GLOBAL POSITIONING SYSTEM WIDE AREA AUGMENTATION SYSTEM (WAAS) PERFORMANCE STANDARD

1st Edition

31 October 2008

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FOREWORD

This document defines the levels of performance the U.S. Government makes available to users of the Global Positioning System (GPS) Standard Positioning Services (SPS) augmented by the Wide Area Augmentation System (WAAS). It has been approved by the Vice President for Technical Operations, Federal Aviation Administration (FAA). Please refer any questions or comments, in writing, to:

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Executive Summary

The U.S. Global Positioning System (GPS) Standard Positioning Service (SPS) consists of space-based positioning, navigation, and timing (PNT) signals generated from space vehicles orbiting the earth and delivered free of direct user fees for civil, commercial, and scientific uses worldwide. The Wide Area Augmentation System (WAAS) provides an augmentation signal to GPS, delivered free of direct user fees, that provides correction and integrity information intended to improve positioning navigation and timing (PNT) service over the United States (U.S.) and portions of Canada and Mexico. WAAS is the first operational implementation of an International Civil Aviation Organization (ICAO) compliant Space Based augmentation System (SBAS). This WAAS Performance Standard (WAAS PS) specifies the levels of navigation performance that will be available to suitably equipped users who use both the GPS SPS broadcast signals and the WAAS augmentation signal. The U.S. Government is committed to meeting the minimum levels of service specified in this WAAS PS. Refer to the GPS SPS PS for specific information regarding the USG commitment for the GPS SPS.

Since WAAS was commissioned in 2003, actual performance has typically met and exceeded the minimum accuracy, integrity, continuity, and availability performance requirements specified in this WAAS PS and users can therefore generally expect improved performance over the minimum levels described here. Actual real-time performance, statistical performance and real-time data are provided on-line by the Federal Aviation Administration (FAA). Quarterly Performance Analysis Reports for both GPS and WAAS are also available at the FAA Technical Center WAAS Test Bed web site (http://www.nstb.tc.faa.gov/). Interested readers are encouraged to refer to this site and other sources for updated GPS and WAAS performance information. Note that the number of WAAS-based Localizer Performance with Vertical (LPV) guidance procedures now exceeds the number of Instrument Landing System (ILS) procedures in the United States.

GPS will provide three new modernized civil signals in the future: L2C, L5, and L1C. With the additional signal on L5, airborne receivers will be able to correct for the line of sight ionospheric propagation delay error. This dual frequency (L1/L5) mode of operation will allow changes to be made in the delivery of GPS-based augmentation services, such as WAAS, but this Performance Standard does not consider those future changes. This WAAS Performance Standard only applies to WAAS augmented GPS SPS users of the L1 (1575.42 MHz) Coarse/Acquisition (C/A) signal and the WAAS Signal-In-Space (SIS) broadcast by a geostationary satellite (GEO).

The WAAS PS will be updated as required to reflect substantial changes to WAAS augmentation services. In addition to the WAAS PS, readers are referenced to the GPS SPS PS and FAA Technical Standard Order (TSO)-145/146 for details in both the fundamental GPS SPS service and WAAS receiver equipment. WAAS also meets or exceeds the ICAO Annex 10, Standards and Recommended Practices (SARPs) for Global Navigation Satellite System (GNSS) Satellite Based Augmentation System (SBAS).

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SECTION 1.0 The GPS WAAS Service

The Navstar Global Positioning System, hereinafter referred to as GPS, is a space-based radionavigation system owned by the United States Government (USG) and operated by the United States Air Force (USAF). The Wide Area Augmentation System (WAAS) is owned by the USG and operated by the Federal Aviation Administration (FAA) to provide regional GPS augmentation services coverage in North America.

The FAA is responsible for the design, development, operation, and sustainment of the WAAS. The WAAS Program Office is located at FAA headquarters in Washington, D.C. Second level engineering and logistics are located at Mike Monroney Aeronautical Center in Oklahoma City, and the WAAS performance monitoring center is located at the FAA Technical Center in Atlantic City, N.J.

This *1st Edition WAAS Performance Standard* serves as a companion document to the *GPS SPS Performance Standard* to define the performance of WAAS augmented GPS SPS. This WAAS Performance Standard follows the same format and structure as the GPS SPS PS.

1.1 Purpose

This *1st Edition of the WAAS Performance Standard* (*WAAS PS*) defines the levels of signal-in-space (SIS) performance to be provided by the USG to the WAAS user community. A user will attain this performance with a properly installed receiver compliant with TSO-C145/146.

This *WAAS PS* consists of a main body and two appendices. The *WAAS PS* provides an overview of the WAAS and GPS SPS services, how they are used, and an overview of the aviation operations that are enabled by WAAS augmentation. It then provides the performance standards for the WAAS SIS. It concludes with the relevant reference documents. The appendices provide additional information that quantifies and illustrates WAAS SIS performance. Provided below is a definition of each appendix's purpose.

- **Appendix A: Service Special Topics.** This appendix discusses special topics of interest to the WAAS service and/or flight operations.

- **Appendix B: Definitions.** This appendix provides a list of key terms, definitions, abbreviations and acronyms used in this *WAAS PS*.

1.2 Scope

This *WAAS PS* defines standards for the WAAS SIS performance. Section 3 specifies the WAAS SIS performance standards in terms of performance metrics. This *WAAS PS* employs standard definitions and relationships between the performance parameters such as availability, continuity, integrity, and accuracy.

This *WAAS PS* only applies to the WAAS SIS as it exists on the publication date of this document. This document does not address services relying on future civil signals (L1C, L2C or L5), that will be broadcast by modernized GPS satellites. It should be noted that WAAS receivers certified for aviation use must comply with FAA TSO-145/146.

1.3 GPS SPS Definition

The GPS Standard Positioning Service (SPS) is defined in the SPS PS as follows:

The SPS is a positioning and timing service provided by way of ranging signals broadcast at the GPS L1 frequency. The L1 frequency, transmitted by all satellites, contains a coarse/acquisition (C/A) code ranging signal, with a navigation data message, that is available for peaceful civil, commercial, and scientific use.

1.4 WAAS Service Definition

The WAAS Service is defined as follows:

The WAAS is a Satellite Based Augmentation System (SBAS) for North America that augments GPS SPS by broadcasting differential GPS (DGPS) correction messages from GEO satellites. The WAAS Service provides augmentation of GPS integrity via integrity data included on the WAAS message broadcasts. The WAAS Service is specifically designed to meet high accuracy, integrity, continuity, availability standards of aviation users, but is an open service that has the capability to support other applications as well. WAAS provides a ranging function throughout the entire satellite footprint that improves the availability of GPS positioning for SBAS users. WAAS also provides differential corrections as well as satellite status for GPS satellites.

1.5 Key Terms and Definitions

Terms and definitions that are essential to understanding the *WAAS PS* are provided in Appendix B. A list of abbreviations and acronyms is also provided in Appendix B.

1.6 Global Positioning System Overview

The GPS comprises three segments: the Control, Space, and User Segments. The Control and Space Segments are described below. Together they provide two types of service, the SPS SIS and the PPS SIS. The SPS SIS is available to all users, but the PPS SIS is encrypted and is reserved for authorized users. For further information on the SPS SIS or PPS SIS, refer to the *SPS PS (http://pnt.gov/public/docs/2008-spsps.pdf)or PPS PS (http://pnt.gov/public/docs/2007-pps-unclassified.pdf)*. The WAAS SIS is added as an augmentation to the SPS SIS by separate broadcast from geostationary earth orbiting (GEO) satellites. Together, the WAAS SIS and the SPS SIS entail the WAAS service. The WAAS SIS interface is described in Section 2. This GPS description is taken from the GPS SPS PS.

1.6.1 GPS Space Segment

The GPS baseline 24-slot constellation consists of 24 slots in six orbital planes with four slots per plane. Three of the 24 slots are expandable. The baseline satellites will occupy these slots. Any surplus satellites that exist on orbit will occupy other locations in the orbital planes. There are no a priori specified slots for surplus satellites. The nominal semi-major axis is 26,559.7 kilometers.

The SPS SIS generation and transmission process for a Block IIA satellite is illustrated in Figure 1.6-1. The Atomic Frequency Standard (AFS) generates a nominal 10.23 MHz clock signal. The signal is distributed by the Frequency Synthesizer and Distribution Unit (FSDU) to other payload subsystems. The Navigation Data Unit (NDU) receives the uploaded navigation (NAV) data from the Control Segment (CS) through the Telemetry, Track, and Command (TT&C) subsystem. The Navigation Baseband generates the pseudorandom noise (PRN) ranging codes and adds the NAV

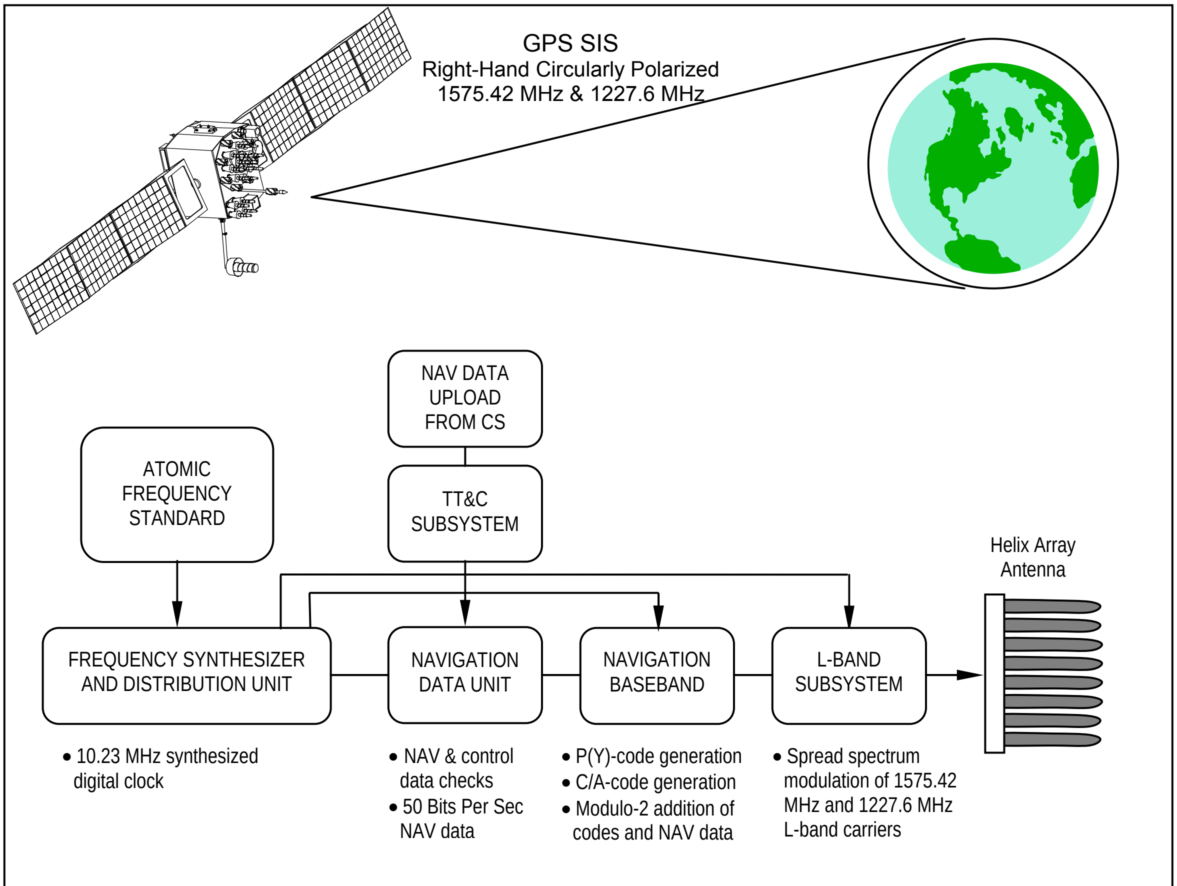


Figure 1.6-1. GPS SIS Generation and Transmission

data message. The L-Band subsystem modulates the binary sequences onto the L1 (1575.42 MHz) and L2 (1227.6 MHz) L-band carriers which are then broadcast by the helix array antenna.

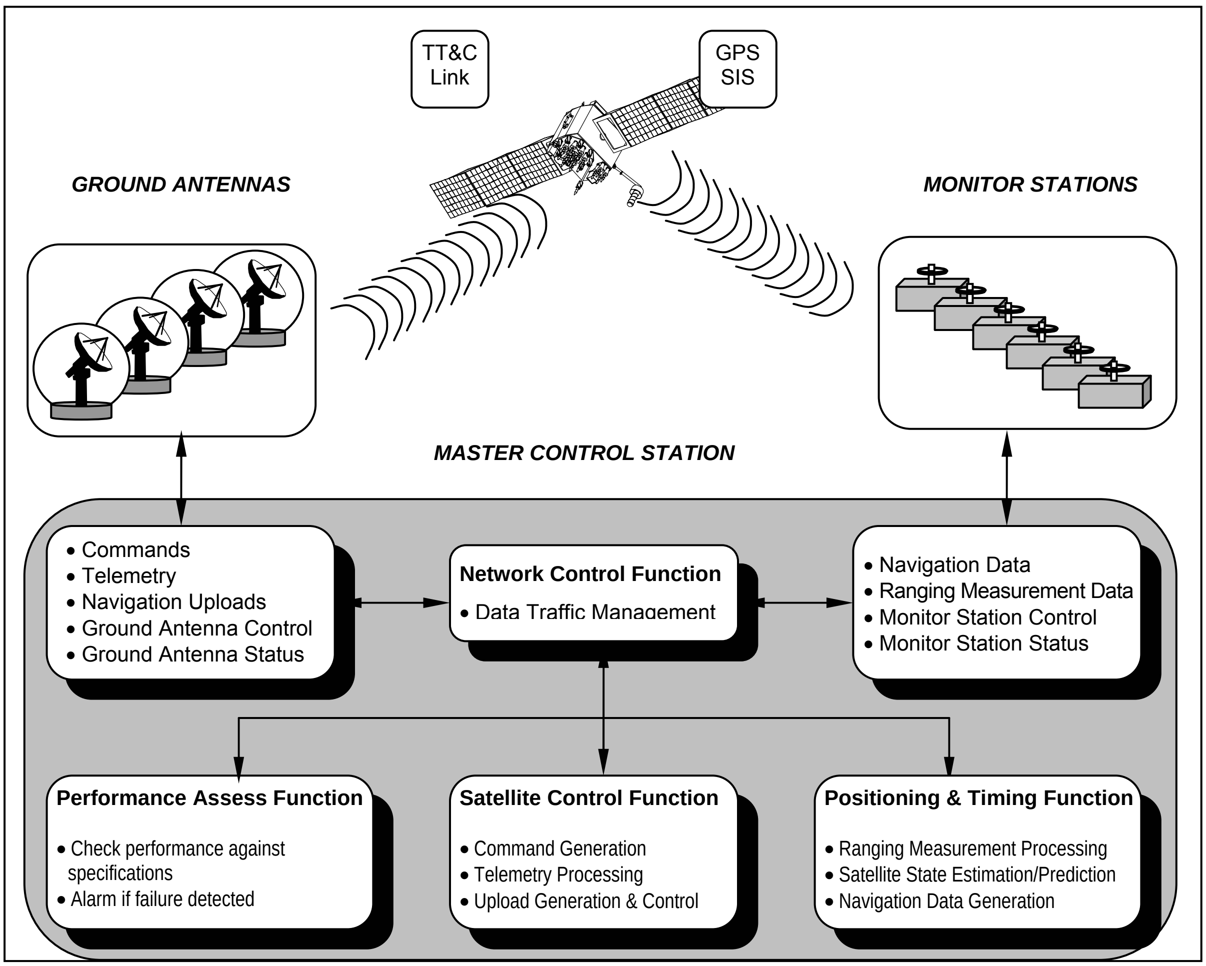
Each satellite broadcasts three PRN ranging codes: the precision (P) code, which is the principal ranging code; the Y-code, used in place of the P-code whenever the anti-spoofing mode of operation is activated; and the coarse/acquisition (C/A) code which is used for acquisition of the P (or Y) code (denoted as P(Y)) and as a civil ranging signal. A NAV message based upon data periodically uploaded from the Control Segment is provided by adding the NAV data to both the 1.023 MHz C/A-code sequence and the 10.23 MHz P(Y)-code sequence. The satellite modulates the two resulting code-plus-data sequences onto the L1 carrier, and modulates just the 10.23 MHz code-plus-data sequence onto the L2 carrier; and then both modulated carriers are broadcast to the user community. The entire set of code-plus-data sequences and carriers is referred to as the PPS SIS. A subset of the PPS SIS, the SPS SIS, comprises only the 1.023 MHz code-plus-data sequence on the L1 carrier. Collectively, the PPS SIS and the SPS SIS are known as the satellite's navigation signals (or navigation SIS or GPS SIS).

The satellites are designed to provide reliable service over a 7.5- to 11-year design life, depending on the production block, through a combination of space qualified parts, multiple redundancies for critical subsystems, and internal diagnostic logic. The satellites require minimal interaction with the ground and allow all but a few maintenance activities to be conducted without interruption to the broadcast SIS. Periodic uploads of NAV message data are designed to cause no interruption to the SIS, although Block IIA satellites may experience a 6- to 24-second interruption during the upload.

1.6.2 GPS Control Segment

The Operational Control System (OCS) is comprised of four major subsystems: a Master Control Station (MCS, soon to be replaced by a New Master Control Station [NMCS]), a Backup Master Control Station (BMCS, soon to be replaced by an Alternate Master Control Station [AMCS]), a network of four ground antennas (GAs), and a network of globally-distributed monitor stations (MSs). An overview of the OCS is provided in Figure 1.6-2.

Figure 1.6-2. The GPS Operational Control System (OCS)



The MCS is located at Schriever Air Force Base, Colorado, and is the central control node for the GPS satellite constellation. Operations are maintained 24 hours a day, seven days a week throughout the year. The MCS is responsible for all aspects of constellation command and control, to include:

- Routine satellite bus and payload status monitoring
- Satellite maintenance and anomaly resolution
- Management of GPS SIS performance in support of all performance standards (*SPS PS* and *PPS PS*)
- NAV message data upload operations as required to sustain performance in accordance with accuracy and integrity performance standards
- Detecting and responding to GPS SIS failures

In the event of a prolonged MCS outage, GPS operations can be moved to the BMCS (or from the NMCS to the AMCS).

The OCS's four ground antennas (GAs) provide a near real-time TT&C interface between the satellites and the MCS. The monitor stations (MSs) provide near real-time satellite pseudorange measurement data and recovered NAV message data to the MCS and support continuous monitoring of constellation performance. The current OCS monitor stations provide 100% global coverage with the inclusion of National Geospatial-Intelligence Agency (NGA) stations

1.7 Wide Area Augmentation System (WAAS) Overview

The primary mission of WAAS is to augment GPS SPS for air navigation. The WAAS signal provides the integrity, accuracy, availability, and continuity required for instrument approach operations in terminal, en route (ER), and final approach phases of flight in all signal coverage areas defined in Section 3. In the primary area of coverage, the WAAS SIS also supports vertically guided instrument approach operations called Localizer Performance with Vertical (LPV) guidance and enables an aircraft to descend as low as 200 foot height above touchdown (HAT).

WAAS provides an en route navigation and approach landing capability (lateral and vertical guidance) that; (a) improves safety by reducing controlled flight into terrain on approach, (b) increases the number of candidate runway ends that can have vertically guided approach procedures, and (c) supports area navigation (RNAV) en route for aircraft that are not equipped with inertial navigation and/or flight management systems. WAAS provides the additional accuracy, availability, continuity and integrity necessary to enable users to rely on GPS for all phases of flight, from en route through approaches with vertical guidance, at all qualified airports within the WAAS LPV coverage area. This WAAS service enables development of more standardized approach procedures, missed approach procedures, and departure guidance for numerous runway ends and heliport/helipads in the National Airspace System (NAS).

Section 1.7.1 describes both GPS-only and GPS WAAS operations. GPS-only operations depend on the receiver-based integrity monitoring technique called receiver autonomous integrity monitoring (RAIM). GPS WAAS operations add an additional WAAS SIS broadcast from a geostationary earth orbit (GEO) satellite to improve the accuracy of the GPS SPS SIS and to provide integrity by alerting when not to use satellites as part of the WAAS solution. The GEO broadcast may also be used as an additional ranging signal to improve the availability of the augmented GPS service. Section 1.7.2 describes the WAAS approach for ensuring integrity performance. Section 1.7.3 describes the WAAS architecture in detail including its operational environment. Further details about how the WAAS user receiver interprets the protection levels that provide integrity are described in Appendix A. The WAAS SIS interface is described in Section 2, and performance standards in Section 3.

1.7.1 GPS WAAS Air Navigation User Segment

GPS WAAS is a combination of ground-based and space-based equipment that augments the GPS SPS. A network of ground monitoring stations with precisely surveyed GPS antennas is strategically positioned to collect GPS satellite data across the NAS including sites in Alaska, Hawaii, and Puerto Rico. Additional stations are located in Canada and Mexico to further improve availability in the NAS and extend coverage to most of Canada and Mexico. Using site measurements of the GPS SIS, GPS WAAS calculates errors in the GPS signal and then provides users with correction data to compensate for these GPS SIS errors as well as integrity information associated with those corrections. WAAS GEO satellites, used to relay the correction and integrity information to users, also provide an additional GPS-like ranging capability that further improves the availability of GPS positioning. Hence, WAAS provides for increased availability and accuracy in position reporting, enabling more uniform and high-quality NAS-wide air traffic management. The end result is a GPS WAAS service that supports navigation from the en route phase of flight to approach with ceiling and visibility minimums equivalent to Category (CAT) I.

GPS WAAS augments the GPS SPS SIS with integrity and corrections to make the GPS SPS a trusted air navigational aid. Figure 1.7-1 depicts aircraft with a GPS-only operation with an FAA Technical Standard Order (TSO) C129 compliant receiver and an aircraft with TSO-C145/146 compliant WAAS receiver.

The GPS-only receiver compliant with TSO-C129 uses RAIM to assure the integrity of its solution. A GPS receiver solves for position and time using signals from a minimum of four GPS satellites.

RAIM requires a fifth satellite, or barometric aiding, to perform a consistency check to detect a fault on a single satellite.

The GPS WAAS receiver compliant with TSO-C145/146 also uses RAIM for instances when the augmentation signal becomes unavailable. The WAAS receiver adds a fault detection & exclusion (FDE) feature requiring a minimum of 6 satellites to detect and exclude a faulted satellite. Instead of declaring GPS SPS service unusable with a RAIM alert, RAIM/FDE excludes the bad satellite and continues to provide an integrity-assured solution provided the geometry of the remaining satellites in view is sufficient. The WAAS GEO broadcast also provides an additional ranging source for improved availability of navigation services. When a WAAS receiver is using the corrections and integrity messages broadcast by the GEO, only four GPS or GEO satellites are needed, which increases the availability of service versus RAIM or RAIM/FDE.

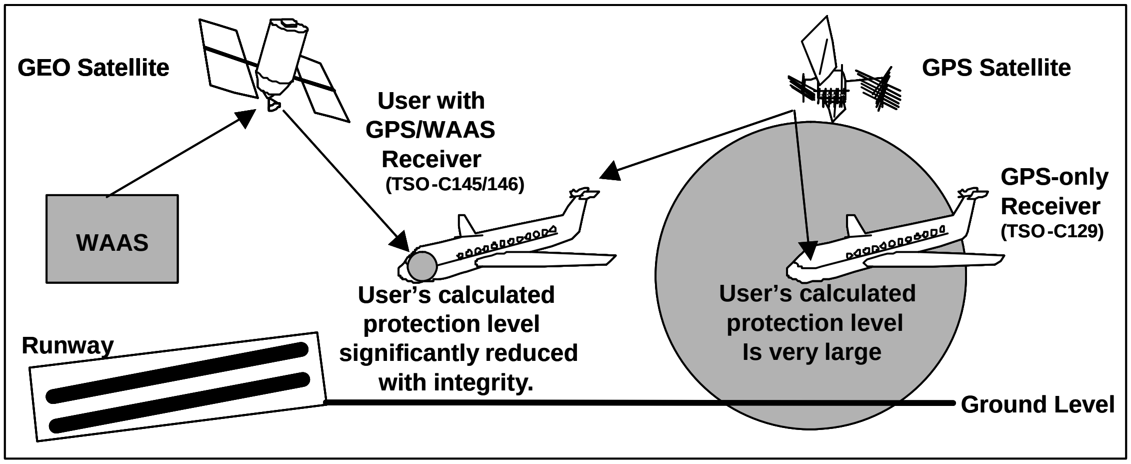


Figure 1.7-1 WAAS Augmented and GPS-Only Operations

1.7.2 GPS WAAS Corrections and Integrity

The WAAS receiver uses the WAAS broadcast-corrections in conjunction with GPS SPS signals to calculate an accurate position with high-confidence error bounds on this position. Correction data is used to differentially correct errors in the broadcast GPS range measurements. Integrity data is used to calculate integrity bounds called protection levels. Depending on the flight operation, the user equipment may either simply compute a Horizontal Protection Level (HPL) or both a HPL and a Vertical Protection Level (VPL). The user receiver compares the computed protection levels with the alert limit thresholds established for the selected phase of flight. If one of the protection levels exceeds the corresponding alert limit, the receiver provides an annunciation to the pilot. The overall system design ensures that the user receiver does not exceed a time-to-alert of 6.2 seconds.

WAAS estimates GPS satellite clock and ephemeris errors and ionosphere delays for satellites and ionospheric grid points that are adequately viewed by WAAS wide-area reference stations, calculates corrections for those errors, and broadcasts the corrections through the GEO satellites. Three types of corrections are broadcast: 1) Fast Corrections (FCs) for each GPS satellite clock's rapid, short-term errors; calculated and broadcast every 6 seconds for each satellite, 2) Long Term Corrections (LTCs) for each GPS satellite clock's slow drift errors and slow ephemeris errors; calculated every 256 seconds and broadcast at least every 120 seconds, and 3) Ionospheric Grid Point (IGP) Corrections (ICs) for the estimated ionosphere signal propagation delays; calculated for every 5 degrees latitude and longitude grid point over the LPV coverage area and broadcast every 5 minutes.

WAAS calculates integrity data associated with its generated corrections at the required level of integrity for the intended flight operation. Integrity data is provided in the form of error bounds which are used to compute the protection levels taking all relevant error sources into account. The integrity data consists of the User Differential Range Error (UDRE) and the Grid Ionospheric Vertical Error (GIVE). UDRE characterizes the residual error in the FC and LTC. The UDRE is transmitted with the FC message. GIVE characterizes the residual error in the IC for the estimated ionosphere signal delays calculated for IGPs, defined in the IGP mask and broadcast every 5 minutes. The GIVE is transmitted with the IC message.

If using WAAS vertical guidance, the user receiver utilizes this integrity data to calculate a "protection cylinder" as defined in the RTCA Inc. (formerly Radio Technical Commission for Aeronautics) Minimum Operational Performance Standard (MOPS) (RTCA/DO-229), incorporated by reference, in TSO-C145/146. A simplified depiction is shown in Figure 1.7-2. The user receiver applies the various WAAS corrections described above and calculates a user position using the WAAS corrected range and ephemeris data. Then, the user receiver applies the UDRE, GIVE (and other error characteristics for residual troposphere delay and receiver errors) values to calculate VPL and HPL. These protection limits can be envisioned as defining a protection cylinder, depicted as the dark cylinder in Figure 1.7-2.

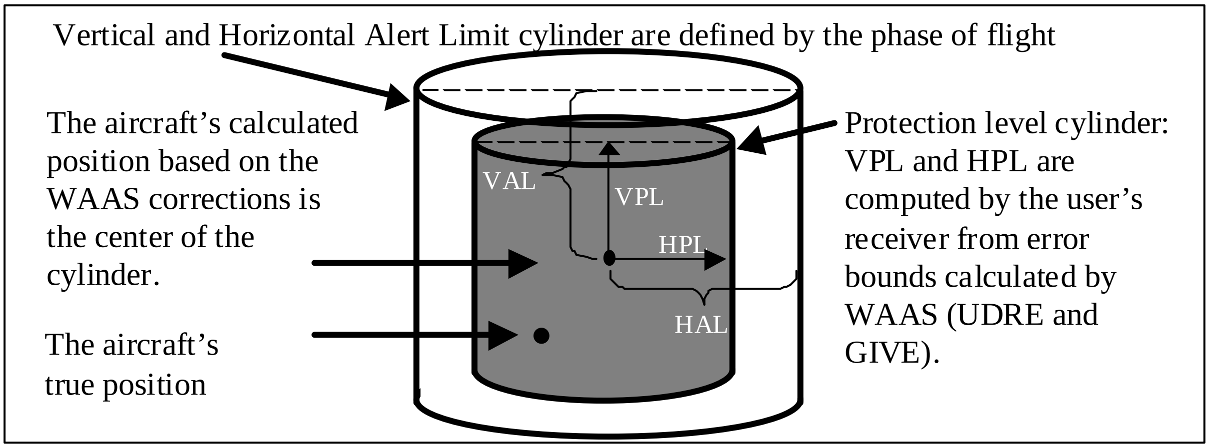


Figure 1.7-2 WAAS Integrity Protection Cylinder

This protection cylinder, centered on the user's calculated position of the aircraft, represents the uncertainty of that calculated position. The user's receiver calculates and compares the VPL and HPL against the Vertical Alert Limit (VAL) and Horizontal alert Limit (HAL) values, respectively. These alert limits have values that are fixed for each flight operation and can be thought of as defining the clear alert limit cylinder in Figure 1.7-2. The alert limit cylinder is centered on the aircraft's WAAS calculated position, just as the protection level cylinder. Normally, the aircraft's true position is within the dark protection level cylinder.

If the WAAS integrity data results in a protection level cylinder that is too large to be contained within the alert limit cylinder for a particular flight operation, the user receiver will indicate to the pilot that the operation is not available. For example, if the alert limit for LPV is exceeded, the receiver will notify the pilot that LPV is no longer available. It is likely in this scenario that the Lateral Navigation (LNAV) alert limit, which is much larger, will not be exceeded and therefore the receiver indication of LNAV operation would still be available.

Hazardously Misleading Information (HMI) exists when the user's position error exceeds the protection levels for a period longer than the time-to-alert (TTA). If the protection cylinder is too small, it will not enclose the aircraft's true position. This is an underbound condition. When the underbound condition persists for longer than the TTA, this event is then called HMI. An underbound condition cannot be detected by the receiver so the WAAS integrity algorithms are designed to ensure that UDRE and GIVE will not cause an underbound condition under any conditions of flight operation.

1.7.3 WAAS Architecture and Operational Environment

The GPS WAAS architecture and operational environment are shown in Figure 1.7-3. The space segment consists of the GPS and GEO satellites. The GPS constellation nominally consists of 24 satellites located in orbital slots distributed in 6 different orbital planes (an average of approximately 8-10 satellites are in view to a user at any time). The GPS SPS PS contains a complete description of the GPS constellation. Each GPS satellite transmits signals on two frequencies that are used by WAAS. The Link 1 (GPS L1) 1575.42 MHz Coarse Acquisition (C/A) coded signal contains the orbital and timing parameters that a receiver requires to calculate the user's position. The L2 signal is the 1227.60 MHz P(Y) coded signal. Currently, the WAAS user receiver receives only the L1 signal.

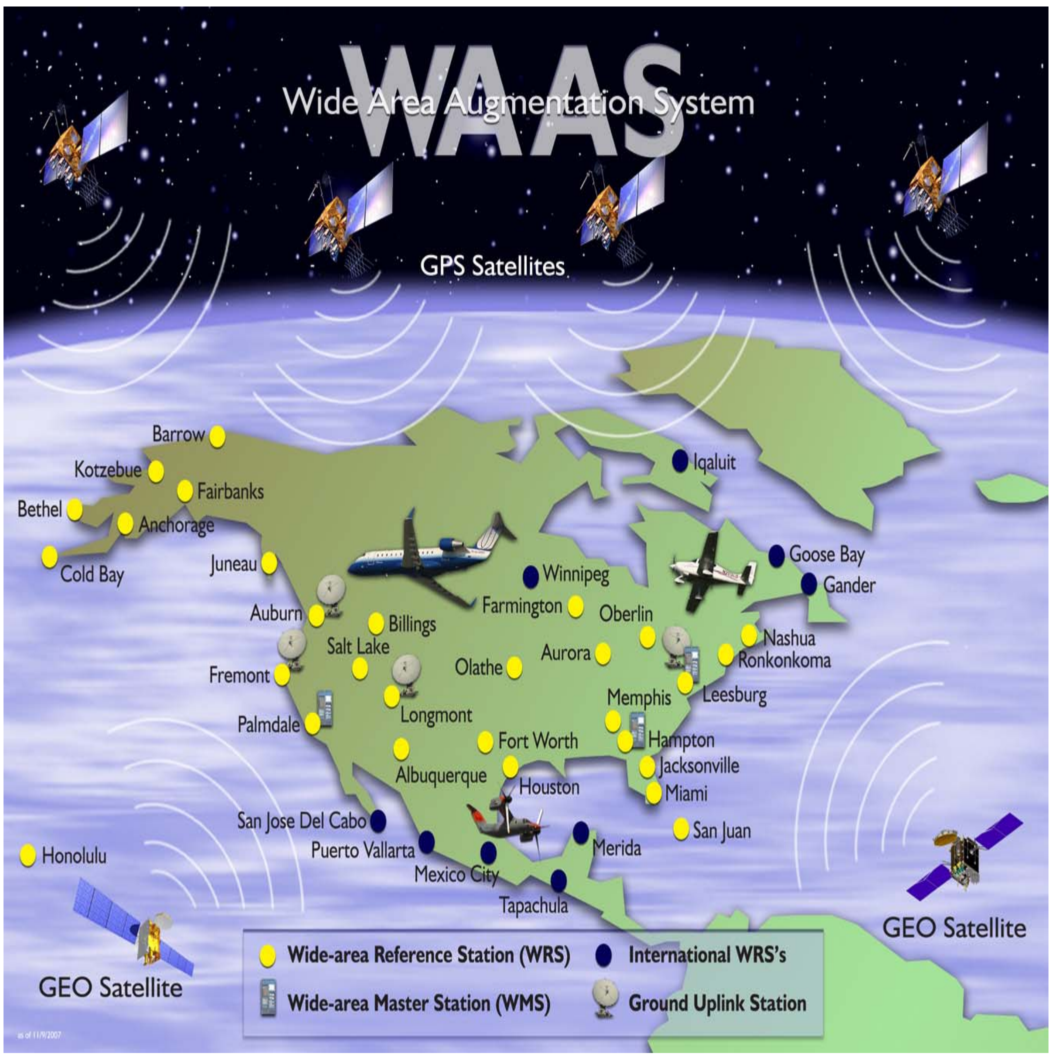


Figure 1.7-3 WAAS Architecture and Operational Environment

The WAAS is used to produce a Satellite Based Augmentation System (SBAS) signal-in-space (SIS) that contains GPS corrections and integrity data messages. The WAAS includes Wide-area Reference Stations (WRSs), Terrestrial Communication Network (TCN), Wide-area Master Stations (WMSs), Ground Earth Stations (GESs), and GEO satellites. WAAS is controlled from two operations & maintenance (O&M) workstations located at the National Operations and Control Center (NOCC) and Pacific Operations Control Center (POCC).

Figure 1.7-4 shows the WAAS data processing path. WAAS receives the GPS satellite signals and processes the GPS satellite data to determine the corrections and integrity data for each satellite. The resultant correction and integrity data for each GPS satellite is referred to as the WAAS message. The WAAS message is uplinked to the GEO satellites for broadcast on the GPS L1 frequency. The user receives the signal with a unique GEO satellite pseudo-random noise (PRN) number coding on the SIS. The user receiver extracts the various corrections and integrity data for the GPS and GEO satellites to calculate an accurate position and associated protection level(s). WAAS also controls the timing of the GEO satellite signal and generates the GEO satellite navigation message data (GEO satellite position and clock) that enables use of the GEO satellites as an additional GPS-like ranging source.

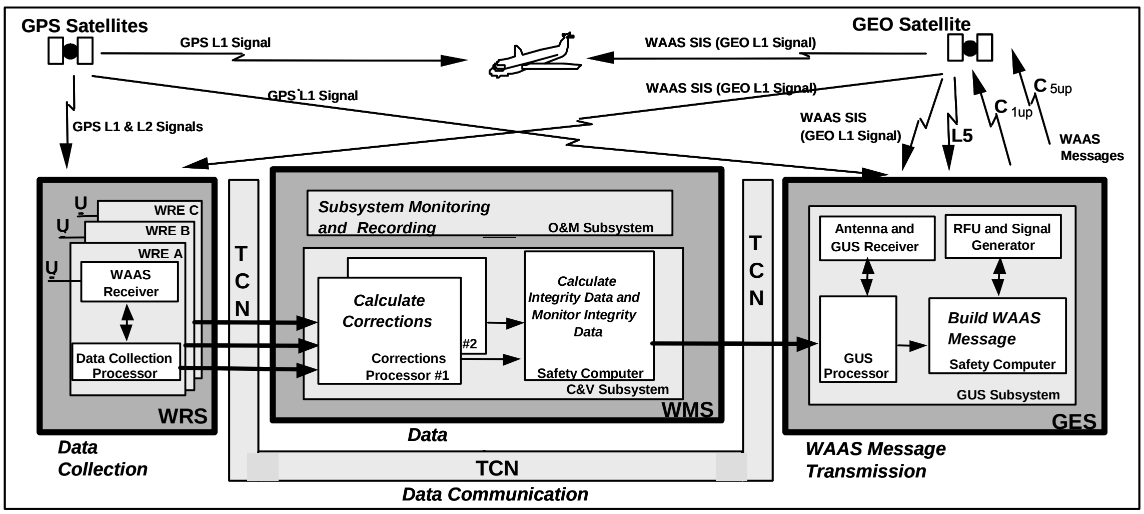


Figure 1.7-4 WAAS Data Processing Path

The WAAS consists of the following configuration items.

Wide-area Reference Stations (WRS): There are 38 WRSs located through the Contiguous United States (CONUS), Hawaii, Puerto Rico, Alaska, Canada, and Mexico. Each WRS contains three sets of Wide-area Reference Equipment (WRE). Each WRE consists of a dual frequency (L1 & L2) WAAS Receiver, cesium clock, and a Data Collection Processor (DCP). L2 signal processing is accomplished using a semi-codeless tracking technique. The DCP collects, packages, and forwards the satellite data to the WMS for processing. Each WRE, referred to as WRE-A, -B, and -C, independently collects satellite data. On September 23, 2008, the DoD announced its intent to no longer support semi-codeless or codeless receiver capability after December 31, 2020. The FAA plans to upgrade the WRSs with receivers capable of processing the new civil signals. A substantial effort will be required to transition the WAAS software and algorithms. After this transition, WAAS will no longer be able to monitor satellites that do not transmit L5.

Terrestrial Communications Network (TCN): The TCN provides the communications link between the WAAS subsystems for transmitting WAAS data. The TCN consists of two dedicated, redundant, and diverse networks to provide highly reliable communications.

Wide-area Master Station (WMS): There are three WMSs and any one can perform the WAAS corrections & integrity processing function. In each WMS, there is one corrections & verification (C&V) subsystem. The C&V receives the satellite data from each WRE. The C&V consists of two Corrections Processors (CP1 and CP2) and one Safety Computer (SC) that contains two Safety Processors (SPs) and a hardware comparator. Each CP calculates clock and ephemeris corrections from WRE data. The SC calculates ionospheric corrections and high-confidence error bounds for clock, ephemeris, and ionospheric corrections and ensures that the outputs from the CP have not been corrupted. The data is then forwarded to the Ground Earth Station (GES) via the TCN.

WMS Operations and Maintenance (O&M): Each of the two O&M subsystems located at the OCCs (NOCC and POCC) provide subsystem monitoring and recording. Each O&M workstation monitors the status of the other WAAS subsystems and allows the single controlling operator to monitor the state of the system and recording. WAAS is a fully automated system that requires minimal operator involvement.

Ground Earth Station (GES): Each GES is a location where the function of transmitting the WAAS message to the GEO is performed. At the physical GES location, there may be one or more co-located GEO Uplink Subsystems (GUSs). Each GEO is served by two GUSs located at different GESs in order to retain geographic diversity for the uplink sources. Each GUS has a Signal Generation Subsystem (SGS) and an RF Uplink (RFU). The SGS contains a GUS Processor (GP) and a WAAS Message Processor (WMP). The GP provides network and RS-232 communications interfaces for the WMP and the WMP formulates the WAAS user message for transmission to the GEO. The RFU uplinks the WAAS signal to the GEO satellite.

Geostationary Earth Orbit (GEO) satellites. WAAS currently relies on the service of two leased GEOs positioned at 107W and 133W longitude. A third GEO is planned to ensure dual coverage requirements are met. The WAAS objective is for a user receiver to have a minimum of two GEOs in view during LPV operations. Each GEO receives 2 uplinked C-Band signals (C_{1up}, C_{5up}) from one of two RFUs (primary & backup) and uses bent-pipe transponders that frequency translate each signal to broadcast WAAS signals on L1 and L5. Each GEO satellite transmits the WAAS message in an L1 signal (1575.42 MHz) coded in a similar manner as a GPS satellite C/A code transmission. The L5 signal is currently used internally to determine ionosphere line of sight delays at the GUS, which are needed to properly control the timing of the L1 SIS. Currently, both L1 and L5 broadcast the L1 integrity and correction messages. In the future, L5 will broadcast correction and integrity messages specifically designed for dual frequency (L1 & L5) users.

SECTION 2.0 WAAS SIS Characteristics

This section provides an overview of the WAAS SIS interface characteristics, WAAS SIS performance characteristics, and the assumptions made to arrive at the performance standards in Section 3.0.

2.1 WAAS SIS Interface Requirements

The WAAS SIS complies with the technical requirements related to the interface between the Space Segment and the WAAS user receivers as established by the current versions of the WAAS Specification, FAA-E-2892 as well as RTCA DO-229 and associated TSOs (TSO-C145, TSO-C146). In the event of conflict between the WAAS SIS interface characteristics described in this document and the TSOs, the TSOs take precedence.

2.2 Overview of WAAS SIS Interface Characteristics

This section provides an overview of the WAAS SIS interface characteristics. WAAS SIS interface characteristics are allocated to two categories: (1) carrier and modulation radio frequency (RF) characteristics, and (2) the structure, protocols, and contents of the WAAS user message.

2.2.1 WAAS SIS RF Characteristics

The GEO satellites transmit right-hand circularly polarized (RHCP) L-band signals. At present, only the WAAS L1 signal is intended for airborne equipment use. The received L1 power level out of a 3 dBil linearly polarized user antenna at worst normal orientation is greater than -128.5 dBm (-158.5 dBW) at elevation angles greater than 5 degrees within the intended service volume. The maximum received power level is -120 dBm (-150 dBW) for such an antenna. For future WAAS GEOs the maximum received power will be -122.5 dBm (-152.5 dBW). WAAS SIS RF characteristics are further defined in the FAA-TSO-145/146.

2.2.2 WAAS Message Characteristics

WAAS transmits a number of different message types. The Table below summarizes the message types and their purpose. For format and information content of the message types and information on the use of the WAAS messages, refer to the FAA-TSO-145/146.

Table 2.1-1 WAAS Message Types

Message Type	Title	Purpose
0	Don’t Use for Safety Applications	Discard data from the transmitting PRN signal. Used for testing or if problem in data is discovered.
1	PRN Mask Assignments	PRNs for GPS and GEOs
2-5	Fast Clock Corrections	Fast corrections & UDREI
6	Integrity Information	UDREI for Fast Corrections and Long Term corrections for all satellites in one message
7	Fast Correction Degradation	Clock error bound acceleration and Timeout interval for Fast Corrections
9	WAAS Satellite Navigation Message	WAAS geostationary satellite orbit information
17	WAAS Satellite Almanac	Almanac data for WAAS satellites

18	Ionosphere grid point (IGP) mask	Mask for IGP corrections
24	Fast & Long Term Clock Corrections	Mixed message consisting of fast & long term corrections
25	Long Term Clock Corrections	Correction to the broadcast ephemeris
26	Ionospheric vertical delay and GIVEI for each IGP in message 18	Ionospheric corrections and error bound indicators
27	WAAS Service Message	Differential UDRE factors for user locations
28	Clock-Ephemeris Covariance Matrix	UDRE multiplier

2.3 Overview of WAAS SIS Performance Characteristics

The WAAS SIS performance characteristics are described below for accuracy, integrity, continuity, and availability.

This overview of the WAAS SIS performance characteristics addresses WAAS service performance. The service relies on GPS SPS service and the WAAS GEO broadcast SIS. The five performance attributes (metrics) are used to characterize performance for all air navigation services, though their application to WAAS service is defined by parameters that are unique to the WAAS service in this PS. The overview addresses each of these performance characteristics and explains those parameters in both their fundamental physical definition and their effect on flight operations.

This section states the system level performance requirements for GPS WAAS. Requirements are defined in terms of horizontal and vertical 95% accuracy, integrity risk (VAL, HAL and TTA), continuity risk, and availability. Integrity is defined in terms of probability of HMI and associated timely notification.

2.3.1 WAAS SIS Accuracy

WAAS SIS accuracy is defined for both vertical and horizontal accuracy as the 95th percentile (95%) of the error in the vertical domain or in the horizontal plane. This assumes the proper application of the WAAS Fast Corrections, Long Term Corrections, and Ionospheric Corrections to the GPS SPS SIS to obtain a position solution. Horizontal accuracy is used to ensure an aircraft's horizontal approach position is aligned with the runway/airway centerline, the vertical accuracy is used to ensure an aircraft's vertical approach position is aligned with the approach glidepath, and along-track position is needed to ensure that an aircraft turns in the correct location. Without WAAS corrections, the GPS SPS by itself is not capable of providing vertical accuracy with integrity that can support vertically guided approach operations defined in Section 3.2 of the PS. With WAAS provided corrections, the horizontal and vertical accuracy meets or exceeds the requirements for vertically guided landing operations as low as 200 HAT for LPV procedures.

2.3.2 WAAS SIS Integrity

Integrity is synonymous with trust. For the Global Navigation Satellite System (GNSS), the International Civil Aviation Organization (ICAO) defines integrity as "A measure of the trust that can be placed in the correctness of the information supplied by the total system. WAAS integrity includes the ability of a system to provide timely and valid warnings to the user (alerts)."

Probability of HMI: HMI exists when the position error exceeds the protection level for a longer period than the time-to-alert without an annunciation to the pilot. To support safety-of-life flight operations, the probability of HMI must be exceedingly small. Certification regulations define several levels of hazard with an associated acceptable level of risk. Some navigation services have a hazardous consequence on flight operations in the presence of an integrity failure. This level of consequence is associated with an inability to remain within obstacle clearance surfaces on approach, missed approach, and en-route operations. The likelihood that a hazardous condition is encountered during any single flight operation must be extremely remote to comply with certification regulations. Extremely remote is interpreted to be less than 1×10^{-7} per hour of en-route flight or per approach (150 seconds) during instrument approach operations.

Alert Limits: For an instrument approach operation, the alert limit provides a threshold that will not be exceeded without issuing an alert. The HAL is used to determine whether indicated horizontal position places the pilot in a horizontal position adequate to successfully execute the landing phase. A 40 meter HAL was determined to meet the localizer performance characteristics required for LPV approach operations. The vertical alert limit is used to determine whether an aircraft type can avoid penetrating the obstacle clearance surface during vertically guided approaches. The 35 meter VAL was evaluated extensively for all types of aircraft to determine whether the pilot could react adequately to avoid penetrating the Obstacle Clearance Surfaces (OCS) defined by Terminal and En Route Instrument Procedures (TERPS) for LPV approach and missed approach operations. For LPV approach operations, it was determined that this vertical alert limit, in combination with the small WAAS vertical position error distribution, supported a vertically guided approach down to 200' HAT and missed approach for all categories of aircraft.

Time-to-alert (TTA): TTA is defined by ICAO as "The maximum allowable time elapsed from the onset of the navigation system being out of tolerance until the equipment enunciates the alert." In the case of WAAS, this requirement is satisfied by alerting that a particular satellite is not to be used in the WAAS solution by a "not monitored" indication or not to be used in any navigation solution by a "do not use" indication. Lateral navigation only (LNAV) approach operations set this value at 10 seconds and Localizer performance with vertical (LPV) approach operations down to 200 HAT requires 6 seconds. The WAAS ground and space segments meet a 6.2 second alert time and the receiver is allocated 0.8 seconds in LNAV/VNAV, LPV and LP modes to receive, process, and display an alert. For En route through LNAV operations, the TTA allocation to the receiver is 2 seconds.

The potential hazard caused by this TTA does not constitute increased safety risk for approach (LPV) operations. Early tube-type ILS systems could lose a channel inducing a "hard over" condition in an approaching aircraft. This is the worst control condition an aircraft can encounter during the most critical phase of flight. These early systems with unreliable monitors had difficulty in supporting any better than a 6 second TTA, so the pilot had to fight the hard over condition until either the ILS system shut down the signal or the pilot disengaged the autopilot. Later, modem technology ILSs reduced this time to, nominally, 2 seconds, but it took modern digital ILS design to eliminate the susceptibility to an equipment failure that could cause a hard over condition. WAAS HMI would not cause a hard over condition because the receiver has a 100 second smoothing delay. Instead, it manifests itself as a bias error. The 6.2 seconds limits the amount of exposure time to a potential bias error.

Issuance of the WAAS alert is typically better than 6.2 seconds for flight operations. In the case of a failed satellite, it is removed from the solution with the alert indication and all further guidance meets the integrity assurances. During LPV operations, if the HPL exceeds the HAL while the aircraft is on the final approach segment, a flag is displayed and the receiver will discontinue guidance or revert to LNAV-only guidance.

2.3.3 WAAS SIS Continuity

WAAS continuity is defined as the probability that the WAAS SIS performance level will continue to be available throughout one flight hour for en route through LNAV operations or 15 seconds for LNAV/VNAV, LPV, and LP operations given that the service was available at the beginning of the specific exposure time, unless the loss of service was the subject of a prior notice to airmen (NOTAM). For en-route operations, this is defined as a probability of loss of service per hour. For approach operations, this is defined as a probability of loss of service over any 15 second period. WAAS continuity is directly dependent on GPS SPS SIS continuity because both are required in order to provide the service. For LPV operations, additional external effects, such as ionospheric storms, can interrupt the service.

2.3.4 WAAS SIS Availability

WAAS availability is the probability that the WAAS SIS performance level is available to support the intended flight operation. This produces different levels of availability for en-route operations and LPV operations because the signal performance level is more stringent for LPV operations. Although the WAAS availability is directly dependent on GPS SPS SIS availability, the probability that WAAS can support an en-route flight operation is higher than the probability that GPS alone can support that operation because the WAAS availability calculation adds the GEO ranging signals and corrections, which enable the aircraft to tolerate fewer numbers of healthy GPS satellites and still meet the minimum required level of performance.

SECTION 3.0 WAAS SIS Performance Standards

3.1 WAAS SIS Coverage

WAAS coverage characterizes the airspace where the WAAS service is available. The WAAS Program defines five areas of coverage for CONUS, Alaska, Hawaii, Puerto Rico, and the geographic area over all U.S. territory. The service level expectations for availability and continuity are different for these coverage areas primarily because the ability to site reference stations to adequately monitor the ionosphere does not exist for Hawaii and Puerto Rico. Alaska is affected both by being in the Northern latitudes at the edge of GEO coverage and by the ability to locate enough reference stations. For clarity, the descriptions and maps of these coverage areas are incorporated below:

Zone 1 - Zone 1 is defined as the region from the surface up to 100,000 feet above the surface of the 48 contiguous states, extended to 30 nautical miles (nm) outside of its borders.

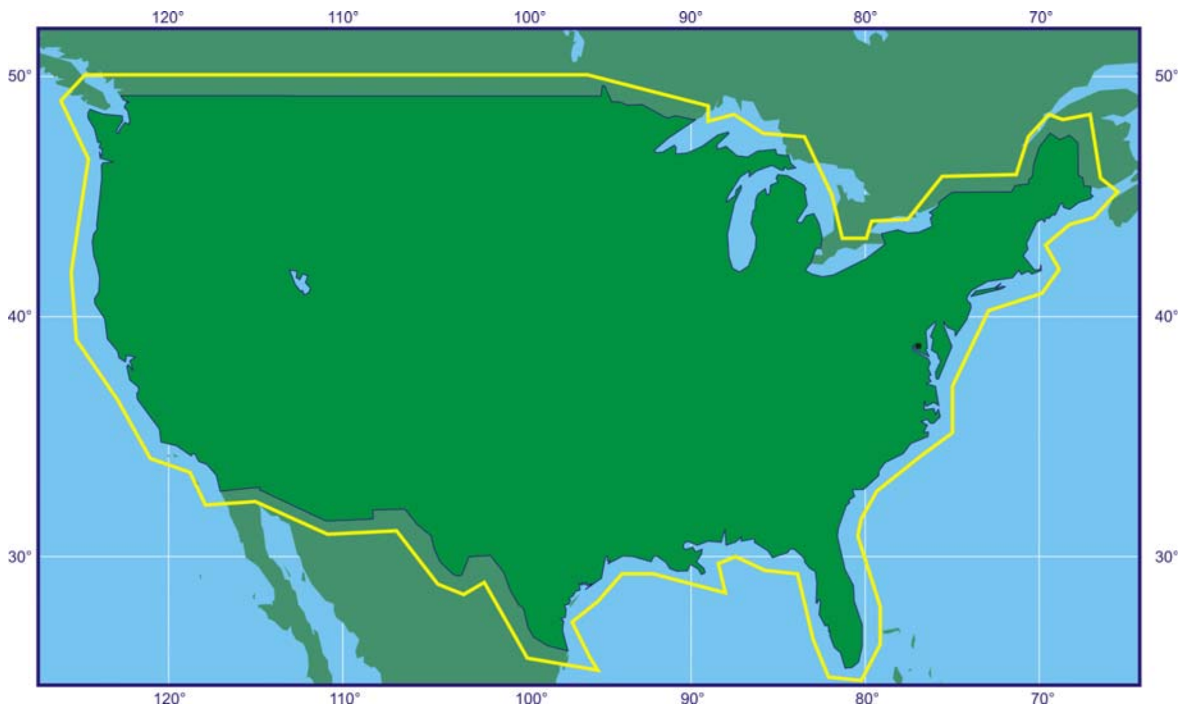


Figure 3.1-1 WAAS Zone 1 Coverage Area

Zone 2 – Zone 2 is defined as the region from the surface up to 100,000 feet above the surface of Alaska, including 30 nm outside its borders.

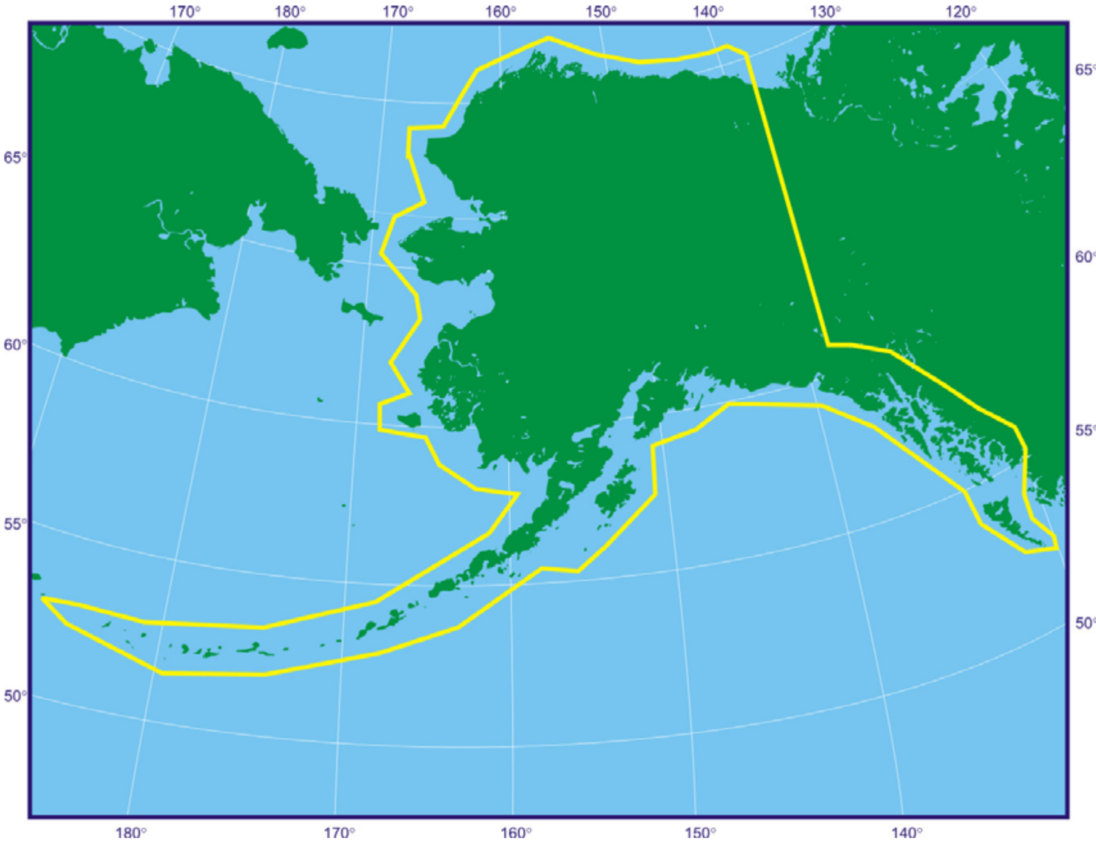


Figure 3.1-2 WAAS Zone 2 Coverage Area

Zone 3 – Zone 3 is defined as the region from the surface up to 100,000 feet above the surface of Hawaii, including 30 nm outside its borders.

Figure 3.1-3 WAAS Zone 3 Coverage Area

Zone 4 – Zone 4 is defined as the region from the surface up to 100,000 feet above the surface of the Caribbean islands shown in Figure 2.3-4.

Figure 3.1-4 WAAS Zone 4 Coverage Area

Zone 5 – Zone 5 is defined as the region from the surface up to 100,000 feet above Mean Sea Level (MSL) of the region defined by the following points (see table below) , excluding the volume covered by zones 1-4.

Lat.	50N	50N	70N	70N	68N	20N	17N	17N	30N	16N	16N	50N
Lon	61W	122W	140W	165W	169W	164W	160W	155W	120W	75W	61W	61W

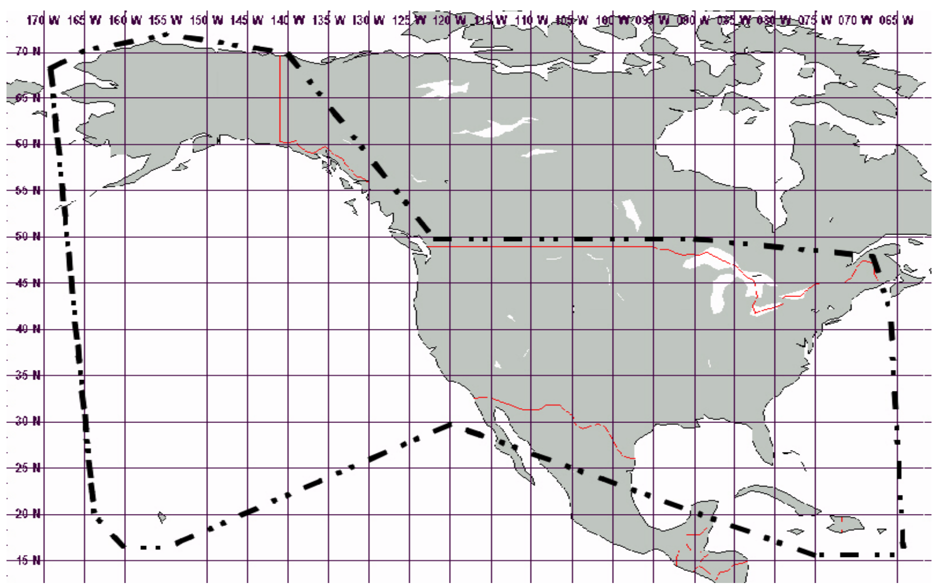


Figure 3.1-5 WAAS Zone 5 Coverage Area

Subsequently, the service areas were expanded in some areas when the number of WRSs was increased from 25 to 38 WRS through the addition of four WRSs in Alaska (in addition to the original three), four in Canada, and five in Mexico.

3.2 WAAS Signal-In-Space Performance Requirements

The WAAS SIS performance requirements are specified in this section. Performance is predicated on a user receiver compliant with TSOs 144 antenna and 145/146 user equipment based on GPS providing the SPS in full compliance with the SPS PS. These performance requirements are subdivided into En-route, Terminal, LNAV, LNAV/VNAV, LPV, and LPV-200 flight operations. The requirements are based on the navigation performance required to support the flight operation and are presented in Table 3.2-1

Table 3.2-1 WAAS Navigation Performance Requirements

	En Route	Terminal	LNAV	LNAV /VNAV	LPV	LPV 200
TTA	15 s	15 s	10 s	10 s	6.2 s	6.2 s
HAL	2 nm	1 nm	556 m	556 m	40 m	40 m
VAL	N/A	N/A	N/A	50 m	50 m	35 m
Probability of HMI	10^{-7} per hour	10^{-7} per hour	10^{-7} per hour	2×10^{-7} per approach	2×10^{-7} per approach (150 seconds)	2×10^{-7} per approach (150 seconds)
Zone 1 Continuity	$1\text{-}10^{-5}$ per hour	$1\text{-}10^{-5}$ per hour	$1\text{-}10^{-5}$ per hour	$1–5.5 \times 10^{-5}$ /15 seconds	$1–8 \times 10^{-6}$ /15 seconds	$1–8 \times 10^{-6}$ /15 seconds
Horizontal Accuracy (95%)	0.4 nm	0.4 nm	220 m	220 m	16 m	16 m
Vertical Accuracy (95%)	N/A	N/A	N/A	20 m	20 m	4 m
Availability (Zone 1 Coverage)	0.99999 (100%)	0.99999 (100%)	0.99999 (100%)	0.99 (100%)	0.99 (80-100%)	0.99 (40-60%)
Availability (Zone 2 Coverage)	0.999 (100%)	.999 (100%)	.999 (100%)	.95 (75%)	0.95 (75%)	N/A
Availability (Zone 3 Coverage)	0.999 (100%)	.999 (100%)	.999 (100%)	N/A	N/A	N/A
Availability (Zone 4 Coverage)	0.999 (100%)	.999 (100%)	.999 (100%)	N/A	N/A	N/A
Availability (Zone 5 Coverage)	0.99999 (100%)	.999 (100%)	.999 (100%)	N/A	N/A	N/A

1. Real-time and statistical performance results for WAAS and GPS are available at the FAA Technical Center WAAS Test Bed web site at http://www.nstb.tc.faa.gov. For real-time performance maps, select the type of service (LNAV/VNAV, LPV, or LPV 200) and coverage area (CONUS, Alaska, etc.). For WAAS statistical performance, select the WAAS Performance Analysis Reports. Note that GPS SPS Performance Analysis Reports are also available.
2. The continuity exposure time for LNAV is one flight hour rather than the duration of one approach in order to assure a high probability that an aircraft is able to land after diverting from the destination to the alternate airport (in case of unpredicted loss of approach capability, after departure, at the destination airport) and conduct an instrument approach at the alternate airport.
3. WAAS continuity is the probability that service is supported throughout an hour in en-route, terminal, and LNAV operations, and throughout 15 seconds for vertically guided approach operations, given that service was supported at the beginning of the interval and predicted to be supported throughout the interval (i.e., a prior NOTAM was not issued 48 hours in advance stating that service would not be supported).

3.3 WAAS Signal-In-Space Performance

WAAS SIS performance meets or exceeds the aviation requirements. The actual WAAS performance has been measured and analyzed by the FAA Technical Center throughout the period it has been in service.

The WAAS delivers the level of service based on the most demanding flight operation, LPV-200. This level of service is available throughout the coverage area, as indicated on the web site. In areas where that level of service is not available, the WAAS signal indicates the reduced level of service that is available (LPV or LNAV/VNAV). The level of service available is displayed on the receiver. The WAAS design delivers an integrity alert within a TTA of 6.2 seconds. Otherwise, the receiver RAIM/FDE alerts within 8 seconds. The probability of HMI analysis for the WAAS design is less than 1×10^{-7} per approach (150 seconds). Continuity is not tracked. Accuracy nominal is approximately 1.6 m vertical or horizontal 95% of the time. The maximum observed error is less than 12 m when the VPL is less than 50 m.. Treating this as a 6σ limit, a conservative 95% maximum error is the same as the vertical accuracy requirement of 4 m. Availability maps are illustrated real-time and historically on the FAA Technical Center web site at www.nstb.tc.faa.gov. Table 3.3-1 presents WAAS SIS performance based on the system design, analysis, and actual performance.

Table 3.3-1 WAAS SIS Performance

	Performance	Comment
TTA	6.2 s	Same as requirement
TTA receiver RAIM/FDE	8 s	TSO-C145/146
Probability of HMI	$<1 \times 10^{-7}$ per approach (150 seconds)	Less than requirement
Continuity	$1 - 8 \times 10^{-6}$/15 seconds	Same as requirement
Horizontal Accuracy nominal	1.6 m (95%)	Performance Analysis Report
Horizontal Accuracy maximum	12 m (maximum observed)	
Horizontal Accuracy limit	4 m (conservative 95% limit)	
Vertical Accuracy nominal	1.6 m (95%)	Performance Analysis Report
Vertical Accuracy maximum	12 m (maximum observed)	
Vertical Accuracy limit	4 m (conservative 95% limit)	
Availability	real-time availability maps	www.nstb.tc.faa.gov

3.4 WAAS Current Services and Availability

a) WAAS provides a ranging function throughout the entire satellite footprint, as shown in Figure 1. GPS/SBAS avionics are designed to incorporate this ranging signal to improve RAIM/FDE availability, even when no other SBAS service is available.

b) WAAS provides the GNSS satellite status and differential corrections function for all satellites that are in view of the ground network, for any user within the footprint of one of the geostationary satellites. GPS/SBAS avionics are designed to use this service for en route through LNAV approach navigation when the resulting integrity bound is better than that provided by RAIM/FDE. This function must be provided on at least four satellites for the receiver to use the differential correction function for integrity. When this function is available for fewer than four satellites, the GPS/SBAS equipment can still use the corrections and integrity information that is available to improve the performance of RAIM/FDE. At a given location, the number of satellites which receive this service varies during a typical day as satellites orbit the Earth. This function is provided on at least four satellites throughout a typical day in the light blue area shown in Figure 3.4-1.

It should be noted that it has been the FAA's policy that WAAS must meet the integrity requirements over the entire coverage area. This policy ensures that GPS/SBAS receivers can be used throughout the WAAS satellite footprint with the assurance that the navigation solution will have integrity whether based on WAAS augmentation or on RAIM/FDE.

c) WAAS provides the ionosphere corrections function within the dark blue region shown in Figure 3.4-1. GPS/SBAS avionics use a standard ionospheric model outside this region, and no LPV capability is available.

3.4.1 Mapping Functions to Operational Capability

It is important to recall that the availability of service for a given flight operation is not determined by the location of a user, inside or outside a particular pre-defined service volume, but by the user equipment. Service availability is determined by the GNSS satellites the receiver is able to track, the availability of WAAS corrections and magnitudes of the error bounds for these satellites, and, for vertically guided approach operations, the availability of ionosphere corrections and magnitudes of their error bounds.

Figures 3.4-2 and 3.4-3 show the operational capability of GPS/WAAS.

- Figure 3.4-2 shows the availability of LNAV approach capability. Note that this capability exists even outside the WAAS footprint, as the GPS/WAAS avionics automatically revert to GPS-only operation.
- Figure 3.4-3 shows the availability of LPV approach capability.

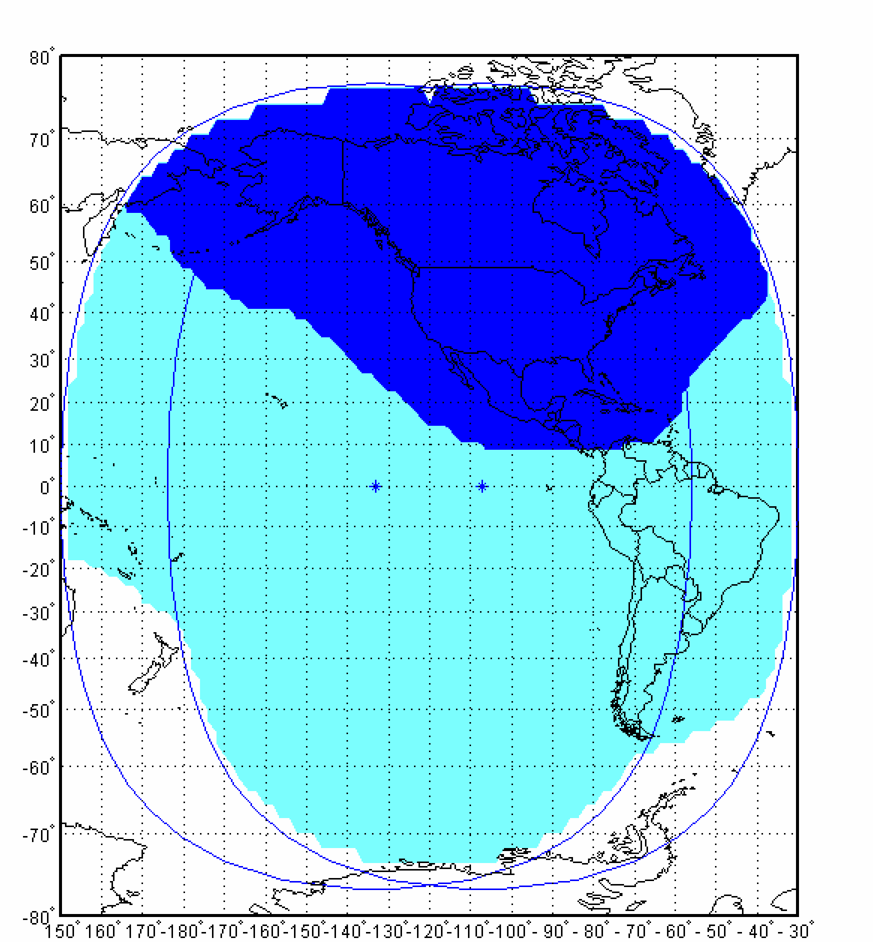


Figure 3.4-1 WAAS Ranging Function, Satellite Status and Differential Correction Function

Legend:

- The ranging function is available throughout the footprints of the two WAAS Geostationary satellites located at 133W and 107W.
- The satellite status and clock/ephemeris differential correction function is available on at least four satellites throughout the entire day within the light blue region.
- All four services, including ionosphere correction function, are available for at least four satellites during an entire typical day within the dark blue region.
- The figure shows average performance over 288 5-minute epochs (24 hours).
- The figure assumes a 24 satellite GPS constellation without failures and the two WAAS GEOs.

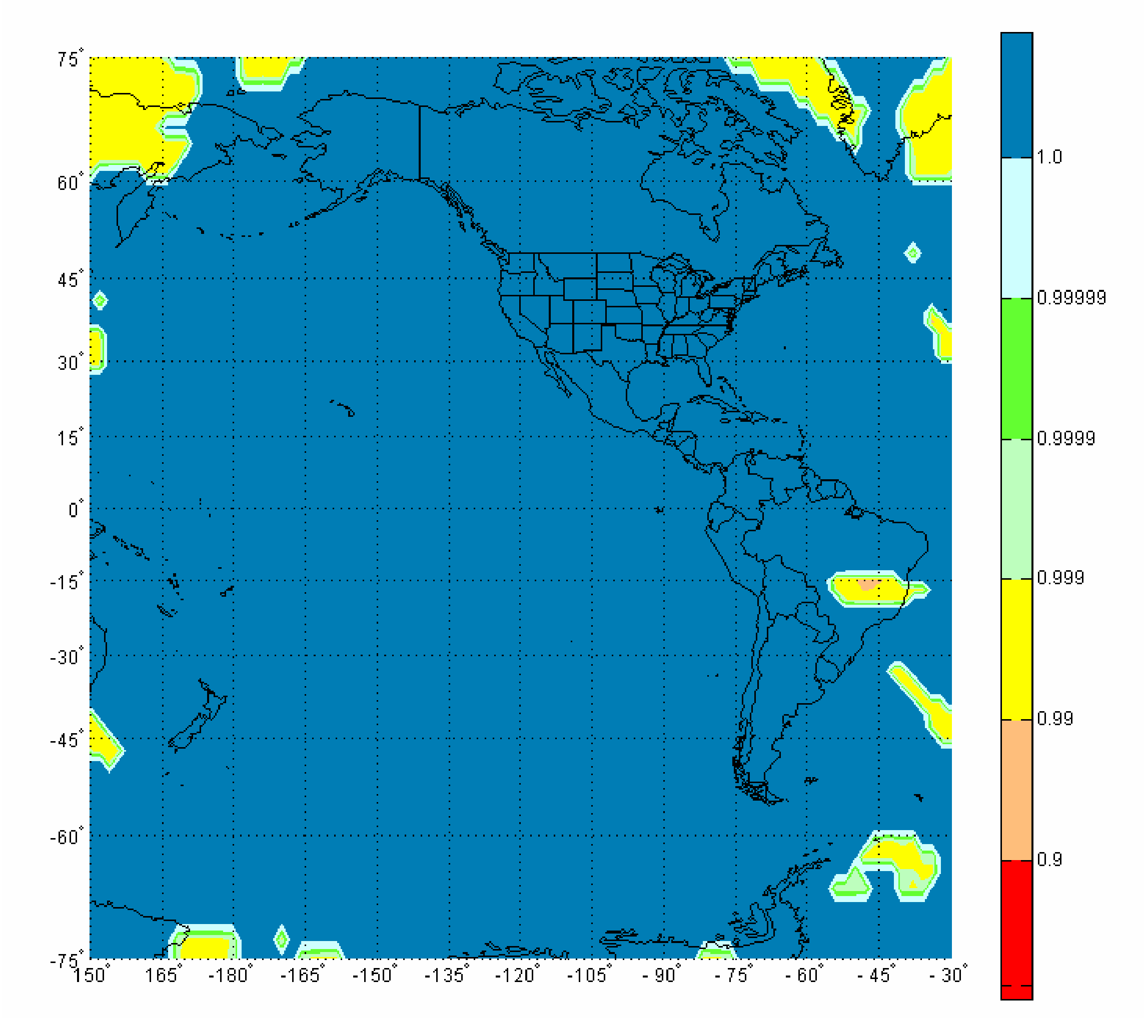


Figure 3.4-2 WAAS Service Area for LNAV

Legend:

- The figure shows average LNAV availability performance over 288 5-minute epochs (24 hours).
- The different colors correspond to different levels of LNAV service availability as shown by the color bar on the right side of the figure.
- SBAS receivers will use either SBAS or Fault Detection and Exclusion to provide en route through LNAV service; this explains that the figure shows service in areas where the WAAS signal cannot be received (e.g., Greenland).
- The figure assumes a 24 satellite GPS constellation without failures and two WAAS GEOs with ranging function.

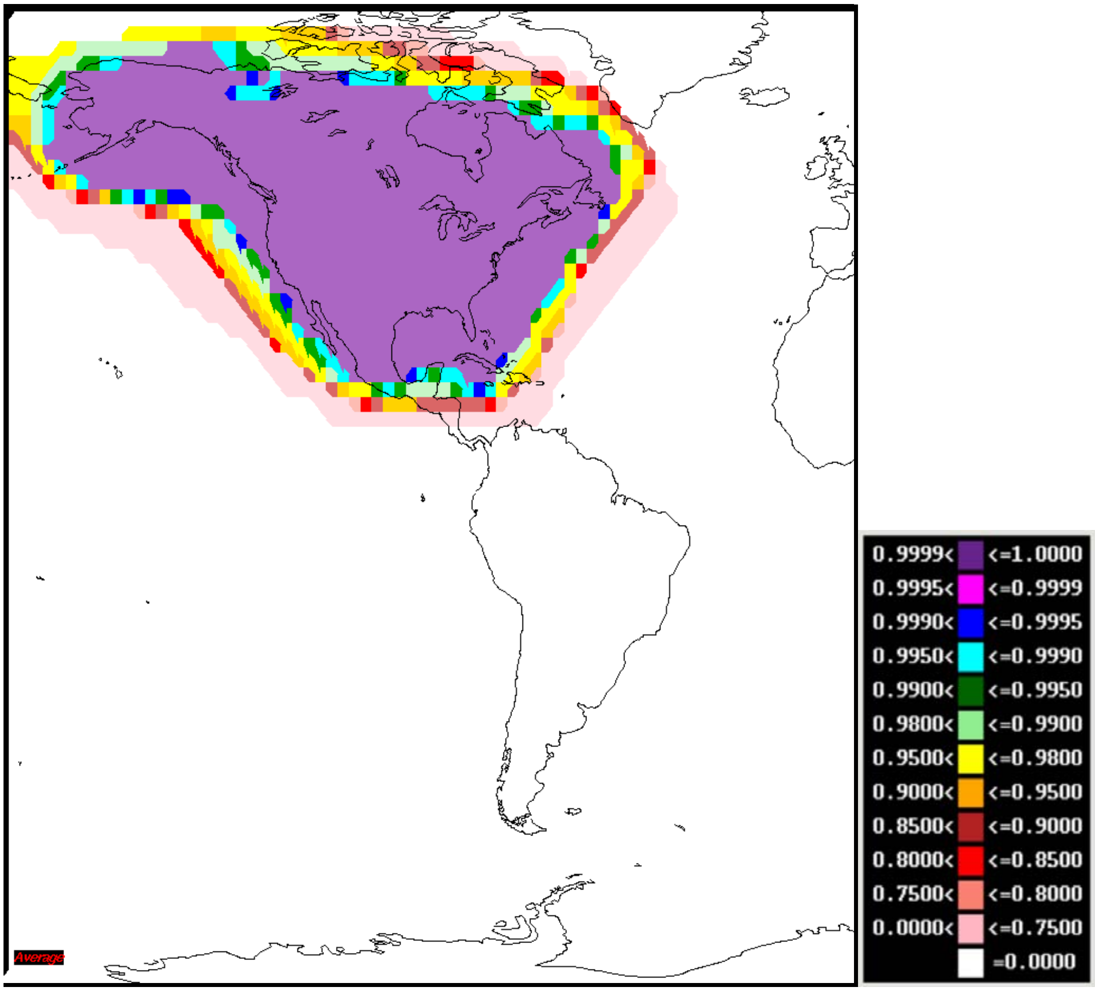


Figure 3.4-3 WAAS Service Area for Localizer Precision with Vertical Guidance (LPV) Approach (HAL = 40 m; VAL = 50 m)

Legend:

- The figure shows average LPV availability performance over 288 5-minute epochs (24 hours).
- The different colors correspond to different levels of LPV service availability as shown by the color bar on the right side of the figure
- The figure assumes a 24 satellites GPS constellation without failure and two WAAS GEOs with ranging function.

SECTION 4.0 References

This section identifies the Government documents and non-Government documents explicitly referenced in or related to the content of this *WAAS PS*.

4.1 Government Documents

SPECIFICATIONS:

Federal

23 February 2007	Global Positioning System Precise Positioning Service Performance Standard, 1st Edition
30 September 2008	Global Positioning System Standard Positioning Service Performance Standard, 4th Edition
13 August 2001	WAAS Specification FAA-E-2892b(C2)

Military

None

STANDARDS:

Federal

TSO-C129 10 December 1992	Technical Standard Order (TSO), *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)*
TSO-C129a 20 February 1996	Technical Standard Order (TSO), *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)*
TSO-C144a 30 March 2007	Technical Standard Order (TSO) Passive Airborne Global Positioning Antenna
TSO-C145a 19 September 2002	Technical Standard Order (TSO), *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)*
TSO-C145b 14 February 2007	Technical Standard Order (TSO), *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Satellite Based Augmentation System*
TSO-C145c 2 May 2008	Technical Standard Order (TSO), *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Satellite Based Augmentation System*
TSO-C146a 19 September 2002	Technical Standard Order (TSO), *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)*
TSO C146b	Technical Standard Order (TSO), *Stand-Alone Airborne*

14 February 2007	*Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Satellite Based Augmentation System*
TSO C146c 9 May 2008	Technical Standard Order (TSO), *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Satellite Based Augmentation System*
TSO C190 20 March 2007	Technical Standard Order (TSO) Active Airborne Global Navigation Satellite System (GNSS) Antenna

Program

IS-GPS-200 Current Revision	*Navstar GPS Space Segment / Navigation User Interfaces*

OTHER PUBLICATIONS:

Plans

DOT-VNTSC-RITA-05-12 5 January 2006	*2005 Federal Radionavigation Plan* (Additionally numbered as DoD-4650.5)
DOT-VNTSC-RSPA-01-3.1 19 March 2002	*2001 Federal Radionavigation Systems* (Additionally numbered as DOD-4650.5)

Miscellaneous

N 8110.60 2 February 1997	Federal Aviation Administration Notice *GPS as a Primary Means of Navigation in Remote/ Oceanic Operations*
AC 20-138A 22 December 2003	Federal Aviation Administration Advisory Circular (AC) *Airworthiness Approval of Global Satellite Navigation System (GNSS) Equipment*
AC 90-96A 13 January 2005	Federal Aviation Administration Advisory Circular (AC) *Approval of U.S. Operators and Aircraft to Operate Under Instrument Flight Rules (IFR) in European Airspace Designated for Basic Area Navigation (BRNAV) and Precision Area Navigation (PRNAV)*
AC 90-100A 1 March 2007	US. Terminal and En Route Area Navigation (RNAV) Operations
AC 90-101 15 December 2005	Approval Guidance for RNP Procedures with SAAAR

4.2 Non-Government Documents

SPECIFICATIONS:

None

STANDARDS:

SARPs Annex 10 Amendment 83 20 July 2008	International Civil Aviation Organization (ICAO) *Annex 10 to the Convention on International Civil Aviation, International Standards and Recommended Practices, Aeronautical Telecommunications, Volume 1, Radio Navigation Aids*
RTCA/DO-229D 13 December 2006	RTCA Document, Special Committee 159 *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*
RTCA/DO-236B 28 October 2003	RTCA Document, Special Committee 181 *Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation*
RTCM Paper 136-2001/SC104-STD August 2001	RTCM Document, Special Committee 104 *RTCM Recommended Standards for Differential Navstar GPS Service, Version 2.3*

GLOBAL POSITIONING SYSTEM WIDE AREA AUGMENTATION SYSTEM (WAAS) PERFORMANCE STANDARD

APPENDIX A

WAAS SERVICE SPECIAL TOPICS

31 October 2008

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SECTION A.1 Introduction

This Appendix provides background information about topics that affect WAAS performance standards or flight operations. It is intended to provide a repository of information that may be relevant to current changes to improve WAAS operations or to expected improvements in the WAAS performance standards.

The first topic in this appendix deals with the difference between the observed Navigation System Error (NSE) and the WAAS Protection Level. The WAAS protects the user against navigation errors by broadcasting a protection level that is greater than the expected error with a probability that meets the integrity requirement.

The second topic in this appendix deals with the effect of the DoD plans to no longer support users of codeless or semi-codeless receivers starting December 31, 2020. WAAS uses semi-codeless receivers to measure the ionosphere induced propagation delay. WAAS plans to transition to processing of the ‘new’ L5 civil signal in order to avoid a disruption in service upon loss of the L2 P(Y) capability.

SECTION A.2 Integrity Protection Levels

This section discusses the WAAS integrity protection levels. Historical performance for the horizontal and vertical protection levels derived from the WAAS service are examined. Their effect on the availability of service is examined. Actual statistical error is compared to the protection levels. The effect on flight operations is examined.

A.2.1 Background – Protection Levels

WAAS provides integrity by transmitting the information necessary for a user to correct the GPS signal and to calculate an integrity protection level in the horizontal and vertical plane. This is compared against the HALs and VALs required to an operation to determine whether this operation is available to the pilot.

Statistical performance of the WAAS service in providing VPL and HPLs is available in the WAAS Performance Analysis Reports posted on the FAA Technical Center WAAS Test Bed web site at http://www.nstb.tc.faa.gov/. The Report lists the 95% average VPL and HPL values for each reference site in the WAAS reference network. An example of these values is included in below in Table B.2-1.

Table A.2-1 Example Protection Levels from WAAS Performance Analysis Report

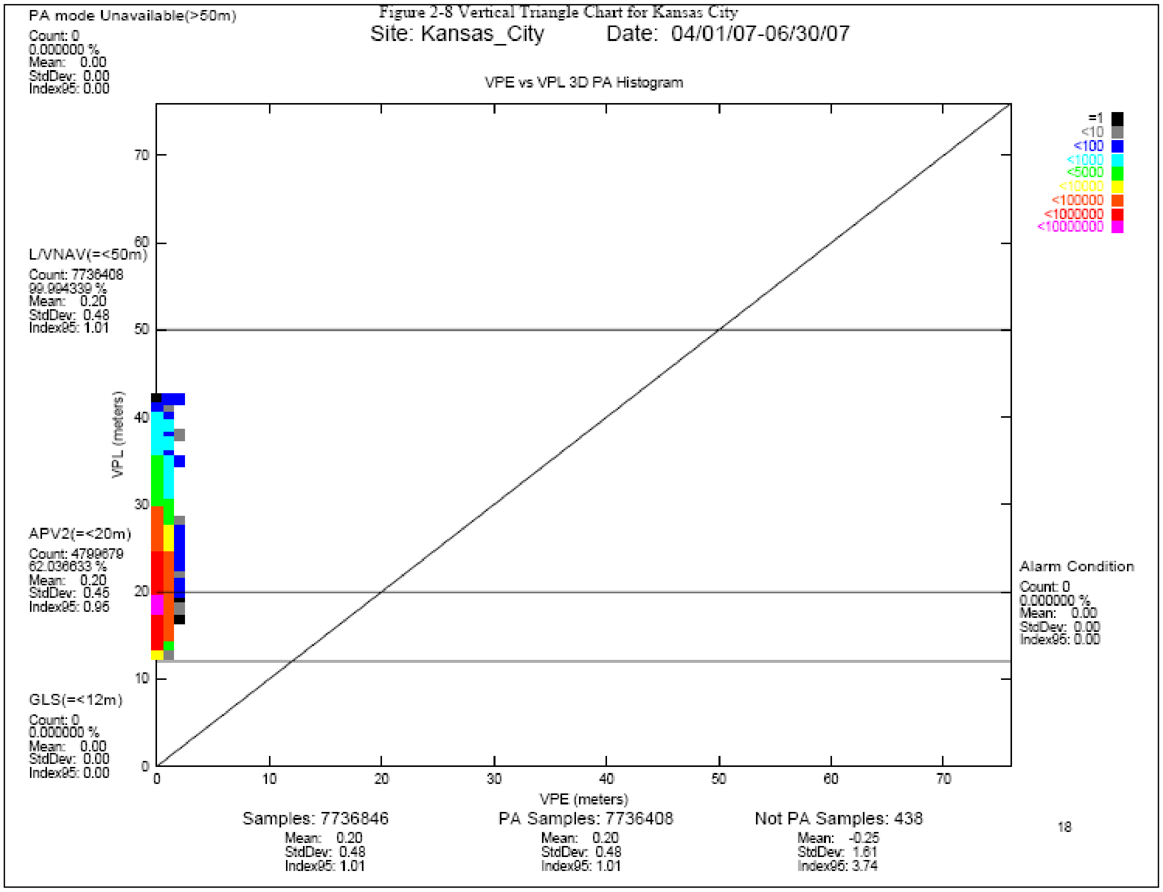
Parameter	CONUS Maximum	Alaska Maximum
HPL 95%	Boston 28.615 meters	Barrow 49.90 meters
VPL 95%	Boston 46.743 meters	Barrow 93.816 meters

A.2.2 Actual Error – Compared to Protection Levels

This does not reflect, however, what the actual necessary protection level should have been. The WAAS calculated protection level is more conservative than the observed error, but flight safety is evaluated based upon the presumption that the flight user could be exposed to an error of the maximum protection level – that is equivalent to the alert limit. Unfortunately, although this is accepted as a conservative assumption, the WAAS is not able to assure a protection level closer to the actual error with the requisite integrity.

The relationship between position error, protection level and the alert limit designated for a particular flight operation is depicted in the Figure A.2.2-1, Vertical Triangle Chart for Kansas City, below. The VPL is on the Y-axis and the vertical position error along the X-axis. The diagonal line is the limit where vertical position error would exceed the VPL, in which case HMI would be present. The horizontal lines designated at 12m, 20m, and 50m show the alert limits for GNSS Landing System (GLS), APV-II, and APV-I (LNAV/VNAV) respectively. Colors are used to depict the number of data samples at a particular point on the chart. If any position error points appear on the right side of the diagonal line, the HMI exists and the cause for this must be investigated, possibly requiring a design change to the WAAS to ensure the broadcast messages bound the users errors at all times. Position error points that appear above the alert limit lines (horizontal) indicate that the intended flight operation is not available.

Figure A.2-1 Vertical Triangle Chart for Kansas City



Actual error observed at the reference sites was examined by the FAA Technical Center. The results were used to support the WAAS LPV-200 Safety Risk analysis. These results are presented below in two forms. The first is Table A.2-2 which presents the maximum observed vertical error when VPL was reported to be less than 50 m over the entire period of WAAS performance at the time of the study. The second is Figure A.2-1 which presents a histogram of the full data set from all sites. These show that when LPV was available, the maximum observed error was less than 10.0 m based on observed system performance. This is substantially less than the 16 – 28 m VPL calculated for these sites.

Table A.2-2 Maximum Vertical Position Error

SITE	Max. Vert. Error (m)	SITE	Max. Vert. Error (m)
Washington, DC	7.47	Denver, CO	7.59
Anderson, SC	6.89	Houston, TX	6.85
Grand Forks, ND	11.60	Jacksonville, FL	7.64
Great Falls, MT	7.32	Kansas City, MO	6.86
Oklahoma City, OK	7.17	Los Angeles, CA	8.02
Albuquerque, NM	6.62	Memphis, TN	5.41
Atlanta, GA	6.26	Miami, FL	10.50
Billings, MT	6.95	Minneapolis, MN	8.03
Boston, MA	9.49	New York, NY	9.82
Chicago, IL	6.46	Oakland, CA	7.63
Cleveland, OH	6.95	Salt Lake City, UT	8.58
Dallas, TX	9.46	Seattle, WA	6.89

A histogram of the total data set is shown below. The figure shows data points larger than 12m that were later determined to be invalid.

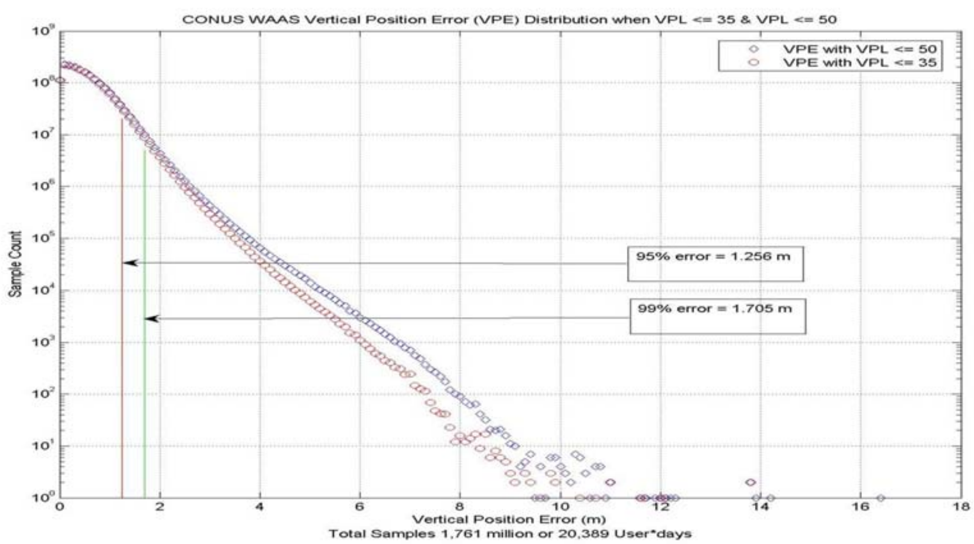


Figure A.2-2 Histogram of WAAS WRS Vertical Navigation Signal Error (VNSE)

A.2.3 Effect on Flight Operations

The largest effect on flight operations is caused by the VPL. A VAL of 35 m is required to support LPV-200. The availability of LPV-200 depends on the WAAS service at the user location obtaining a VPL of 35 m or less. Current availability of this procedure is approximately 90% of CONUS, as can be readily seen when consulting the FAA Technical Center web site above and pulling up the current LPV 200 availability map.

Actual vertical error for WAAS, however, has not been observed to exceed 12 m in the history of operational service, as shown in Figure A.2-1. This means that if the predicted VPL based on historical statistics for observed error would be 12 m – always less than 35 m – and LPV-200 would always be available. The real-time VPL predicted by the WAAS safety processor algorithms, however, is substantially larger than the actual vertical error measured at the WAAS Reference Stations. The difference between this potential service and the actual service that is provided is substantial.

Availability of LPV-200 is not the only substantial flight restriction resulting from the difficulty to generate tighter bounds for vertical error. Autoland operations require the VPL to be 12 m or less. Because of the 35 m VAL and the inability of the WAAS to guarantee actual vertical error performance, auto-coupling is restricted to altitudes above 200 feet under the LPV-200 rules. This restriction is applied even though actual statistics suggest that full autoland operations could be safely conducted, because past vertical error statistics are not a sufficient basis for approval.

SECTION A.3 Semi-Codeless GPS Receiver Transition

This section discusses the transition of WAAS from semi-codeless receivers to modernized civil code receivers and algorithms. On September 23, 2008, the DoD announced its intent to transition from semi-codeless and codeless receiver support by December 31, 2020. WAAS plans to transition its architecture from one dependent upon semi-codeless receivers to measure ionosphere induced propagation delay to one that uses the civil codes on L1 and L5. This transition will require updates to the safety-critical algorithms in addition to replacement of the receivers. Transition of the WAAS will also support a two frequency service (L1, L5) with a much larger service volume.

A.3.1 Background – Semi-Codeless Receivers

GPS transmits PPS signals known as P(Y)-code at the L1 and L2 frequencies. The P(Y) signals are intended primarily for U.S. and allied military use, but the civilian community has developed techniques that exploit P(Y) at L1 and L2 to achieve significant accuracy gains. Such techniques, collectively known as codeless or semi-codeless GPS access, have been integrated into a range of GPS receivers sold commercially around the world. WAAS uses semi-codeless receivers, primarily to measure ionospheric delays, at each WAAS Reference Site.

The U. S. Government has historically supported codeless and semi-codeless users by documenting a time-limited commitment to the P(Y) signal in the GPS Standard Positioning Service (SPS) Performance Standard and the Federal Radionavigation Plan. For example, the 2001 version of the GPS SPS Performance Standard included the statement that, "Until such time as a second coded civil GPS signal is operational, the U.S. Government has agreed to not intentionally reduce the current received minimum Radio Frequency signal strength of the P(Y)-coded signal on the L2 link, as specified in ICD-GPS-200C or to intentionally alter the P(Y)-coded signal on the L2 link." As a result, manufacturers have continued to develop codeless/semi-codeless GPS equipment.

The U.S. Government acknowledges the global use of GPS codeless and semi-codeless techniques and has committed to maintain the existing GPS L1 P(Y) and L2 P(Y) signal characteristics until such time that an alternative capability exists to replace it. Since 1999, the Department of Defense has worked closely with the civilian agencies on the National Executive Committee for Space-Based PNT (and its predecessor, the Interagency GPS Executive Board) to add new capabilities to GPS that supplant the need for codeless/semi-codeless access. In 2005, the U.S. Air Force began launching modernized GPS satellites featuring a new civil signal at L2 called L2C. L2C is designed to work in combination with the legacy C/A signal at L1 to enable high accuracy without codeless/semi-codeless techniques. In 2009, the Air Force will begin adding a third civil signal called L5 to all new GPS satellites. L5 will also work in combination with L1 C/A and/or L2C to enable high accuracy without codeless/semi-codeless techniques.

The National Executive Committee for Space-Based PNT seeks to encourage the development and adoption of next-generation GPS receivers that achieve high accuracy via use of L2C and/or L5 instead of codeless/semi-codeless techniques. To facilitate business decisions and stable planning for equipment developers and end users, the National Executive Committee has established a fixed date of December 31, 2020, for the equipment transition.

The date is based upon the current launch schedule for the GPS program, which will have 24 GPS satellites transmitting the L2C signal to users by 2016, and 24 GPS satellites transmitting L5 by 2018. The date is also based on industry inputs collected by the Department of Commerce through interviews and through public comments submitted by GPS user equipment manufacturers, service providers, and users in response to a Federal Register notice dated May 16, 2008. The manufacturers and service providers indicated that a 12-year transition period should be sufficient to allow the installed base of codeless/semi-codeless GPS users to re-equip with next-generation receivers as part of their normal equipment amortization, obsolescence, and upgrade cycle.

Should there be unforeseen delays in the GPS modernization program, the transition date will reassessed.

After 2020, the characteristics of the P(Y) signals transmitted by modernized GPS satellites may change without further notice and may preclude codeless/semi-codeless use of the P(Y) signals. However, for those legacy satellites that have no modernized capabilities, codeless/semi-codeless access to P(Y) at L1 and L2 will continue until those satellites are decommissioned.

A.3.2 Semi-Codeless Receiver Requirements

The civil community assumptions associated with codeless/semi-codeless processing of the L2 SIS are as follows:

- Maintain a stable 90 degree phase offset between L1 C/A and L1 P(Y) codes (C/A must lag L1-P(Y)). The offset is expected to be within +/- 100 milliradians.
- Code offset between P(Y) on L1 and L2 less than 15 ns (as specified in IS-GPS-200D). The offset is expected to be within +/- 15 ns and corrected with T_{GD} in the navigation message.
- Maintain a stable 90 degree offset between L2C and L2 P(Y) codes (L2C must lag L2 P(Y)). The offset is expected to be within 100 milliradians.
- L1 modulated by C/A and P(Y) codes in phase quadrature, i.e., P-code nominal -90 degrees from C/A (as defined in IS-GPS-200D).
- Y-code is an encrypted version of P-Code.
- L2 modulated with same P(Y) as L1.
- Same navigational data broadcast on L1 P(Y) and L2 P(Y) (note this is stated as optional in IS-GPS-200D).
- L1-L2 differential bias stability less than 3 ns, 2-sigma (as stated in IS-GPS-200D to support clock accuracy, based on L1 combined with L2) over any 5 minute interval.

A.3.3 Effect on WAAS Users

When WAAS transitions to use L1 and L5, it will no longer monitor GPS satellites that don't transmit L5. At the transition date, 24 GPS satellites will be broadcasting the L5 signal. There may be some Block IIR or IIR-M satellites operational within the constellation that cannot broadcast the L5 signal. WAAS will no longer monitor these satellites after transition.

WAAS transition will enable a new two frequency service. This new service will be available to users with receivers that rely on L1 and L5 to correct for the ionosphere induced error instead of using the ionosphere error correction grid provided for single frequency users. .

A.3.4 Semi-Codeless Federal Register Notice

On September 23, 2008, the DoD published a Notice in the Federal Register titled "Preservation of Continuity for Semi-Codeless GPS Applications". The Notice was published under the Office of the Secretary, Assistant Secretary of Defense for Networks and Information Integration/DoD Chief Information Officer, Department of Defense. It may be obtained electronically at http://edocket.access.gpo.gov/2008/pdf/E8-22197.pdf. The complete Notice, FR Doc. E8-22197, is as follows:

Federal Register: September 23, 2008 (Volume 73, Number 185)
Notices
Page 54792-54793
From the Federal Register Online via GPO Access (wais.access.gpo.gov)
DOCID:fr23se08-49

DEPARTMENT OF DEFENSE

Office of the Secretary

Preservation of Continuity for Semi-Codeless GPS Applications

AGENCY: Assistant Secretary of Defense for Networks and Information Integration/DoD Chief Information Offices, Department of Defense.

ACTION: Notice

SUMMARY: To enable an orderly and systematic transition, the U.S. Government has established December 31, 2020 as the date by which users of semi-codeless/codeless receiving equipment are expected to transition to using GPS civil-coded signals. Based on the current launch schedule and projected budget, the December 31, 2020 transition date represents the planned availability of the second and third coded civil GPS signal being broadcast from a minimum of 24 GPS satellites. Department of Defense will reassess the transition date should significant GPS program delays arise.

FOR FURTHER INFORMATION CONTACT: Mr. Raymond Swider, 703-607-1122.

SUPPLEMENTARY INFORMATION:

The Department of Defense (DoD) provides the GPS Standard Positioning Service (SPS) for peaceful civil, commercial, and scientific uses on a continuous worldwide basis free of direct user fees. The SPS is a single-frequency GPS service which is presently limited to the coarse acquisition (C/A) code on the L1 frequency.

Access to two or more civil signals are needed to enable high accuracy civil applications. Civil users are currently employing codeless or semi-codeless techniques to gain access to encrypted GPS signals, L1 P(Y) and L2 P(Y). To facilitate expansion of civil GPS applications, the DoD has planned and begun to broadcast additional civil signals that will obviate the further need for use of codeless and semi-codeless techniques. The second coded civil GPS signal (L2C) and the third coded civil GPS signal (L5) are planned to be broadcast from 24 GPS satellites in 2016 and 2018, respectively. Full operational capability of the L2C and L5 GPS signals in combination with the existing L1 C/A signal will enable the full spectrum of dual frequency applications without using the P(Y) signals.

The U.S. Government acknowledges global use of GPS codeless and semi-codeless techniques and commits to maintaining the existing GPS L1 C/A, L1 P(Y), L2C and L2 P(Y) signal characteristics until December 31, 2020 when the second and third civil signals (L2C and L5) are planned to be broadcast from a minimum of 24 GPS satellites.

After the planned transition date, the characteristics of the L1 P(Y) and L2 P(Y) signals transmitted by any or all GPs satellites broadcasting two or more civil-coded signals may change without further notice and may preclude the use of P(Y) coded signals for high accuracy applications.

The U.S. Government is committed to support civil PNT services based on GPS civil signals: L1 C/A, L2C, L5, and L1C. To this end, GPS civil signal characteristics are specified in the relevant Interface Specifications (ISs) and will be included in Performance Standards (PSs) subject to the operating descriptions contained in the Federal Radionavigation Plan (FRP). The U.S. Government has met or exceeded the GPS service performance commitments in the Standard Positions Service Performance Standard since 1993 and is committed to continually improving GPS services as codeless and semi-codeless users complete a timely transition to dual-coded civil GPS equipment.

Dated: September 16, 2008
Patricia L. Toppings
OSD Federal Register Liaison Officer, Department of Defense
FR Doc. 8-22197 Filed 9-22-08: 845 am

GLOBAL POSITIONING SYSTEM WIDE AREA AUGMENTATION SYSTEM (WAAS) PERFORMANCE STANDARD

APPENDIX B

KEY TERMS, DEFINITIONS, ABBREVIATIONS AND ACRONYMS

31 October 2008

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SECTION B.1 Key Terms

Alert. An indication provided to other aircraft systems or annunciation to the pilot to identity that an operating parameter of a navigation system is out of tolerance. [ICAO definition]

Alert limit. For a given parameter measurement, the error tolerance not to be exceeded without issuing an alert. [ICAO definition]

Baseline 24-Slot Constellation. Constellation of operational satellites deployed in the 24 defined baseline orbital slots. Each orbital slot is characterized by a near one-half sidereal day period such that the orbit ground trace repeats each sidereal day. The orbital slots are organized by the orbit plane, with each orbit plane having multiple slots and each slot having a unique orbital ground trace. In the baseline 24-slot constellation, there are six orbit planes, each with four slots.

Block II Satellites. The current deployed constellation consists entirely of Block II series satellites. For the purposes of these performance standards, the Block II series of satellites (the IIA, IIR, IIR-M, and IIF) provide an identical service.

Global navigation satellite system (GNSS). A worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation. [ICAO definition]

Hazardously Misleading Information (HMI). Information that persists beyond the allowable TTA causing the errors in the position solution output by a WAAS receiver to exceed the user's particular tolerance for error in the current application.

Integrity. A measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid warnings to the user (alerts). [ICAO definition]

Precise Positioning Service (PPS). The GPS broadcast signals based on the L1 P(Y)-codes, L1 C/A-codes, and L2 P(Y)-codes, as defined in the GPS ISs/ICDs, providing constellation performance to authorized users, as established in the *PPS Performance Standard (PPS PS)*.

Receiver Autonomous Integrity Monitoring (RAIM). RAIM is an algorithm used in a GPS receiver to autonomously monitor the integrity of the output position/time solution data. There are many different RAIM algorithms. All RAIM algorithms operate by evaluating the consistency of redundant measurements.

Satellite-based augmentation system (SBAS). A wide coverage augmentation system in which the user receives augmentation information from a satellite-based transmitter. [ICAO definition]

Standard Positioning Service (SPS). The GPS broadcast signals based on the L1 C/A-codes, as defined in IS-GPS-200, providing constellation performance to civil, commercial, and scientific users, as established in the *SPS Performance Standard (SPS PS)*, in accordance with U.S. Government (USG) policy.

Time-to-alert. The maximum allowable time elapsed from the onset of the navigation system being out of tolerance until the equipment enunciates the alert. [ICAO definition]

SECTION B.2 Definitions

Accuracy. Accuracy is defined to be the statistical difference between the estimate or measurement of a quantity and the true value of that quantity. For the purposes of this WAAS *PS*, accuracy is expressed as either as 95th percentile (95%) differences or as rms differences.

Availability. Availability is defined as the percentage of time that a particular WAAS service is available to the WAAS user. Real-time availability maps are published by the FAA Technical Center at www.nstb.tc.faa.gov, and dispatch availability predictions are available to support flight operations.

Continuity. Continuity is defined to be the probability that a WAAS service will continue to be available over an hour time interval for en route through LNAV operations, over a 15 second interval for LNAV/VNAV and LPV operations, given that it was available at the beginning of the interval and that an outage was not announced in a prior notice to airmen (NOTAM).

Integrity. Integrity is a measure of the trust which can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of the WAAS SIS to provide timely alerts (alarms or warnings) to receivers when the WAAS service HPL or VPL no longer bound the horizontal position error (HPE) or vertical position error (VPE) or a GPS satellite should not be used as part of the WAAS augmentation solution.

SECTION B.3 Abbreviations and Acronyms

- A -

- B -

- C -

C/A	Coarse Acquisition
C&V	Corrections & Verification
CAT	Category
CONUS	CONtiguous U.S.
CS	Control Segment

- D -

dBm	Decibels with respect to one milliWatt
DCP	Data Collection Processor
DGPS	Differential GPS
DoD	Department of Defense
DOT	Department of Transportation

- E -

ER	En Route

- F -

FAA	Federal Aviation Administration
FCs	Fast Corrections
FDE	Fault Detection and Exclusion
FRP	Federal Radionavigation Plan

- G -

GEO	Geostationary Earth Orbit
GES	Ground Earth Station
GIVE	Grid Ionospheric Vertical Error
GNSS	Global Navigation Satellite System
GPS	Global Positioning System (or Navstar Global Positioning System)
GUS	GEO Uplink Subsystem

- H -

HAT	Height Above Touchdown

HAL	Horizontal Alert Limit
HMI	Hazardously Misleading Information
HPL	Horizontal Protection Level

- I -

ICs	IGP Corrections
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
IFOR	Interagency Forum on Operational Requirements
IFR	Instrument Flight Rules
IGP	Ionospheric Grid Points
ISs	Interface Specifications

- J -

- K -

- L -

L1	The SIS centered at the 1575.42 MHz frequency
L1C	A future civil signal centered at L1
L2	The SIS centered at the 1227.60 MHz frequency
L2C	A future civil signal centered at L2
L5	A future civil SIS centered at the 1176.45 MHz frequency
LNAV	Lateral Navigation
LPV	Localizer Performance with Vertical
LTC	Long Term Corrections

- M -

MCS	GPS Master Control Station (part of the OCS)
MHz	MegaHertz
MOPS	Minimum Operational Performance Standard
MS	GPS Monitor Station (part of the OCS)
MSL	Mean Sea Level

- N-

NAS	National Airspace System
NOCC	National Operations and Control Center
NOTAM	Notice to Airmen
NSE	Navigation System Error
NSTB	National Satellite Test Bed

- O -

OCS	GPS Operational Control System
OCS	Obstacle Clearance Surface (defined within TERPS)
O&M	Operations and Maintenance

- P -

P-code	Unencrypted Precise PRN ranging code
PDOP	Position Dilution of Precision
POCC	Pacific Operations and Control Center
PPS	Precise Positioning Service
PRN	Pseudorandom Noise (a characteristic of the SIS ranging codes)
PS	Performance Standard (as in *PPS PS* or *SPS PS*)
P(Y)-code	Precise PRN ranging code (unencrypted or encrypted)

- Q -

- R -

RAIM	Receiver Autonomous Integrity Monitoring
RAIM/FDE	RAIM with FDE
RF	Radio Frequency
RFU	RF Uplink
RHCP	Right Hand Circularly Polarized
rms	Root-Mean-Square
RNAV	Area Navigation
RNP	Required Navigation Performance
RTCA Inc.	Formerly Radio Technical Commission for Aeronautics

- S -

SARPs	Standards and Recommended Practices
SBAS	Satellite Based Augmentation System
SC	Safety Computer
SGS	Signal Generation Subsystem
SIS	Signal-In-Space
SP	Safety Processor
SPS	Standard Positioning Service

- T -

TERPS	Terminal and En Route Instrument Procedures
TCN	Terrestrial Communication Network
TSO	Technical Standard Order
TTA	Time to Alert
TT&C	Telemetry, Track, and Command

- U -

UDRE	User Differential Range Error

- V -

VPL	Vertical Protection Level
VAL	Vertical Alert Limit

- W -

WAAS	Wide Area Augmentation System
WMP	WAAS Message Processor
WMS	Wide-area Master Station
WRE	Wide-area Reference Equipment
WRS	Wide-area Reference Station

- X -

- Y -

- Z -