

FAA LAAS Specification: Requirements for Performance Type 1

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BIOGRAPHY

Victor Wullschleger is a Senior Electronics Engineer at the Federal Aviation Administration (FAA) William J. Hughes Technical Center (WJHTC) in Atlantic City, NJ. He has been employed by the FAA for over 10 years. Mr. Wullschleger received his Bachelor of Science in Electrical Engineering from Wichita State University in 1990. He has worked in support of the FAA GPS Program Office Product Team on GPS issues since 1991. Mr. Wullschleger was the project manager for numerous FAA-sponsored differential GPS (DGPS) flight tests and co-authored a number of papers detailing the results of those tests. In 1994 he was a co-recipient of the Institute of Navigation Samuel M. Burka Award. In 1998 he was selected by the GPS Product Team to head the FAA Local Area Augmentation System (LAAS) specification development effort. He has also supported the FAA Product Team on international harmonization issues for DGPS.

Theodore Urda is a Senior Aeronautical Engineer at the Federal Aviation Administration in Washington, D.C. Mr. Urda received his Bachelor of Science in Mechanical Engineering from the Illinois Institute of Technology in 1978 and Master of Science in Aeronautical Engineering Avionics from the U.S. Naval Postgraduate School in 1986. He served 18 years in the United States Navy, first as a Naval Aviator and then as an Aeronautical Engineering Duty Officer. Mr. Urda's experience includes tours in the Naval Air Systems Command as an Avionics Systems Project Officer and the Space and Naval Warfare Systems Command in the Navy's GPS Program Office as the Deputy Program Manager for GPS User Equipment Acquisition. Mr. Urda has been with the FAA GPS Product Team since 1996, initially as a private sector engineering consultant and currently as the Lead Systems Engineer on the FAA Local Area Augmentation System (LAAS) project where he orchestrates the systems engineering efforts for the development of the LAAS.

Ronald Braff is a Senior Principal Staff Engineer in the MITRE Corporation Center for Advanced Aviation System Development in McLean, VA. Mr. Braff received his Bachelor of Science in Physics in 1962 from Montana State

University and his Master of Science in Electrical Engineering in 1969 from New York University. He was the editor of NAVIGATION, The Journal of the Institute of Navigation (ION) from June 1987 to June 1997. Mr. Braff is currently an associate editor of NAVIGATION and chairs the ION Publications Policy Committee. Mr. Braff was the recipient of the Institute of Navigation's 1996 Norman P. Hayes Award in recognition of his technical and management accomplishments over thirty years in the application of radionavigation to aviation. He also received the ION's Distinguished Service Award in 1998 for his work as editor of the Journal and support of other ION publications. He has authored numerous technical papers on the application of differential GPS for precision approach and landing systems. Mr. Braff currently serves as the Senior Technical Advisor for the Local Area Augmentation System (LAAS) precision approach program, which includes the technical supervision of the LAAS Key Technical Advisors and the LAAS Integrity Panel.

ABSTRACT

The FAA, under the Government Industry Partnership (GIP), entered Stage 0 with the agreement to develop LAAS standards for Performance Type (PT) 1. PT 1 is intended to provide for a level of operation down to Category I minimums. During Stage 0, GIP team members, Honeywell and Raytheon, participated in the LAAS Ground Facility (LGF) specification development. These requirements were derived in part from the FAA LAAS Requirements Document (RD) and the RTCA LAAS Minimum Aviation System Performance Standard (MASPS), DO-245. Also, harmonization between the International Civil Aviation Organization (ICAO) Ground Based Augmentation System (GBAS) Standards and Recommended Practices (SARPS) and the LGF specification was completed. FAA contractors from SRC, Rannoch, MITRE, and government personnel from the Naval Air Warfare Center (NAWC) participated in the development and harmonization efforts. The FAA also assembled a team of experts from Ohio University and Stanford University to assist with the LAAS architecture and to assist with recommendations on specific design

details. This collaboration of efforts produced a LGF specification that was essentially a performance specification with little detail on design, allowing maximum flexibility for the GIP teams who are developing PT 1 LAAS without FAA funding. However, several areas of the LGF had to be addressed in the event that the FAA assumed system maintenance. Additionally, FAA Air Traffic Control (ATC) requirements to monitor the condition of the GPS constellation had to be met. This paper covers the basic performance requirements; accuracy, integrity, continuity, availability, and coverage. Details on the FAA operations and maintenance interfaces are given, including the ATC constellation alert. Finally, a status and summary of the FAA/GIP program is given.

INTRODUCTION

The FAA is transitioning the National Airspace System (NAS) from ground-based navigational aids to satellite-based navigational aids in order to modernize navigation and landing capabilities, resolve current deficiencies, and meet future needs. As outlined in the NAS Architecture Plan, version 4.0, the satellite-based system consists of the Global Positioning System (GPS), augmented by the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS). These satellite-based navigation and landing systems will provide the basis for NAS-wide direct routing, provide guidance signals for precision approaches to most runway ends of public use airports within the NAS, allow for surface navigation, Automatic Dependent Surveillance (ADS), and reduce the variety of navigation avionics required aboard aircraft.

The FAA and industry anticipate a number of benefits to be gained when the transition to satellite based navigation are complete. Unfortunately, existing budget constraints have forced the FAA to use creative measures to follow through with current transition and implementation plans. For the LAAS program, product development and initial deployment is solely in the hands of industry partners willing to invest internal funds with the intent of gaining type acceptance of their systems for commercial use under Federal Aviation Regulation (FAR) Part 171. This program, known as the FAA LAAS Government Industry Partnership (GIP), is currently in Stage 1, the development and certification stage for the Performance Type (PT) 1 LAAS Ground Facility (LGF). Stage 0 was partially completed on September 21, 1999 when the FAA LGF PT 1 specification [1] was signed by FAA senior management and baselined into the NAS. Initial Stage 0 work lasted approximately one year, wherein the FAA led discussions with the GIP teams, Raytheon and Honeywell, to determine the exact requirements for the LGF PT 1 specification. Stage 0 is expected to continue in the fall of 2000 with work on the Performance Type 2/3 specification.

This paper outlines performance requirements for the LGF as a system capable of providing operational capability down to

Category I minimums (2400 foot runway visual range and a 200 foot decision height). Specifics about the FAA operational, control, and security requirements will be discussed. Finally, details of the FAA maintenance concept are given.

LAAS PERFORMANCE TYPE 1

Performance requirements for LAAS are based on the FAA LAAS Requirements Document (RD). Since the RD specifies performance at the system level, it was necessary to sub-allocate at a subsystem level. In some cases, sub-allocation was tied to satellite (ranging source) measurements and reference receiver (RR) processing. The LAAS Minimum Aviation System Performance Standard (MASPS), DO-245, developed by RTCA Special Committee (SC-159) provided much of the necessary information on sub-allocation of requirements. Also, as directed by the LAAS RD, this document complies with the International Civil Aviation Organization (ICAO) Ground Based Augmentation Standards (GBAS) requirements, currently in the validation stage, and expected to be approved by the middle of 2000, see Figure 1.

LGF Accuracy and Availability

The FAA LAAS RD requires less than 4.4 m vertical and 9.0 m lateral Navigation Sensor Error (NSE), 95%, for PT 1. Because this is system accuracy, it is necessary to specify the LGF accuracy performance in such a way that the accuracy is guaranteed, as measured at the approaching aircraft. The accuracy curves in DO-245 were derived based on all known error sources. A description of these error sources can be found in Appendix D of DO-245, wherein the curves are referred to as the "LAAS SIS pseudorange errors". The largest contributor to pseudorange error is multipath. For the highest accuracy ground station, Ground Accuracy Designator (GAD) C, multipath is not a function of elevation below 35°. GAD C assumes the use of multipath limiting antenna (MLA) technology similar to the 16-element vertical dipole array antenna first demonstrated by Ohio University in FAA-sponsored flight tests [2,3]. The performance of this antenna is a significant improvement over that of conventional antennas that employ choke-ring technology for multipath reduction that could be employed by GAD A and B ground stations. Another factor influencing the accuracy curves is the number of RRs included in the solution. The use of multiple RRs allows for averaging, enhancing pseudorange accuracy by a factor of $1/\sqrt{N}$, where N is the number of independent pseudorange measurement per ranging source.

The FAA could have specified the characteristics of a single antenna suitable for all precision approach

applications in the NAS. Since the FAA provided no funding for the GIP Stage 1, forcing a particular design on the manufacturers was not thought to be justifiable. However, availability was thought to be a justifiable consideration. The FAA LAAS RD requires a minimum availability of 99.9% for all airports that support Category I operations. Based on availability requirements, appendix E of the LAAS MASPS indicates that GAD A will not meet FAA requirements. Since both GAD B and GAD C meet the minimum availability requirements, both are specified in the LGF specification, and the selection will depend on specific airport requirements.

The LGF specification requires three RRs to enable fault detection and isolation of a failed RR. Additionally, the FAA specified 0.1 chip correlator spacing in the LGF RRs. Specific details on the ground facility will ensure that all avionics manufacturers can optimize their airborne receivers by matching the processing used in the ground RRs. The 0.1 chip spacing technology has been thoroughly tested by the FAA, ensuring the necessary performance for a PT 1 ground facility.

Benefits of code-aided carrier smoothing are well known and the LGF specification requires a standard Hatch Filter with a 100 second time constant. This sufficiently reduces the noise, and by specifying explicitly the characteristic of the smoothing filter, ensures that avionics manufacturers can match the filtering characteristics in the avionics thereby improving performance.

Integrity

Integrity is the probability of transmitting erroneous or misleading information. The FAA LAAS RD requires an integrity of 1×10^{-7} per approach (150 seconds) in the lateral and vertical position domain for PT 1. This is typical for traditional landing systems where the lateral and vertical guidance is provided by independent sub-systems. In the LAAS, vertical and horizontal guidance are derived from the same ranging information. Therefore, the LAAS MASPS uses the combined value of 2×10^{-7} per approach, and sub-allocates 0.5×10^{-7} per approach to the H_0 and H_1 hypotheses. H_0 is the fault free case and H_1 is the case of a single RR failure in the ground station. The remainder of the allocation, 1.5×10^{-7} , is sub-allocated between failures in ranging sources and "all other ground station failures." Failures due to ranging sources, which includes "evil waveforms," local interference, low signal level, code-carrier divergence, excessive acceleration of a pseudorange measurement, and ephemeris error must be detected with a probability of less than 1.4×10^{-7} per approach. "Other failures," which include VDB message corruption, multiple RR failures, LGF failures, and failures due to the local environment, must not exceed 0.1×10^{-7} per approach.

Continuity

Continuity is the probability of an unscheduled interruption of the service provided. The FAA LAAS RD requires the probability of a loss of continuity to not exceed 4×10^{-6} per 15 seconds, for each lateral and vertical dimension. The LAAS MASPS combines the lateral and vertical requirements resulting in a continuity requirement of 8×10^{-6} per 15 seconds. The LAAS MASPS gives an example allocation in Appendix D that sub-allocates between VDB failure and the probability of the lateral or vertical protection level exceeding the lateral or vertical alert limit. There is another level that sub-allocates between a loss of continuity due to a configuration change. A configuration change, for example, is the loss of a ranging source from the position solution. The FAA LGF specification requires the probability of an interruption in the VDB transmission to not exceed 1×10^{-6} per 15 seconds. The MASPS specifies this as 1×10^{-7} per 15 seconds, but RTCA SC-159 recently recommended that this probability be decreased by the same amount that the probability of a loss of continuity with no configuration change should be increased. As an additional measure of robustness, the FAA LGF specification requires the VDB transmitter to transmit 999 consecutive messages in 1000.

The LGF specification allocates 2.3×10^{-6} per 15 seconds as the probability of loss of continuity due to RR failure and ground integrity monitoring for any valid ranging source. The requirement states that a reduction in the number of valid B-values for any valid ranging source constitutes a continuity fault. This ensures that the aircraft will receive the maximum amount of information during an approach.

Coverage

The FAA LAAS RD requires that a usable signal be provided to the aircraft at a distance of 20 nm in the area of operation. An additional requirement is that the LAAS provide precision approach capabilities simultaneously to multiple runways. The FAA LGF specification addresses both issues by requiring an approach coverage volume on a per runway basis, which is wedge shaped and similar to the ILS coverage volume, and requiring that the VDB provide an omni-directional signal down to 12 ft above the ground to 3 nm, except where obstacles mask the VDB signal. In this way, LAAS coverage is guaranteed within the nominal approach region, and where obstacles are do not preclude, a signal is provided for terminal operations and surface navigation in all directions.

LGF OPERATION AND CONTROL

Any navigation aid deployed by the FAA must provide FAA Air Traffic Control (ATC) specialists and

maintenance specialists with the ability to configure, operate, and control the various capabilities of the system. This paper discusses three key areas that are addressed in the LGF specification for the purpose of maintaining and operating the LGF; the Air Traffic Control Unit (ATCU), the Maintenance Data Terminal (MDT) and security.

Air Traffic Control Unit

The ATCU will be integrated into the ATC tower and will provide status information regarding LGF performance. The LAAS RD requires that ATC be provided information on (1) status and configuration of LAAS components and ground equipment, (2) representation of the GPS/LAAS coverage, (3) representation of the level of service being provided to the coverage area, and (4) status of GPS satellites.

The ability to select the runways served by the LGF is the main control function of the ATCU. This feature will allow the ATC specialists to configure the LGF so that Final Approach Segment (FAS) data is broadcast for only the runways that ATC has declared as active runways.

Status information is provided in the tower by a set of visual and aural alarms that indicate the condition of the ground station. The LGF specification addresses two states, On and Off, and three modes, Normal, Not Available, and Test. There are various levels of alerts and alarms related to the modes when the system is in the On state.

An alert is an event triggered by an integrity monitor, but does not require any maintenance action. For example, a ranging source detected to be out of tolerance due to code-carrier divergence would be logged as an alert. ATC will not be informed of alerts in the system.

A service alert requires immediate maintenance action, but the LGF remains operational and can support Category I operations. In most cases, a service alert will notify a maintenance specialist of a hardware failure. The system may be operating on redundant or standby equipment during this time. A service alert is not annunciated to ATC since it is not considered to affect normal operations.

An alarm requires immediate maintenance action and indicates that the system is unavailable to support Category I operations. An alarm usually indicates a failure such that the integrity of the system cannot be guaranteed. The alarm is annunciated at the ATCU and results in the system mode changing from Normal to Not Available. In all cases of an alarm, the LGF will broadcast information to the aircraft to indicate that the signal should not be used. If the LGF cannot guarantee the information in the broadcast, the broadcast must cease. The LAAS RD requires an overall time-to-alarm of 6 seconds. The LGF is allocated 3 seconds from the time of onset of a failure to the time the condition is broadcast.

A constellation alert is based on the overall performance of the ground station while in the Normal Mode (no alarms). This type of alert is intended to predict when an outage may occur based on the number of ranging sources in view, the sigma pseudorange values, the B-values, and assumptions about typical aircraft performance. A constellation alert will warn ATC that an outage is imminent, but approaching aircraft will receive no indication of this until Category I is no longer supported. Since the prediction is targeted to precede the actual outage condition by 20 minutes, ATC can divert aircraft or hold them on the ground until the condition is corrected.

The ATCU will also display the active runways that the LGF is supporting and allow ATC specialists control over which runways are available for precision approach via LAAS. The capability to control 16 runway ends will be provided.

Maintenance Data Terminal

The MDT is the primary means for FAA maintenance specialists to interact with the LGF. The MDT is connected on-site through the Local Status Panel (LSP), and is intended to be similar to a notebook computer or a PC workstation.

A maintenance specialist will have the capability to perform non-intrusive and intrusive diagnostics. Non-intrusive diagnostics do not affect the current LGF operation. Such diagnostics include power levels, frequency of integrity monitor alerts, or availability of standby equipment. Intrusive diagnostics may interfere with the normal operation of the LGF and may cause the LGF to declare itself not available in the event that a latent failure is detected.

In the event the ATCU fails, the capability for a maintenance specialist to configure the active runways is possible through the MDT. Other site-specific parameters are configurable, including VDB power and frequency, TDMA time slot, RR geodetic coordinates, and the reception mask. The MDT provides the capability for changing some parameters in the Type 1 and Type 2 message, and for loading in FAS data points (Type 4 message). All the message types and descriptions are found in the RTCA LAAS Interface Control Document (ICD), DO-246.

Security

Security of the LGF has been addressed in several ways. The FAA LAAS RD requires that the LGF must provide for the physical security of all navigation aids per FAA Order 1600.69. This limits access by having perimeter fences, card readers, and other mechanisms to minimize

intrusions. The FAA LAAS RD further states that a personnel security program must be developed in accordance with FAA Order 1600.1D. This order discusses the granting of access to sensitive information systems, when an information system is considered sensitive, and how limited access is enforced. The security program is intended to prevent an intruder from access to controls with the potential of changing a critical parameter leading to a hazardous situation (e.g., RR geodetic reference coordinates for the LGF).

Limiting access to the critical parameters in the LGF is a security issue. The FAA LGF specification limits input of site specific parameters to when a maintenance specialist is logged on an MDT at the permanent site where the main hardware, (RRs, VDB, transmitter, etc.), are housed. There is a requirement for a Remote Status Panel (RSP), but access to the LGF through this hardware is limited to actions performed while the system is in the Normal or Not Available mode. Changing specific parameters requires the LGF to be in Test Mode first, to ensure that the changes made are thoroughly checked prior to the system coming on-line.

Three access levels are required for the LGF. Level one is for general use, and allows for the user to request and read information only. Level two allows for read and write capability by a certified maintenance specialist. Level three is the administrative level with access restricted to supervising personnel. The LGF will accommodate up to 24 user ID and password combinations.

FAA MAINTENANCE CONCEPT

The FAA LAAS RD specified a Mean-Time-Between-Failures of 2190 hours. The LGF specification satisfies this requirement by specifying the mean time between unscheduled maintenance actions be 2190 hours. This allows for redundant elements to fail which may not require immediate corrective maintenance. The Mean-Time-to-Repair (MTTR) is specified to be less than 30 minutes. This is consistent with the LAAS RD minimum requirement for service availability of 99.9 percent averaged over a year.

The RD specifies that maintenance be performed at the sub-system Line-Replaceable Unit (LRU) level, and not the component level. Therefore, a failed LRU must be identified, removed, and replaced within 30 minutes. Failed LRUs will be reordered and refurbished as needed by the FAA depot maintenance specialists or the manufacturer.

Periodic maintenance of the LGF cannot interrupt service for more than eight hours per year and is limited to four visits per year by a maintenance specialist. Periodic maintenance for external LGF equipment is limited to two visits per year.

Occasionally, a maintenance visit may include changing site-specific parameters, such as adding new FAS data or

modifying LGF integrity monitor alert and alarm thresholds. In this situation, the LGF will be operating in the Test Mode. The test message keeps users from inadvertently using the signal while the system is undergoing maintenance activity. Flight inspection aircraft may use LAAS avionics that have the capability to decode the signals in test mode to enable various test procedures to be conducted.

SUMMARY

The FAA PT 1 LGF Specification was signed on September 21, 1999 and defines the requirements for the performance, design, control and maintenance of Category I LAAS based on the FAA LAAS RD. The LGF specification requirements are consistent with all of the relevant standards and documents including the ICAO SARPS and the RTCA LAAS MASPS.

The FAA GPS Product Team, AND-730 is in Stage 1 of a Government Industry Partnership with two companies to develop and field LAAS according to the requirements spelled out in this specification. Under this partnership, the LGF will be developed with industry funding and in-kind resources from the FAA. Type Acceptance must be granted before any systems are commissioned for public use. The FAA has an implementation plan, spelled out clearly in the NAS Architecture Plan, version 4.0. Additionally, the FAA Joint Resource Council (JRC) recommended that LAAS be developed by industry and purchased as a commercial off-the-shelf item. The requirements defined in this specification are the minimum requirements necessary for the FAA to field an LGF that is interoperable with ICAO standards, meets FAA and ICAO performance standards, provides necessary air traffic control interfaces, and provides for a maintenance program applicable to current maintenance standards.

FUTURE WORK

Stage 0 of the LAAS GIP is expected to continue in fall 2000 with the FAA Performance Type 2/3 LGF. The challenges in meeting the stringent integrity requirements for PT 3 will be a primary consideration. Figure x provides an illustration of how more stringent the CAT III integrity requirements are compared to CAT I. These calculations are based on the GPS satellite geometries observed outside of Washington, DC on January 16, 2000. The upper and lower curves are calculated VPL values for GAD B3 and GAD C4 LGF RR configurations, respectively. GAD B3 represents the minimum RR configuration for a CAT I LGF. It should be noted that although the GAD C4 provides greater accuracy its VPL values are comparable to that of GAD B3. They are comparable because the CAT III VPL contains a larger fault-free state missed-detection buffer. Since the CAT

III vertical alert limit is almost one-half that for CAT I, its margin for no-fault alerts is one-half that for CAT I, see Figure 2.

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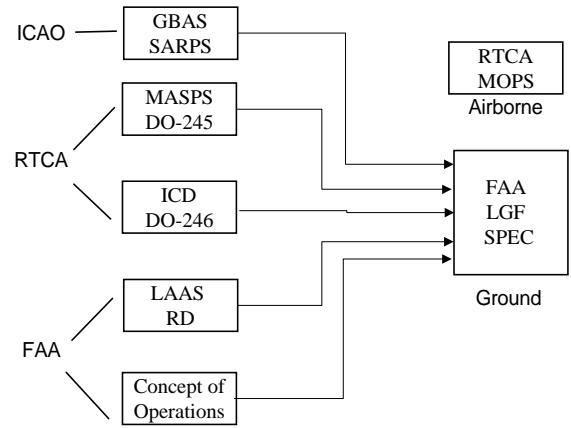


Figure 1. LGF Specification Relationship to Other LAAS Requirements

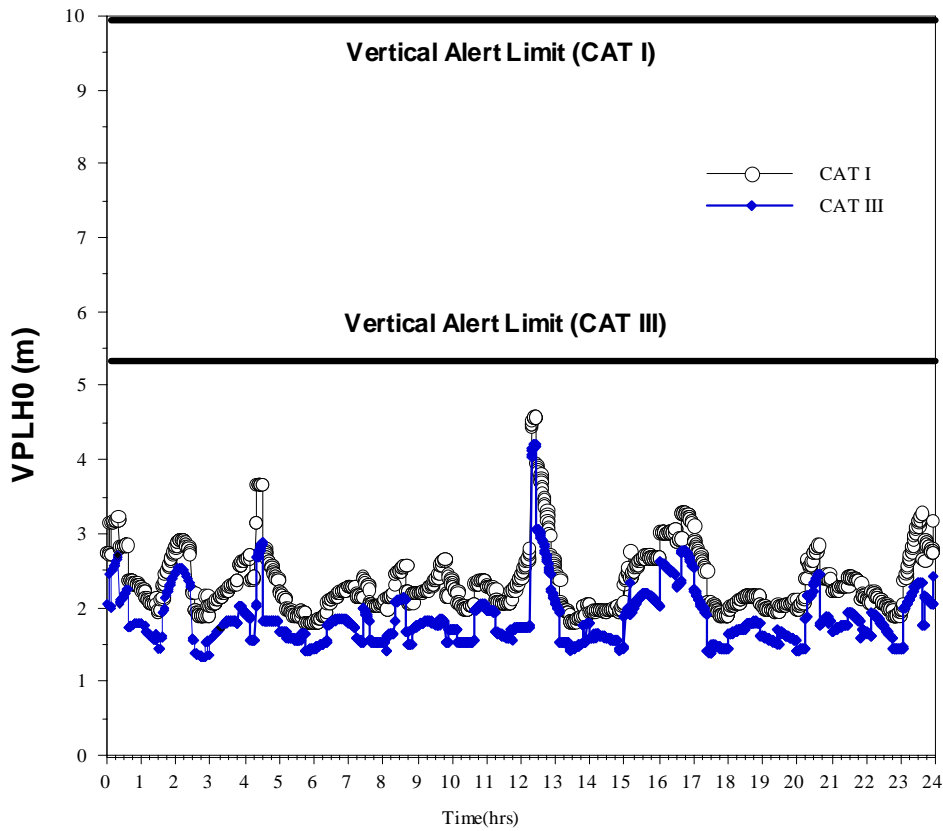


Figure 2. Vertical Alert Limit Comparison between Category I and Category III.