS are more tolerant of GPS velocity error than pure PVT (position, velocity, time) input to a navigator.

Q.6 Autopilot Considerations

If coupled autopilot or flight director approaches are to be implemented, the autopilot or flight director will be capable of tracking the lateral and vertical deviation profiles at speeds below the certified V-mini for the helicopter being flown. Stable coupled flight below V-mini is required to insure that the coupled autopilot or flight director approach will remain stable at V-mini and above with acceptable FTE.

Q.7 Heliport Approach Databases

Heliport procedure design characteristics differ considerably from runway procedure design characteristics. Databases must contain sufficient information to properly construct the helicopter instrument approach procedure.

Q.8 References

1. FAA Order 8260.3B, “Terminal Instrument Procedures”.
2. FAA Order 8260.37, “Heliport Civil Utilization of Collocated Microwave Landing System”
3. FAA Order 8260.48, “Area Navigation (RNAV) Approach Construction Criteria”

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Appendix R

REQUIREMENTS AND TEST PROCEDURES FOR TIGHTLY INTEGRATED GPS/INERTIAL SYSTEMS

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Appendix R—REQUIREMENTS AND TEST PROCEDURES FOR TIGHTLY INTEGRATED GPS/INERTIAL SYSTEMS

R.1 Introduction

This appendix includes assumptions, requirements and verification procedures for equipment that utilizes a tight integration of GPS and inertial information to enhance GNSS satellite failure detection and exclusion performance for en-route through non-precision approach under the assumption that selective availability (SA) noise is present. Tightly integrated systems process and monitor pseudo ranges individually based on inertial information such that faulty pseudo ranges can be excluded and removed from the navigation solution. Systems that perform blending of GPS and Inertial Reference System (IRS) position information with no access to individual pseudorange measurements are not tightly integrated. Examples are included to clarify the meaning of assumptions, requirements and validation procedures. The requirements in this appendix apply to tightly integrated GPS/inertial systems using an aircraft-based augmentation of integrity (fault detection and exclusion) under the assumption that WAAS/LAAS differential corrections are not available. Equipment that satisfies these requirements shall also satisfy the requirements in Section 2.1 of this MOPS or alternatively the requirements set forth in TSO-129A.

R.2 Requirements

Section 2.1.2.2.2 provides the basic requirements for any FDE implementation. Section R.2.1 clarifies the application of these requirements to GPS/inertial applications. Additional requirements that are unique for this type of integration are included in Section R.2.2.

R.2.1 General FDE Requirements

The basic FDE requirements from Section 2.1.2.2.2 are summarized in Table R-1.

TABLE R-1 SUMMARY OF FDE REQUIREMENTS

Parameter	Requirement
Missed detection probability (satellite failure)	0.001
False detection rate	10^{-5}/hour
Probability (p_{MI}) of exceeding HPL_{FD}	10^{-7}/hour
Failed exclusion probability (satellite failure)	0.001

The equipment shall be capable of computing the horizontal protection level HPL_{FD}. HPL_{FD} shall be a function of measurement accuracy and geometry only and shall not depend on individual measurements.

Note: *This appendix focuses on the detection and exclusion of satellite failures. Failures may also occur in the equipment providing baro altitude, the GPS receiver e.g., receiver clock, inertial sensors and inertial data processing. Traditionally these types of equipment failures has been detected and excluded based on dual or triple redundancy of equipment. Some of these errors can however alternatively be detected by the tightly integrated system. Guidelines for single string (no redundancy) detection and exclusion of such failures have not yet been developed by the RTCA. It must be demonstrated that the tightly integrated GPS/Inertial system as installed provides adequate detection and exclusion capability to meet the system integrity requirements also when considering equipment failures.*

R.2.1.1 Fault Free Performance

The fault free performance has two components, the 95% accuracy and the rare normal performance. In the presence of Selective Availability (SA) noise as defined in appendix B, the 95% accuracy shall be better than HDOP × 100 m / 1.5 (see Section 2.1.2.1). The rare normal performance relates to the horizontal protection level (HPL) which is a 10^{-7}/ hour limit. The probability that the horizontal error exceeds the horizontal protection level in the fault free case must be allocated a value less than 10^{-7} per hour. Assuming a 2 minute correlation time for the SA noise, this approximately translates to a probability of $10^{-7}/30 = 0.33 \times 10^{-8}$ per sample.

Note: *The integrity risk of 10^{-7}/hour covers all types of satellite failure conditions and fault-free extreme conditions such as SA excursions and airborne equipment induced rare normal drifts. The allocation for rare normal performance must be determined by the manufacturer.*

For example, the rare normal limit (HPL_0) for a snapshot algorithm based on a 0.33×10^{-8} per sample integrity risk allocation, corresponding to 5.95-sigma (two sided Gaussian), is

$$HPL_0 = K_{ffd}\ HDOP\ \sigma_{SA} = 5.95\ HDOP\ \sigma_{SA} \qquad [R\text{-}1]$$

where, based on the accuracy requirement in Section 2.1.2.1

$$2\ HDOP\ \sigma_{SA} \le 100\ m \qquad [R\text{-}2]$$

For comparison, the protection limit HPL calculated by a snapshot FDE algorithm using Gaussian statistics under the hypothesis of one faulty satellite is

$$HPL = \max \{ HPL_n \} \qquad [R\text{-}3]$$

where

$$HPL_n = K_{fd}\ a_n\ \sigma_{SA} + K_{md}\ b_n\ \sigma_{SA} \qquad [R\text{-}4]$$

In these equations a_n (n=1,..,N) and b_n (n=1,..,N) are geometry dependent parameters of the same order of magnitude as the HDOP. The sigma numbers for false detection and missed detection are approximately K_{md}=3 and K_{fa} = 5. This demonstrates that the HPL generally exceeds HPL_0 in snapshot Receiver Autonomous Integrity Monitoring (RAIM) and the HPL_0 is therefore usually not emphasized. In integrated systems where inertial signals are used to propagate GPS information between GPS filter updates, the HPL_0 contribution to the integrity risk is essential.

In addition, mis-modeling of the inertial sensor errors may result in an incorrect 1-sigma position accuracy, which in turn results in an incorrect HPL_0. To ensure integrity, it is important to verify that the accuracy requirement is met with SA and thermal noise included. For integrated GPS/inertial systems it is further important to include gyro/accelerometer noise and bias instability as well as the errors induced by normal airplane dynamics. All error models used must be validated.

R.2.2 Unique Additional Requirements

R.2.2.1 Assumed Failure Mechanisms

Tightly integrated GPS/inertial systems can effectively detect and exclude range rate error steps greater than 2 meters/second. Averaging of the RAIM discriminator (see Section R.2.2.6) can improve the RAIM based HPL for drifts smaller than 0.1 meters/second. The dependence on the failure characteristics makes it necessary to use a set of representative failure mechanisms for testing. Integrity FMEA (Reference 6) has been conducted on

Block I, II and IIA satellites and provided predictions of the misleading information (MI) failure probability for all known failure mechanisms. Observed failure rates have confirmed that these probabilities are conservative. In order to provide some additional margin and to factor in the uncertainty associated with future satellite failure modes, the assigned failure probabilities are enlarged (3.448 ×) relative to the predicted probabilities, and the minimum assumed failure probability has been inflated to 10^{-6} /hour/satellite. The step of 700-3000 meters is already required to be detected by the step monitor in Section 2.1.1.5.1 and this failure mode is therefore not included. Table R-2 lists the predicted failure types, the predicted probability, assigned test range and assigned probability. The assigned MI failure probabilities will be updated if appropriate FMEA data becomes available.

TABLE R-2 SUMMARY OF FAILURE TYPE PROBABILITIES

Predicted MI Failure Type, meters/second (m/s)	Block I, II, IIA Predicted MI Failure Probability in units of 10^{-7}/ hour/satellite	Assigned Test Range	Assigned MI Failure Probability in units of 10^{-6}/ hour/satellite
Ramp 0.01 m/s	2	Ramp 0.01-0.05 m/s	1
Ramp 0.1 m/s	1	Ramp 0.05-0.25 m/s	1
Ramp 0.5 m/s	3	Ramp 0.25-0.75 m/s	1
Ramp 1.0 m/s	10	Ramp 0.75-2.5 m/s	3.5
Ramp 5.0 m/s	12	Ramp 2.5-5.0 m/s	4.1
Step 300 meters	1	Step 300-700 meters	1
Step 3000 meters	34	Step 700-3000 meters	N/A

Note: *The IFMEA and observed failure rates for Block I, II, and IIA satellites indicate that larger acceleration errors occur with a probability that is negligible versus 10^{-7}/ h, and that failure induced accelerations with a probability of 10^{-7}/h or higher, can not exceed 0.1 μg. Performance degradation due to small accelerations (<0.1μg) are covered by the 0.01 m/s ramp and an acceleration failure mechanism is therefore not included.*

R.2.2.2 Detection Limit

The probability, p_{MI}, of exceeding HPL_{FD} with no integrity alert (integrity risk) specified in Table R-1 shall be defined as

$$p_{MI} = \sum_{k=1}^{K} p_{f,k}\, p_{md,k} \qquad \text{[R-5]}$$

where $p_{md,k}$ is the conditional probability of exceeding HPL_{FD} for failure mode k, $p_{f,k}$ is the assigned MI failure probability in Table R-2 and K is the number of failure modes. The continuity risk p_{cont} associated with a satellite failure that cannot be excluded before a loss of function occurs, shall be defined as

$$p_{cont} = \sum_{k=1}^{K} p_{f,k}\, p_{fexl,k} \qquad \text{[R-6]}$$

where $p_{fexl,k}$ is the conditional probability of failed exclusion for failure mode k.

Notes: ***1.*** *The HPL provided by the tightly integrated system as defined in this appendix only needs to consider the limited set of failure scenarios defined above.*

2. *The required continuity risk depends on operational considerations and is expected to be in the range 10^{-7}/h – 10^{-5} /h.*

R.2.2.3 SatZap

Due to the monitoring performed by the GPS control segment (SatZap) and the changes planned to occur as part of the GPS modernization it is expected that slowly drifting satellites will be detected and removed before the error has any significant impact. As soon as this monitoring is in place and its performance documented it will be possible to make use of the synergy between tightly integrated systems and the control segment monitoring by modifying the equipment to comply with a different set of MI failure probabilities.

R.2.2.4 Receiver Clock Aiding

The receiver clock frequency random walk 1-sigma shall not exceed 1 feet/s / $\sqrt{s}$ under steady state thermal conditions. The frequency drift shall not exceed 3 ppm/°C under transient thermal conditions.

Notes: **1.** *When using a Kalman filter based integration or other equivalent integration the receiver clock error is usually incorporated in the state model. To assure interoperability when using different GPS receivers a minimum clock standard is required.*

2. *The maximum temperature rate of change specified in DO-160D for all equipment categories is 5°C /minute.*

3. *A significantly lower temperature sensitivity than 3 ppm/°C would require the use of an oven-controlled crystal oscillator (OCXO) and exclude the use of a temperature compensated crystal oscillator (TCXO) in the GPS receiver.*

If receiver clock aiding is used to enhance integrity, the algorithms that perform calibration shall be designed to prevent the satellite failure itself from affecting the integrity of the calibration. Conventional Kalman filter integrations using clock states for offset and drift rate with no further enhancements to protect these states in a failure situation will not meet this requirement.

Note: *Oscillators are temperature sensitive devices. The drift stability in a transient thermal environment, such as a receiver just turned on, is significantly degraded relative to a steady state thermal environment. An airplane descending from enroute to non precision approach experiences significant temperature gradients which affect the stability of the clock.*

R.2.2.5 Altitude Aiding

If pressure altitude aiding is used to enhance integrity, the algorithms that perform calibration shall be designed to prevent the satellite failure itself from affecting the integrity of the calibration. Conventional Kalman filter integrations using a bias error state with no further enhancements to protect this state in a failure situation will not meet this requirement. RAIM algorithms meeting this requirement (without the use of inertial measurements) are included in Appendix G.

Note: *When using a Kalman filter based integration or other equivalent integration, the pressure altitude bias error is usually incorporated in the state model.*

R.2.2.6 Discriminator Averaging

Most integrity monitor algorithms employ a comparison of a satellite-specific discriminator $d_n(t)$ at time t versus a threshold D for detection of satellite MI failures

$$|\, d_n(t)| > D \qquad [R\text{-}7]$$

The SA correlation time τ_{sa} is assumed to be 2 min. For the standard RTCA 2-state model, the correlation coefficient, ρ, for successive samples (ignoring error sources other than SA) taken 2 minutes apart is 0.5, while samples 4 or more minutes apart are essentially uncorrelated. When discriminators taken 2 minutes apart $d_n(t)$, $d_n(t- \tau_{sa})$, $d_n(t- 2\tau_{sa})$,..., $d_n(t- L\tau_{sa})$ are averaged

$$\bar{d}_n^L = \sum_{\ell=1}^{L} d_n(t - \ell\tau_{SA}) \qquad [R\text{-}8]$$

the expected 1-sigma value is reduced to approximately

$$\sigma_{\bar{d}_n^L} = \frac{\sigma_{d_n}}{\sqrt{L}}\sqrt{1 + 2\rho\frac{L-1}{L}} \qquad [R\text{-}9]$$

Note: *This is derived by evaluating the variance* $E[\sum_{m=1}^{L}\sum_{\ell=1}^{L} d_n(t-\ell\tau_{SA})\, d_n(t-m\tau_{SA})]$ *using that* $E[d_n(t-\ell\tau_{SA})d_n(t-m\tau_{SA})] = \rho\sigma^2$ *for adjacent* ℓ*,m of which there are 2(L-1) and ignoring the correlation terms for which* $|\ell - m| > 1$ *.*

This in turn means that the protection limit in the example above is reduced to approximately

$$HPL_n = K_{fd}\, a_n \frac{\sigma_{d_n}}{\sqrt{L}}\sqrt{1 + 2\rho\frac{L-1}{L}} + K_{md}\, b_n\, \boldsymbol{\sigma}_{SA} \qquad [R\text{-}10]$$

For this averaging technique to be effective the failure must change slowly over time so that the average of the failure will become large relative to the averaged noise. This method becomes effective below 0.1 m/s. A system using discriminator averaging when determining the horizontal protection limit (HPL_n) shall consider: (1) the impact of the temporal correlation, ρ, of the discriminator noise e.g., the SA dither, (2) the impact of the SA epsilon component (which is not reduced by averaging), and (3) the reduction in detection performance for failures with dynamics that are fast relative to the averaging period.

R.2.2.7 SA Correlation Effects on Performance

In tightly integrated GPS/inertial systems, the spectral content of the SA dither noise is important. It can be shown that the RTCA SA dither model in Appendix B is not fully de-correlated for measurements taken 2.0 to 2.5 min apart and this results in an underestimation of the position error sigmas by 13%-20%. If no compensation is performed, the false detection rate may not be met. A typical inflation factor as a function of the time step is shown in Figure R-1. The error model used in the HPL calculation shall be compensated to account for the impact of this residual correlation.

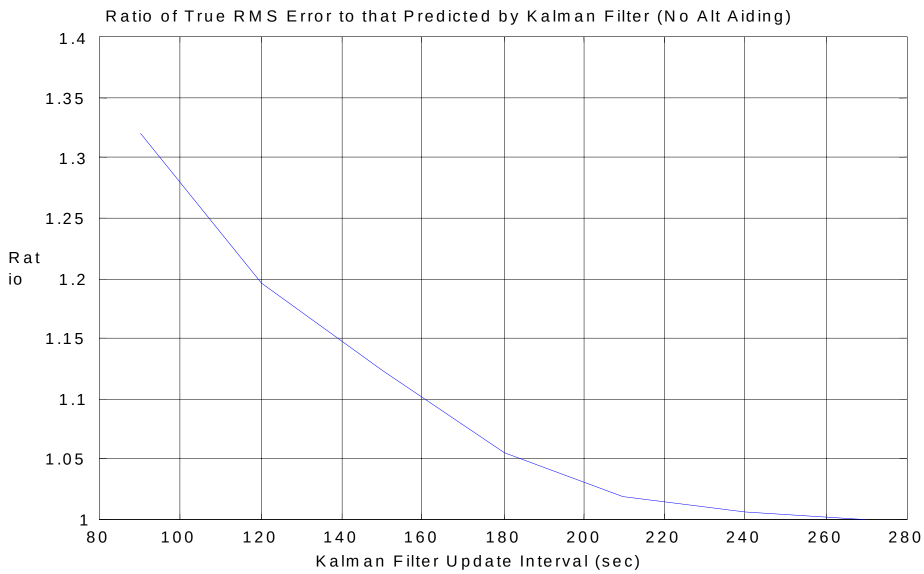

FIGURE R-1 INFLATION FACTOR

Note: *The inflation factor shown in Figure R-1 is typical, but is tied to a specific integration example and cannot be used in other designs without validation*

The SA epsilon part acts as a slowly changing bias and cannot be modeled as white noise measurements for any measurement interval. The tightly integrated system shall factor in the impact of this bias in the HPL calculation.

R.2.2.8 Inertial Coasting Performance Evaluation

The inertial sensors in tightly integrated GPS/inertial systems are continuously calibrated. This means that the system can propagate the established position accurately if the GPS signals are lost due to any unexpected event such as interference, scintillation, masking, unexpected satellite failure, etc. In order to promote the use of this capability a method to establish the coasting performance is defined below.

Note: *The performance requirements applicable to inertial coasting are provided in RTCA/DO-236A. The inertial coasting error represents a navigation system error that combined with the flight technical error constitute the total system error defined by the RNP type. The allowed coasting time (coasting capability) is ultimately determined by the NSE tolerance provided by the RNP type. The coasting capability can be established from the horizontal radial error distribu-*

tion, typically the 95% limit, in meters or nmi as a function of time in minutes from the point the GPS function was lost.

The horizontal coasting error distribution as a function of time shall be evaluated under the following conditions: The calibration time (i.e., the time GPS is available before the loss of satellites) shall be less or equal to 1 hour. The HDOP shall stay above 1.5 throughout the calibration. Frozen satellite positions may be used. The evaluation shall be performed with correct or conservative gyro/accelerometer noise, correct or conservative gyro/accelerometer bias instability and receiver clock model. Altitude information as mechanized in the system under evaluation, may be used during the coasting phase to prevent vertical channel instability. In this evaluation the Calibration and coasting shall be performed during straight and level flight. The coasting error distribution is a statistical measure and covariance propagation techniques may be used to determine the performance. At least 500 Monte Carlo simulations, including calibration and subsequent coasting, using the algorithms implemented in the system shall be run to verify the covariance propagation model used to predict the claimed coasting performance.

Notes: ***1.*** *The 500 Monte Carlo simulations may be replaced by 500 tests performed on the equipment*

2. *This requirement is not applicable if a coasting capability is not claimed as part of the equipment performance parameters.*

An example of coasting performance using 2 nmi/hour sensors illustrating the order of magnitude of the coasting error during straight and level flight, is shown in Table R-3.

TABLE R-3 COASTING PERFORMANCE EXAMPLE WITH Σ_{SA}=33.3 M

Coasting time	95% accuracy
0 min	100 m
10 min	300 m
20 min	750 m
30 min	1400 m
1 hour	2500 m

For additional information on coasting performance see Reference 4 in Section R.6.

R.3 Tightly Integrated GPS/Inertial Design Concepts

This section, which is of descriptive nature and contains no requirements, describes basic techniques that can be used to enhance the integrity of tightly integrated solutions.

R.3.1 Integration Methods

Conventional Kalman filters are used to integrate inertial information with external measurements from various ranging sources such as GPS or Loran. The Kalman filter relies on an accurate inertial error model and known statistical inertial sensor error distributions as well as a linearized measurement model for GPS pseudoranges and the associated pseudorange error statistics.

The transient that is produced by a position step or a sudden drift in a satellite, is detectable in the measurement residuals or innovations. This transient behavior can be used to enhance the detection and exclusion capability for a limited set of failure modes.

Note: *The conventional Kalman filter in itself does not improve the integrity of the GPS solution since it will easily adapt to and incorporate any GPS position off-*

set or drift as a natural dynamic state (position error state or velocity error state).

In a situation when redundant satellite information is available, errors will develop in all satellite post residuals (after application of measurements) or pre residuals (before application) as a satellite failure progresses and the initial transient has settled. Any method that provides a detection scheme solely based on these remaining residuals (transient assumed gone) is approximately equivalent to traditional RAIM and will therefore not further augment the RAIM function. If the residuals are averaged over time the method is equivalent to RAIM using discriminator averaging. One exception to this simple rule is the Gravity/Schuler coupling, which provides additional detection capability over unaided RAIM (see Section R.3.2.4).

R.3.1.1 Pre Residual (Innovation) Screening

This method is routinely used in Kalman filter based estimators. The statistics of the innovations can be calculated from the covariance matrix P. If one or several innovations associated with a measurement far exceed the expected 1-sigma value, the measurement is excluded. This method provides exclusion capability for large steps, ramps and ramp rates. Multiple measurement failures can be handled. Slow drifts or drift rates are, however, not excluded and detection and exclusion of such failure types can only be provided by other methods, e.g., RAIM. Innovation screening will typically eliminate the faulty measurement and the HPL can be calculated by determining the worst-case navigation error impact over all possible satellite failure modes.

R.3.1.2 Post Residual Monitoring

The post residual (residual error after processing of measurements) is calculated right after the estimator has processed all the measurements. The statistics of the post residual can be calculated from the covariance matrix P. If one or several residuals far exceed the expected 1-sigma value, it can be concluded that one or more of the measurements must have been in error. Normally this method mixes elements of RAIM and innovation screening and it is not straightforward to sort out which effect that is dominating. Therefore, an exclusion capability is not provided in the general case.

R.3.1.3 Additional Measurement Bias States

The addition of ramp failure states in a Kalman filter based estimator produces a mechanism for detection that is equivalent to RAIM, but no calculation of HPL has been proposed for this method.

R.3.1.4 Multiple Kalman Filters

If multiple Kalman filters are used, in which a different satellite has been excluded in each filter, the residual monitoring and additional bias states methods, described above, will provide an exclusion mechanism equivalent to RAIM. However no method for calculating the exclusion limit HEL has been proposed for this method.

R.3.1.5 Extrapolation Method

The extrapolation method utilizes a simultaneous combination of both transient and redundancy effects to detect failures. The measurements are stored in buffers over 30 minute periods. This provides a detection capability, which is enhanced over RAIM for slow failures because of the information that is retained from previously processed measurements (compare discriminator averaging). A bank of parallel Kalman filters is used to: (1) test newly acquired satellites before they are used in the main Kalman filter, and (2) to isolate failed satellites once the failure is detected by the main Kalman filter. The HPL is calculated by computing parallel solutions corresponding to different failure modes. The magnitude of the worst-case failure is determined partially based on simulations to provide probability of detection and correct isolation exceeding 99.9%.

R.3.1.6 Solution Separation Method

A bank of Kalman filters using the solution separation method provides a non transient detection capability that has been enhanced over RAIM based on the redundancy information that is retained from previously processed measurements via the inertial function. A procedure for calculating HPL is an integral part of this method. No assumption is made about the dynamics of the failure when HPL is calculated. The enhancements provided by external aiding information (e.g., filter states representing corrections to external aiding information), such as receiver clock and pressure altitude, will be incorporated in the calculated HPL. No miss-calibration is possible since one of the reference sub-filters using the aiding will not contain the failing satellite.

R.3.2 Detection and Exclusion Mechanisms

R.3.2.1 Transient Detection/Exclusion for 2 nmi/hour Grade Systems

The transient effect can be used to exclude a faulty satellite. This type of monitor provides increased detection and exclusion capability in a situation when RAIM is not effective. If for example a pre residual (innovation) monitor is used to detect ramps, it can be shown by simulation that ramps above 2 meters/second can be detected with a 0.999 detection probability in the presence of SA in all situations when RAIM is not effective (assuming at least one hour of good geometry prior to the failure). This leads to 100% (detection and exclusion) availability for ramps above 2 meters/second when RAIM is unavailable. This highly available but restricted exclusion capability demonstrates the basic advantage and also limitation of this type of enhancement.

Note: *The detection/exclusion ramp limit of 2 meters/second is achievable by equipment using commercial grade navigation sensors i.e., inertial systems meeting a 2 nmi/hour performance (95%), under the assumption of SA on.*

R.3.2.2 Satellite Redundancy

Measurement redundancy is the mechanism that is used in RAIM. It is because of the satellite measurement redundancy that Kalman filter post residuals continue to grow with the satellite error after the initial transient has settled. Without any redundancy no such growth will occur.

R.3.2.3 Integrity Coasting

In this case dynamic states that contain redundancy information (defined based on the assumption that only one satellite will fail) are time propagated based on inertial information. An example of this mechanism is the solution separation method where sub-filters and dual covariance propagators are used to retain this redundancy information.

R.3.2.4 Gravity/Schuler Coupling

The Gravity/Schuler coupling effect can be demonstrated by letting the vertical channel, incorporating a z-accelerometer, combine with the Schuler dynamics of one of the horizontal channels in a Kalman filter. As measurements that are the sum of the vertical position and the clock phase error, combine with measurements that are the sum of the lateral position and the same clock phase error, the vertical position error will be pulled in. This effect is not sensitive to the clock performance but is strongly related to the z-accelerometer accuracy. The reason for this effect is that the Kalman filter is able to eliminate the clock phase error due to the radically different dynamics of the vertical and horizontal channels. Most GPS/Inertial Kalman filters will automatically incorporate this type of information. This means that integrity below 1 nmi can be established with only 4 satellites (in good geometry) in view and no altitude aiding if an accurate z-accelerometer is used. It can be demonstrated that an accurate z-accelerometer is approximately equivalent to an altitude measurement. The z-accelerometer versus altitude accuracy relation is summarized in Table R-4 (see Reference 1 in Section R.6).

TABLE R-4 EQUIVALENT ALTITUDE ACCURACY

Acceleration, micro Gs (μg)	Altitude, Meters (m)
300 μg	920 m
100 μg	420 m
40 μg	300 m
20 μg	280 m

R.3.2.5 Other Schuler Coupling Related Effects

When exposed to MI failures (such as ramps) and after the transient has rung out, innovations or residuals often gradually deviates from zero in an oscillatory manner. This phenomenon is due to the horizontal Schuler coupling and other long term coupling effects. The reason for the deviation is that the satellite drift causes a linear position growth while the inertial position error growth has an 84 minute oscillatory component. Due to the long oscillation period (84 minutes) these effects are generally not timely enough to improve the detection and exclusion capability.

R.4 Assumptions

R.4.1 Signal Error Model

The SA noise has two components: dither, w_d, and epsilon, w_ε. The measured spectral content of the SA dither signal is shown in Figure R-2. This result is based on noise data from 26 satellites over 24 hours. The spectral content is approximated by the RTCA 2-state dither model illustrated in Figure R-2. The RTCA model using a 23 meter standard deviation for dither (see Appendix B) shall be used for performance evaluation and certification. Other models that better adhere to the measured spectral density may be used but must be validated versus collected SA data. For the purpose of performance evaluation and certification the epsilon part shall be modeled as a first order Markov process with a time constant of 2 hours and a standard deviation of 23 m.

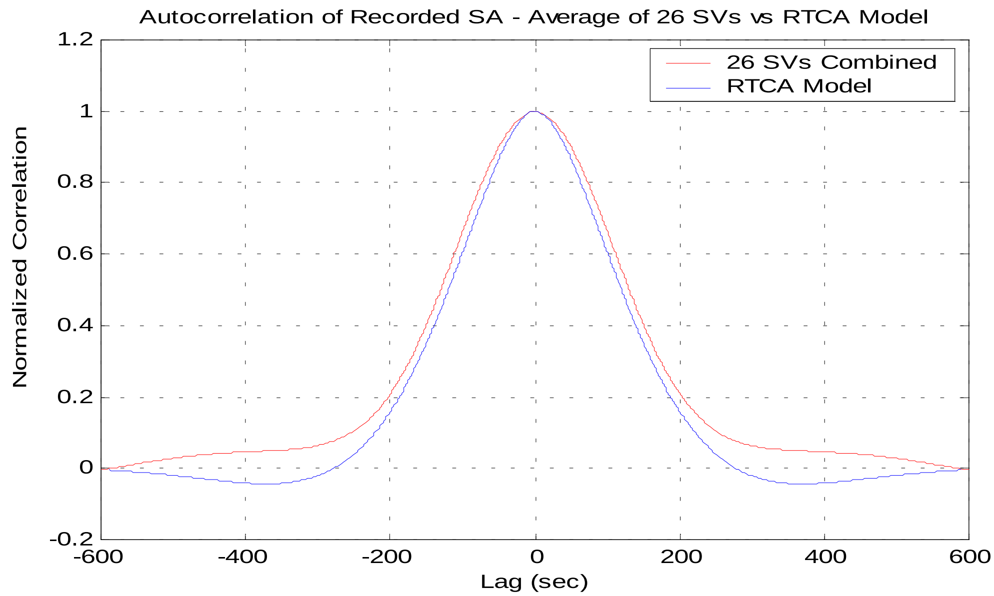

FIGURE R-2 26 SATELLITE 24 HOUR AUTO-CORRELATION VERSUS RTCA MODEL

Notes:

1. *RAIM continuity relies on the assumption that a 2.0 min time interval between measurements will de-correlate the SA measurements. The RTCA SA model, which represents the best 2nd order model fit to the observed spectral power density, does not adhere to this assumption (see Section R.2.2.6).*

2. *The epsilon part is also intended to cover the ionosphere error. This is the reason why the time constant is set to 2 hours. It is essential that the epsilon contribution be included in any test even if no such component has been formally added to the GPS signals by the DOD.*

3. *It is recommended that carrier smoothing of code measurements be performed (see Section J.2.4) so that the thermal noise is negligible. Without smoothing a 4.8m 1- sigma can be assumed or a 1-sigma dependent on the design which is expressed as a function of signal to noise ratio, code tracking bandwidth and correlator type provided by the manufacturer.*

4. *Ephemeris errors will also contribute to the error budget. These errors vary along the satellite trajectory and step changes may occur, as new ephemeris parameters are employed (IOD update). If the change in satellite position estimate due to the IOD update is known, the resulting step change can be predicted and compensated for and only the true satellite position error will affect the integration filter performance.*

R.4.2 Satellite Failure Model

For errors, such as a systematic drift in the atomic clock onboard the satellite, a slow acceleration in the pseudo range error will result. A sudden frequency shift in the satellite clock will lead to a ramp in the pseudo range. Likewise errors in the satellite clock parameters in the navigation message will have a similar impact: for instance an error in a_{f1} causes a ramp type failure and an error in a_{f2} causes an (pseudo range) acceleration error.

Note: *For block II/IIA cesium clocks the af_2 term in the navigation message is hard-coded to zero. The block IIR satellites uses a rubidium clock that exhibit small* *accelerations and the af_2 term is used. The maximum acceleration error that could occur if af_2 was incorrect is 0.1 μg.*

The model in Table R-2 (Section R.2.2.1), which is limited to steps and ramps, has been established based on experimental data and Integrity Failure Modes and Effects Analysis (IFMEA) by ARINC in El Segundo, California. The data used to establish this model is summarized in the Aberration Characterization Sheets (ACS) documented in Reference 6.

R.5 Validation

R.5.1 Categorization of Detection and Exclusion Mechanisms

Due to the special character of a tightly integrated approach the tests in Section R.5 shall be performed with correct or conservative gyro/accelerometer noise, correct or conservative gyro/accelerometer bias instability, correct or conservative scale-factor and misalignment errors, normal airplane dynamics and correct or conservative receiver clock model.

Normal airplane dynamics shall include turns in the terminal area as follows: For terminal and non precision approach use straight and level flight during calibration (when failure is not present) and one single 180 degree turn using a 1.5 degree/second turn rate started right after the failure is initiated. The ground speed is approximately 200 knots.

If altitude and/or clock aiding are used these measurements shall also be included in the verification.

If the position solution is updated at a low rate (such as a 2.5-min time step) the growth in the solution error between updates must be considered. The performance shall be measured and verified both before and after the measurement update.

The manufacturer shall categorize the failure detection and exclusion mechanisms employed by the monitor algorithms that are to be validated. The mechanisms identified in this appendix are:

1. Transient detection and exclusion (e.g., innovation screening)
2. Satellite geometric redundancy (e.g., RAIM)
3. Inertially propagated geometric redundancy (e.g., solution separation)
4. Discriminator or residual time averaging (e.g., RAIM or extrapolation method)
5. Gravity/Schuler coupling

The limitations and performance of each implemented detection/exclusion mechanism shall be demonstrated in test cases chosen by the manufacturer. This material will be used by the certification authority to assess the authenticity of the claimed improvements over normal RAIM.

R.5.1.1 Examples

The transient detection can be demonstrated by testing different ramp scenarios in geometries with no redundancy (4 satellites).

The performance of the redundancy based monitor (RAIM equivalent) which may include discriminator (residual) averaging, altitude and/or clock aiding can be demonstrated using ramps below the transient exclusion threshold or with the transient exclusion mechanism disabled.

In order to demonstrate integrity parameter coasting performance, test cases where this coasting mechanism is active (RAIM integrity holes) should be designed. Any transient mechanism for detection and exclusion must be disabled or slow ramps must be used.

R.5.2 Covariance Simulation

The Kalman filter technique provides a powerful verification tool referred to as covariance simulation. This type of prediction can be used for availability determination for different satellite constellations but shall not replace off line verification of the implemented detection and exclusion algorithms.

R.5.2.1 Covariance Simulation Methods for Availability Evaluation

When system availability is determined, Monte Carlo techniques for verification of detection probability and false detection probability at each space-time point would be impractical since several million space-time points need to be evaluated. The covariance simulation technique which is based on the statistical 1-sigma and correlation information that can be extracted from the Kalman filter covariance matrix P makes it possible to determine these probabilities based on a single run at the desired space-time point.

The Covariance simulation involves six steps for each failure type:

1. Determine the fault free distributions of the discriminator value
2. Determine the fault free distribution of the horizontal error
3. Determine the statistical correlation between the discriminator value and the horizontal error.
4. Determine the fault induced deterministic discriminator value as a function of time with the simulated noise turned off and with the same Kalman filter settings as in 1)
5. Determine the horizontal error as a function of time with the simulated noise turned off and with the same Kalman filter settings as in 2)
6. Establish the radial horizontal protection limit by determining the smallest radial limit (HPL) for which the probability that the test variable are below the thresholds while the horizontal error exceeds HPL is less than or equal to 0.001 for all possible satellite errors. (For a detailed discussion on covariance simulation, see Reference 5, Section R.6).

Notes:

1. *Since the Kalman filter is a linear filter the noise distributions in 1) and 2) can be superimposed on the deterministic functions.*

2. *1) , 2) and 3) define a multidimensional probability density* $f(t_1,\ldots,t_m,x_1,x_2)$ *of horizontal error* x_1,x_2 *and test variables* $t_1 ,\ldots, t_m$ *combined. The condition* $|t_k| < D_k$ $k=1,\ldots,m$ *and* $r=\sqrt{x_1^2+x_2^2} > HPL$ *is an event that can be defined in this multidimensional space. Usually a manufacturer would use approximate conservative methods to simplify the HPL calculation.*

3. *The HPL determined this way relies on a series of assumptions and derivations. It is for instance assumed that the SA noise is Gaussian and uncorrelated between measurements. In reality SA noise errors are not uncorrelated and the resulting 13-20% integrity impact described in Section R.2.2.7 would not be observed in the testing unless the full SA noise model was included in the Kalman filter. The procedure for determining the correct HPL by a multidimensional probability density function is complex and further assumptions would be used to simplify this calculation. It is therefore required that the resulting HPL calculation be validated by Monte Carlo simulation.*

R.5.3 False Detection Probability

Section 2.5.9.4.2 requires that a non-snapshot algorithm be simulated for 82,500 hours per geometry for SA on (40 geometries yield 3,300,000 hours of simulation). Assuming that 2 minutes of simulation time is needed per hour of real time, this leads to 3,300,000 hours of simulation or 2 min /60 /60 /24 = 76 days.

This amount of time is unreasonable and the detection/exclusion threshold may be adjusted so that the test is reduced to 7 days in these tests. The confidence level in the altered (higher) false detection probability obtained with the adjusted detection threshold shall be the same as in Section 2.5.9.4.1.

Notes: ***1.*** *If due to the observed event rate in a particular test, the required confidence as defined in 2.5.9.4.1 can be established with less than the nominal number of independent samples, the test can be terminated earlier.*

2. *It seems preferable to increase the measurement noise level (SA or ionosphere) instead of adjusting the threshold so that the tested algorithm remains intact during testing but in tightly integrated systems it is important to preserve the relation between inertial sensor errors and measurement noise during the testing.*

All the detection/exclusion mechanisms shall be active and tested at the same time. The total amount of false detections and exclusions shall be verified. If more monitors are used the total false detection allocation shall reflect contributions from each additional mechanism.

R.5.4 Fault Free Accuracy Performance

The snapshot 95% horizontal accuracy test is defined in Section 2.5.4.3. If the inertial integration is performed by a recursive filter with memory, the scaling (1.5/HDOP) used in the test is not appropriate. The testing shall be performed versus the 2drms accuracy limit that is provided by the integration filter. For a Kalman filter with position error in states 1, 2, 3 (North, East, Down) this limit is expressed as

$$2\text{drms} = 2\sqrt{p_{11} + p_{22}} \qquad \text{(R-11)}$$

The accuracy test shall be performed with SA according to Section R.4.1 and maximum thermal noise (minimum S/N_0). The accuracy test shall demonstrate that the instantaneous horizontal position error d_i stays below 2drms, as defined above, 95% of the time.

The test shall evaluate at least 360 independent samples resulting in 12 hours of simulated flight time using the satellite constellation in Appendix B.

The calculated 2drms limit shall be less than (HDOP/1.5) $\times$ 100 m at each time point for the system to be available. Of great importance is the verification that K_{ffd} drms < HPL under all circumstances (see rare normal verification).

R.5.5 Off-Line Rare Normal Verification

The rare normal verification test is split in two parts:

1. A verification that K_{ffd} drms < HPL shall be performed. This test can be performed based on Availability (Covariance) analysis provided that the 2drms limit used has been verified in Section R.5.4. This condition is normally automatically satisfied in snapshot algorithms but is not necessarily true in tightly integrated systems where the memory in the recursive algorithms (such as a Kalman filter) play an important role.
2. At the same time the false detection rate simulation is performed the navigation performance shall be tested versus HPL to assure that the position solution stays within

the HPL with a probability commensurate with the 10^{-7}/hour. There shall be no cases when d_i exceeds HPL in the false detection test in Section R.5.3.

The purpose of test 2 is to assure that there are no algorithm errors in the implementation, such as the HPL being exceeded under fault free conditions.

R.5.6 Off-Line Detection/Exclusion Verification

All position errors shall be evaluated relative to the HPL that is calculated by the equipment under test or if exclusion is tested the predicted HEL. The test first verifies normal RAIM performance and then moves on to test cases where the claimed HPL(HEL) performance is better than the performance provided by RAIM. The corresponding RAIM baseline performance shall be provided for all test cases as a reference. A failure to clearly identify and demonstrate the function of the mechanism responsible for the improved HPL (HEL) (relative to RAIM) in a test case, shall render the test invalid (see Section R.5.1).

Note: *The reason for this requirement is that the entire test otherwise could be performed only in regions where RAIM is available and not in regions where the additional performance is claimed.*

R.5.6.1 Detection and Exclusion Mechanism Equivalent to RAIM

The off-line detection/exclusion test procedure in Section 2.5.9.3.3.2 shall be performed to verify the RAIM equivalent performance, i.e., 1650 trials must be run for each of the 40 geometries (20 for detection and 20 for exclusion) with the (software) algorithm that is implemented in the equipment. The following exceptions apply:

1. The RAIM equivalent performance shall be verified based on Section 2.5.9.3.3.2 using ramps that will not trigger any of the other detection/exclusion mechanisms augmenting the RAIM function.
2. If the RAIM algorithm and the augmentation algorithms are implemented separately, the augmentation algorithms may be disabled and RAIM tested according to Section 2.5.9.3.3.2 using 5 meters/second ramps.

Alternatively the RAIM equivalent performance may be tested according to Step 2 to 5 in Section R.5.6.2 using the geometries defined in Section 2.5.9.3.3.2.

R.5.6.2 Claimed Additional Detection and Exclusion Mechanisms

The equipment manufacturer shall perform the following:

1. Select 20/20 different typical scenarios i.e., geometries and previous history providing $HPL < HPL_{RAIM}$ / $HEL < HEL_{RAIM.}$
2. Perform 1650 trials using a mixture of failure modes according to Table R-5 for each scenario (geometry and previous history)
3. For each failure mode, the magnitude of the ramps (step) shall be distributed uniformly in the interval designated in Table R-5. The failure shall be introduced in the most difficult to detect/exclude satellite.
4. For each failure mode, the failure ramp and the change in geometry shall be coordinated so that the desired HPL/HEL would have been exceeded if detection/exclusion had not occurred.
5. Alternatively, if the geometry history is immaterial for obtaining the claimed HPL/HEL, the desired geometry may be frozen.

Evaluated over all 20 scenarios the number of missed detections/exclusions shall be less than the 47. The number of trials for detection and exclusion verification is $40 \times 1650 = 66{,}000$.

TABLE R-5 REQUIRED NUMBER OF TRIALS FOR EACH FAILURE MODE

Failure Type	Number of trials for each failure mode	Assumed MI Failure Probability in units of 10^{-5}/h/satellite
Ramp 0.01-0.05 m/s	114	2/29
Ramp 0.05-0.25 m/s	57	1/29
Ramp 0.25-0.75 m/s	170	3/29
Ramp 0.75-2.5 m/s	569	10/29
Ramp 2.5-5.0 m/s	683	12/29
Step 300-700 m	57	1/29

R.5.6.2.1 Examples

R.5.6.2.1.1 RAIM with Transient Detection/Exclusion

The off-line missed detection/exclusion rate verification is to be performed in time-space points where HPL (HEL) < HPL_{RAIM} (HEL_{RAIM}). HPL (HEL) is solely determined by the inertially aided transient exclusion mechanism. Twenty different geometries must be identified and 1650 trials must be performed for each geometry. The failure ramp and the change in geometry must be coordinated so that the desired HPL (HEL) would have been exceeded if detection/exclusion had not occurred. The number of missed detection (exclusion) must be less than the 47.

Note: *The transient detection is not effective for slow ramps. This test example would illustrate the outcome of the test in which the integrity enhancement is not meeting the requirements.*

R.5.6.2.1.2 Solution Separation Detection and Exclusion

In the regions where this method is claiming no more than snapshot RAIM performance and provided that any transient detection mechanism is disabled, the same method that is used for RAIM verification is also applicable to this method. As the 40 geometry cases are chosen observe that:

1. The geometry may remain fixed through out the test (see Section 2.5.9.3.1)
2. The geometries that reflect a range of HPL/HEL values shall be chosen based on the solution separation HPL_{solsep} (HEL_{solsep}) and not the RAIM related HPL_{raim} (HEL_{raim}).

In the regions where additional performance over RAIM is claimed, the algorithm must be tested separately by choosing 20 geometries each for detection and exclusion that tests detection/exclusion in situations where HPL_{solsep} (HEL_{solsep}) < HPL_{raim} (HEL_{raim}). For solution separation these regions are referred to as RAIM holes. This means that HPL_{raim} (HEL_{raim}) changes from a HPL_{raim} (HEL_{raim}) that meets the horizontal alert limit (HAL) initially, but due to a loss of a crucial satellite, subsequently moves to a higher level (above HAL). Each failure ramp and the change in geometry must be coordinated so that the desired HPL_{solsep} (HEL_{solsep}) would have been exceeded if detection/exclusion had not occurred. The 20 integrity limits HPL_{solsep} (HEL_{solsep}) are chosen in the interval specified in Section 2.5.9.3.2.

R.5.6.2.2 Reference RAIM Models

All example integration methods that provide a HPL output presented in this appendix are associated with a specific snapshot RAIM method. For example, the solution separation technique can also be used as a snapshot RAIM method. The associated RAIM algorithm is the solution separation based RAIM. This method has been proved to be equivalent to the parity space based RAIM using a Gaussian discriminator in Reference 1. The extrapolation method is using $\chi 2$ residual statistics as described in Reference 2 and the corresponding RAIM algorithm using $\chi 2$ statistics and the slope concept, has been shown to be equivalent to parity space and range comparison techniques in Reference 3.

For pressure altitude calibration aiding, the reference is provided in Appendix G. The RAIM algorithm used as a reference shall be tested according to Section 2.5.9.

R.5.7 On-Line Verification

The on-line verification for tightly integrated GPS/inertial follows the guidelines in Section 2.5.9.5. If the off-line simulation is not performed on the target processor using the same software used in the equipment, 40 satellite failure scenarios shall be run using the off-line simulation and the on-target software and the result evaluated according to Section 2.5.9.5.1. The 40 scenarios shall be chosen so that all types of detection/exclusion mechanisms subject to off-line testing are represented. The Behavioral test in Section 2.5.9.5.2 shall be performed as stated but the number of failure scenarios shall be 5 per detection/exclusion mechanisms.

R.6 References

1. Brenner, M., 1995, “Integrated GPS/Inertial Fault Detection Availability,” *Proceedings of ION GPS-95*, Palm Springs, CA, September 1995, Institute of Navigation, Alexandria, VA.
2. Diesel, J. W., and S. Luu, September 1995, “GPS/IRS AIME: Calculation of Thresholds and Protection Radius Using Chi-Square Methods,” *Proceedings of ION GPS-9*5, Palm Springs, CA, Institute of Navigation, Alexandria, VA.
3. Brown, R. G. , 1992, “ A Baseline GPS RAIM Scheme and a Note on the equivalence of Three RAIM Methods” Institute of Navigation Special Monograph Series, Vol. V, Institute of Navigation, Alexandria, VA.
4. Lee, Y. C. and D. O'Laughlin, "A Performance Analysis of a Tightly Coupled GPS/Inertial System for Two Integrity Monitoring Methods," Proceedings of The 12th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GPS-99), September 14-17, 1999, Nashville, Tennessee
5. Lee, Y. C. and D. O'Laughlin, "A Further Analysis of Integrity Methods for Tightly Coupled GPS/IRS Systems," Proceedings of The 2000 National Technical Meeting of the Institute of Navigation, January 26-28, 2000, Anaheim, California
6. RTCA Paper No. 034-01/SC159-867.

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