Federal Aviation Administration

Ground Based Augmentation System

Performance Analysis and Activities Report

Reporting Period: April 1 – June 30, 2015

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1. Introduction

The Ground Based Augmentation System (GBAS) team under the direction of the Navigation Branch (ANG-C32) in the Engineering Development Services Division in the Advanced Concepts and Technology Development Office at the Federal Aviation Administration's (FAA) William J Hughes Technical Center (WJHTC) provides this GBAS Performance Analysis / Activities Report (GPAR).

This report identifies the major GBAS related research, testing, and validation activities for the reporting period in order to provide a brief snapshot of the program directives and related technical progress. Currently, the GBAS team is involved in the validation of the GAST-D ICAO SARPs, long-term ionospheric monitoring, supporting system design approval activities for an update to the CAT-I approved Honeywell International (HI) Satellite Landing System (SLS-4000), and observing trends and anomalies utilizing the FAA's Local Area Augmentation System (LAAS) Test Prototype (LTP) (Internationally standardized as GBAS), six Ground Based Performance Monitors (GBPM), and prototype Honeywell Satellite Landing System here at Atlantic City International Airport (ACY).

Objectives of this report are:

a) To provide status updates and performance summary plots per site using the data from our GBPM installations
b) To present all of the significant activities throughout the GBAS team
c) To summarize significant GBAS meetings that have taken place this past quarter
d) To offer background information for GBAS

2. GBAS Updates by Site

The GBPM was designed and built by ANG-C32 to monitor the performance of our GBAS installations. There are currently six GBPM's in use. They are located in Newark New Jersey (EWR), Houston Texas (IAH), Moses Lake Washington (MWH), Rio de Janeiro Brazil (GIG), and two in Atlantic City New Jersey (ACY). The GBPM is used to monitor integrity, accuracy, availability, and continuity of the LTP and Honeywell's SLS-4000. The plots in each of the following sections utilize a compilation of data collected at one minute intervals. For live, up-to-date data, refer to http://laas.tc.faa.gov. A more detailed description of the GBPM configuration can be found in Appendix D of this report.

2.1 EWR SLS

- Newark Liberty Int'l Airport has a Honeywell SLS-4000 that was granted operational approval on September 28, 2012
- Since the EWR SLS-4000 went live until June 2015, there have been 815 GBAS approaches conducted

Figure 1 - EWR SLS-4000 Configuration

2.1.1 Real Time Performance Data

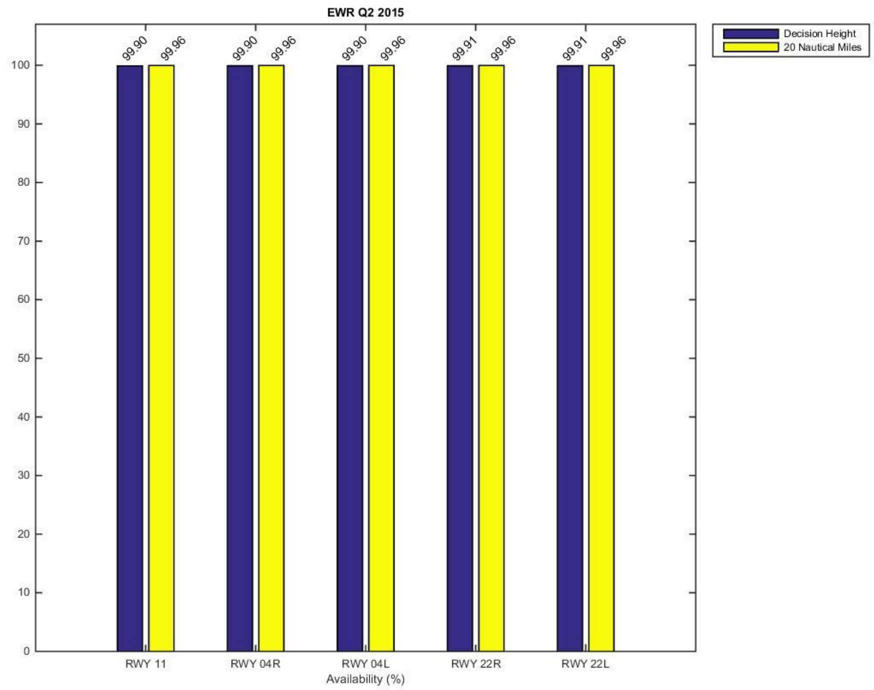


Figure 2 - EWR Availability - The data shown is based upon times when the SLS was transmitting corrections

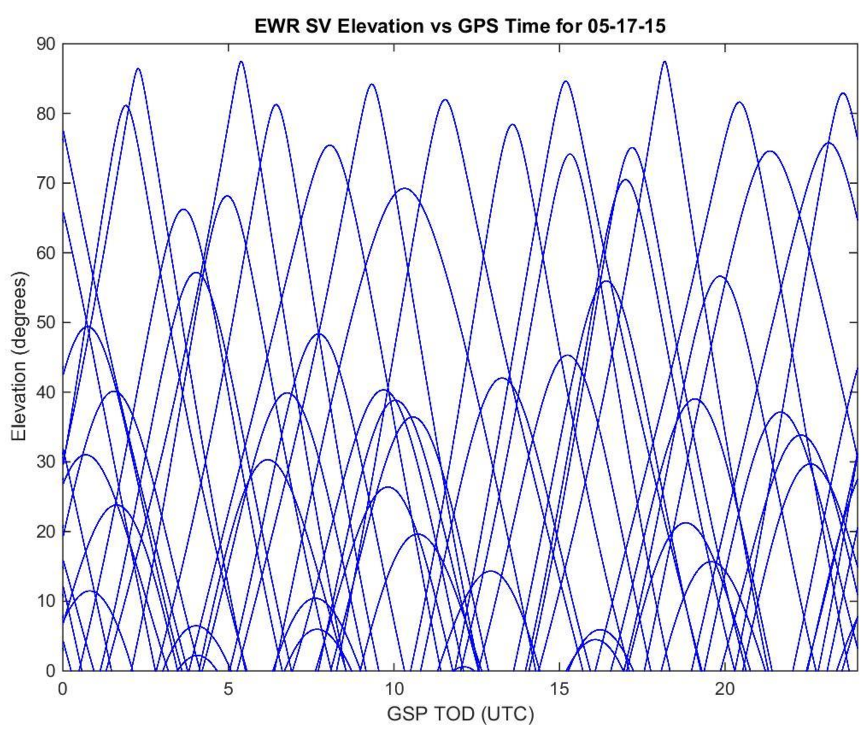


Figure 3 - EWR SV Elevation vs GPS time 05/17/15

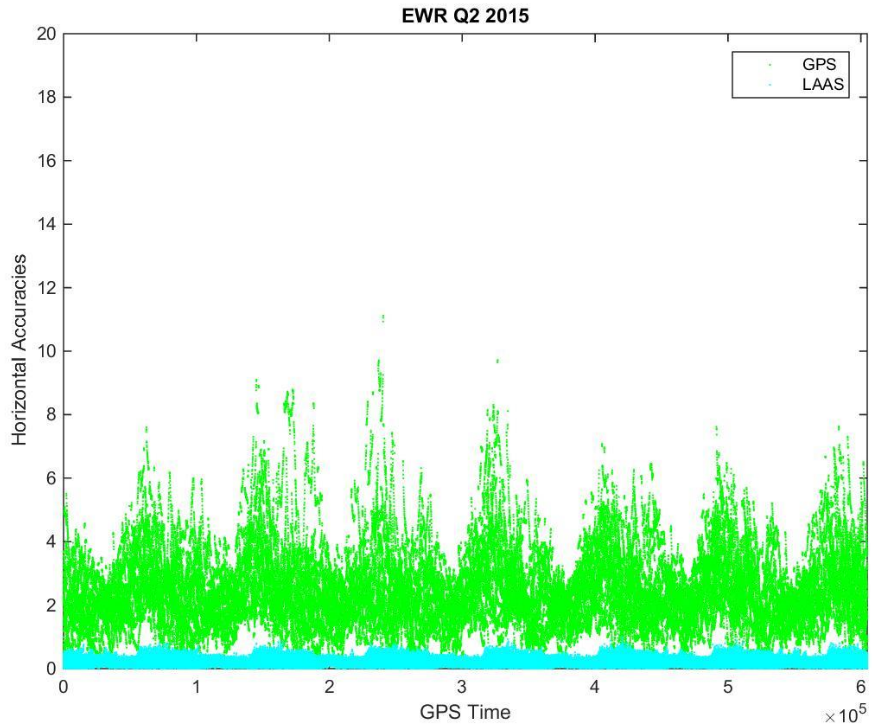


Figure 4 - EWR Horizontal Accuracy Plot

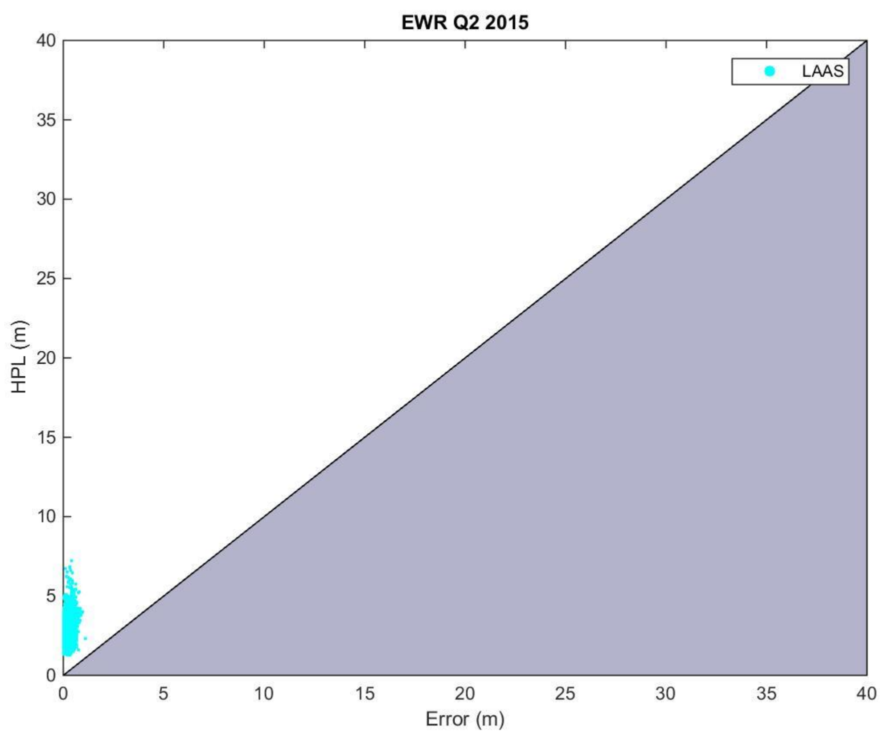


Figure 5 - EWR Horizontal Accuracy vs. Error

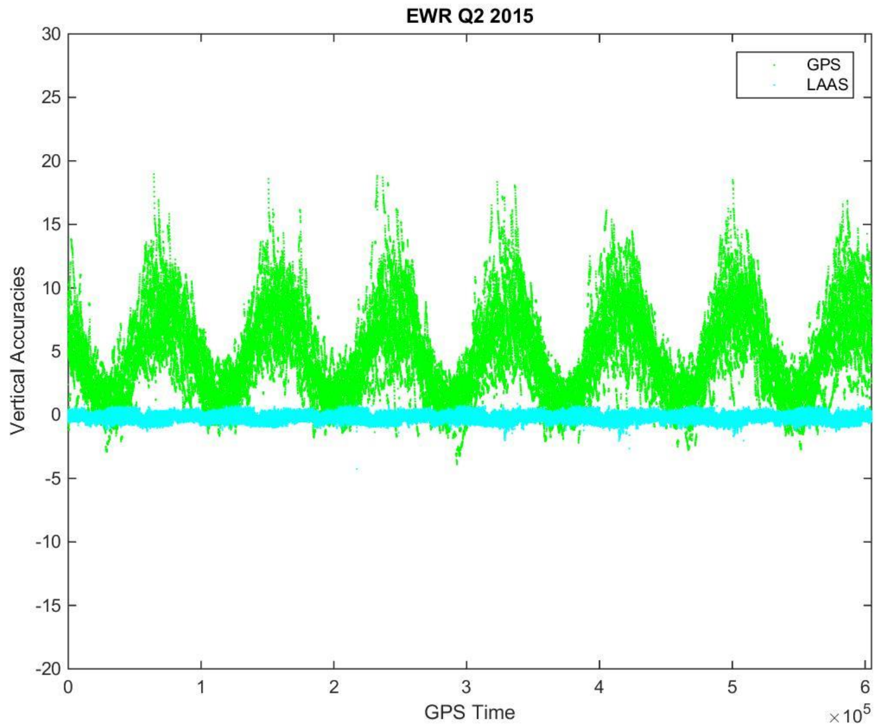


Figure 6 - EWR Vertical Accuracy

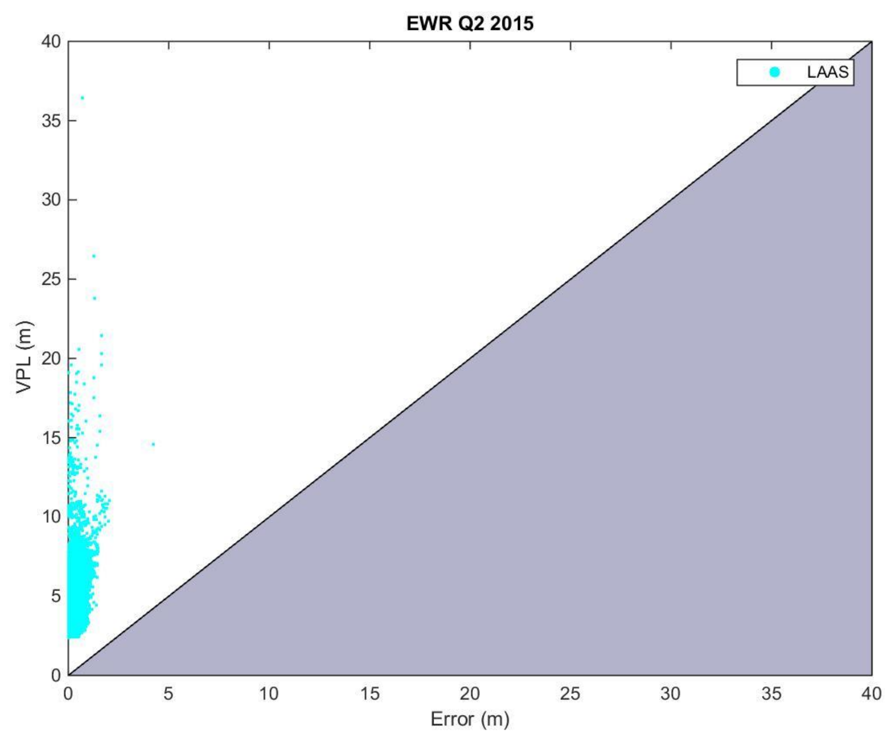


Figure 7 - EWR Vertical Accuracy vs. Error

2.2 IAH SLS

- George Bush Intercontinental Airport in Houston, TX has a Honeywell SLS-4000 that was granted operational approval on April 22, 2013
- Since the IAH SLS-4000 went live until June 2015, there have been 1,022 GBAS approaches conducted

Figure 8 - IAH SLS-4000 Configuration

2.2.1 Real Time Performance Data

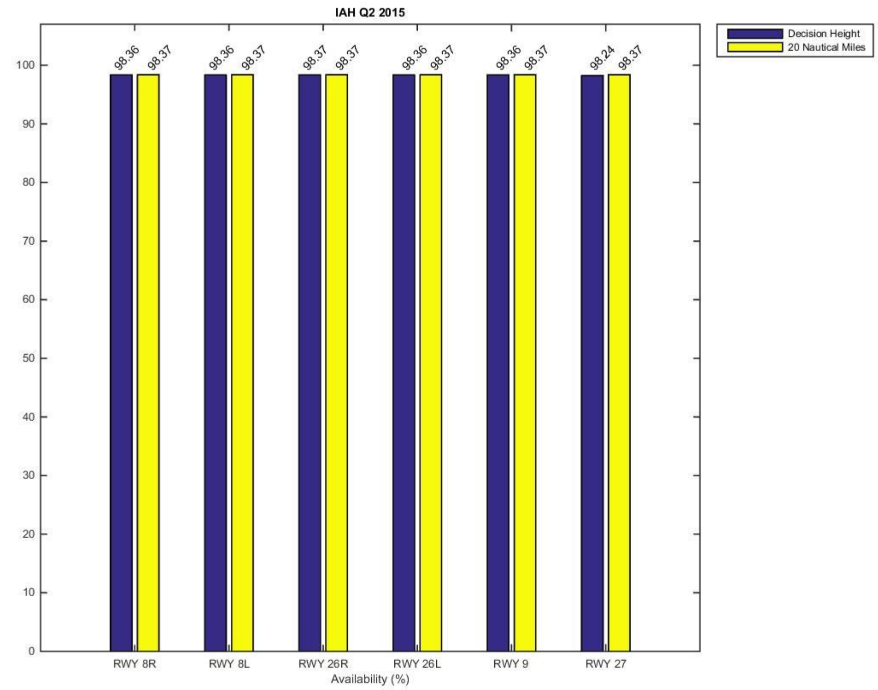


Figure 9 - IAH Availability - The data shown is based upon times when the SLS was transmitting corrections

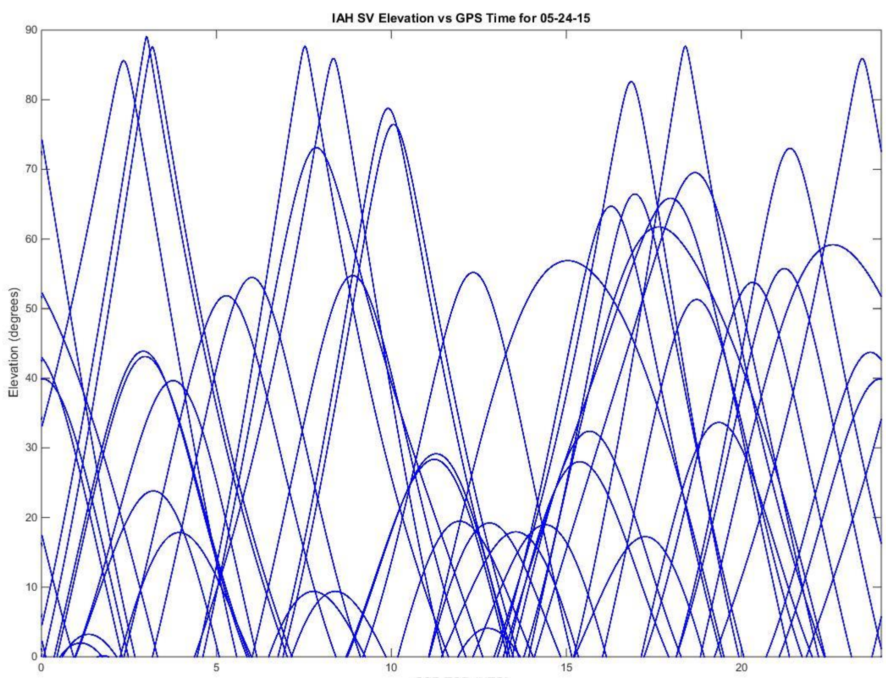


Figure 10 - IAH SV Elevation vs GPS time 05/24/15

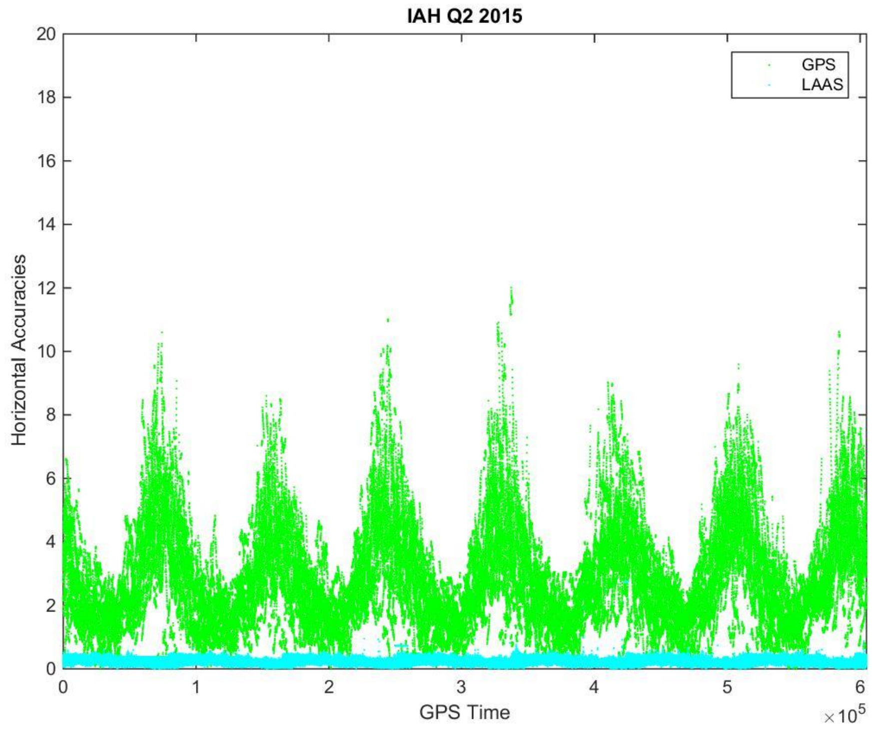


Figure 11 - IAH Horizontal Accuracy Plot

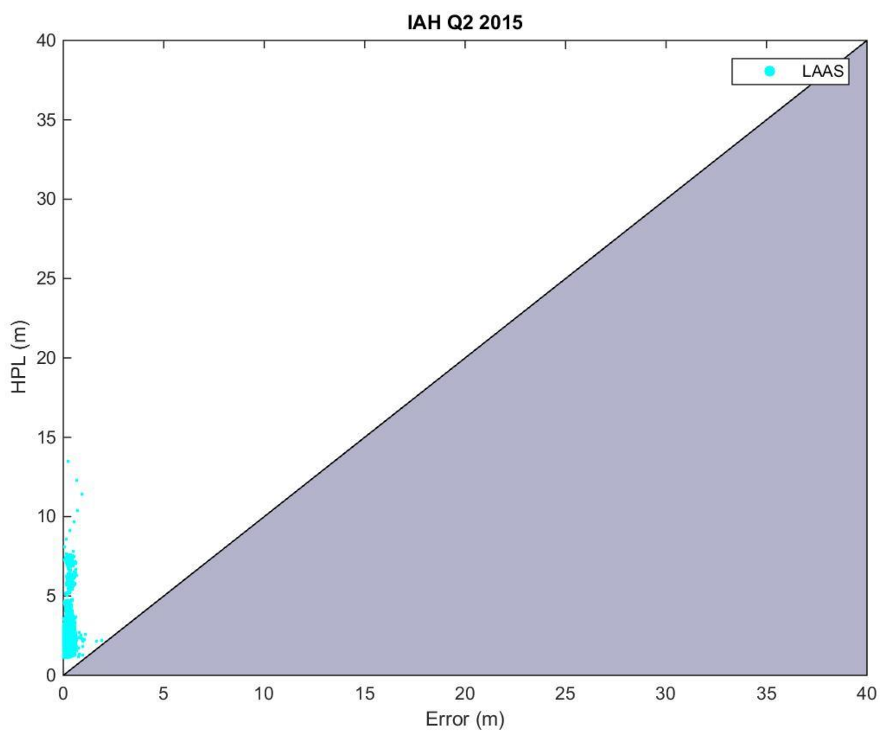


Figure 12 - IAH Horizontal Accuracy vs. Error

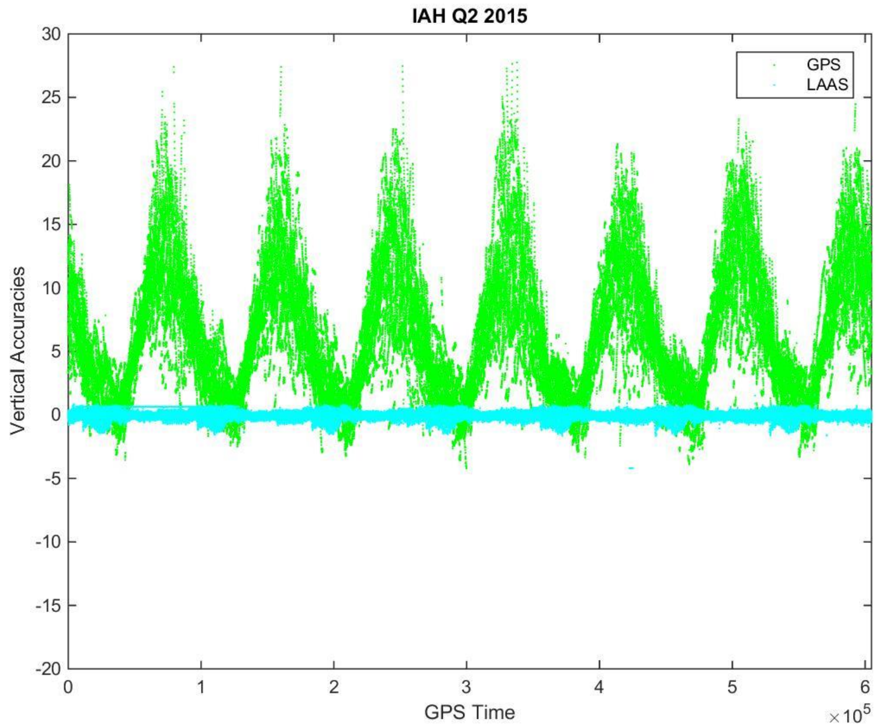


Figure 13 - IAH Vertical Accuracy

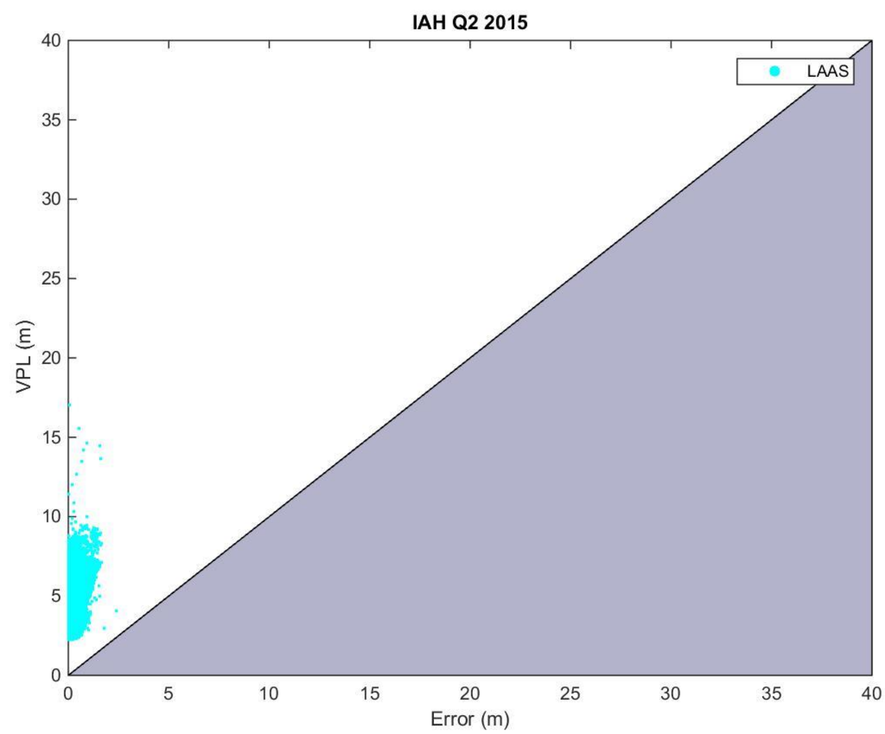


Figure 14 - IAH Vertical Accuracy vs. Error

2.3 MWH SLS

- Grant County Airport in Moses Lake, WA has a private-use Honeywell SLS-4000 that was granted operational approval on January 9, 2013
- Boeing uses this site for aircraft acceptance flights and production activities
- Boeing has also operated this site in a prototype GAST-D mode for flight testing to support GAST-D requirements validation
- While Grant County Airport (GEG) is a public use airport, it has no commercial flights

Figure 15 - MWH SLS-4000 Configuration

2.3.1 Real Time Performance Data

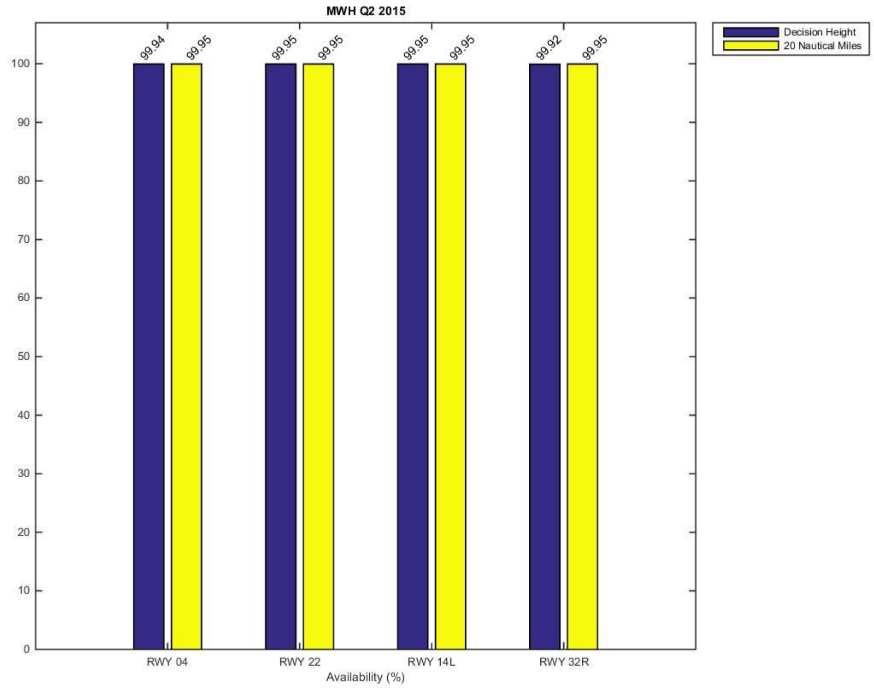


Figure 16 - MWH Availability – The data shown is based upon times when the SLS was transmitting corrections

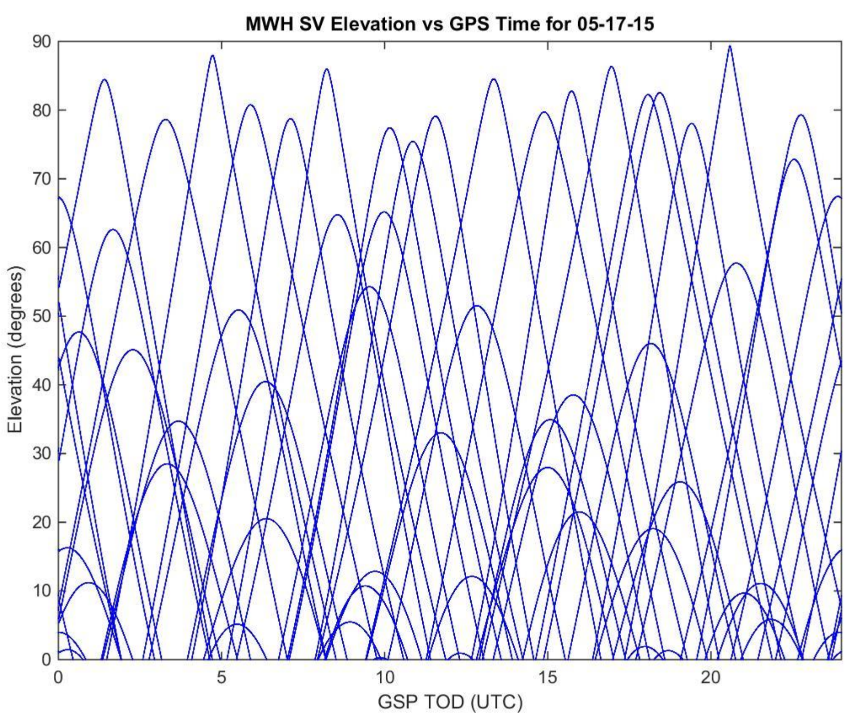


Figure 17 - MWH SV Elevation vs GPS time 05/17/15

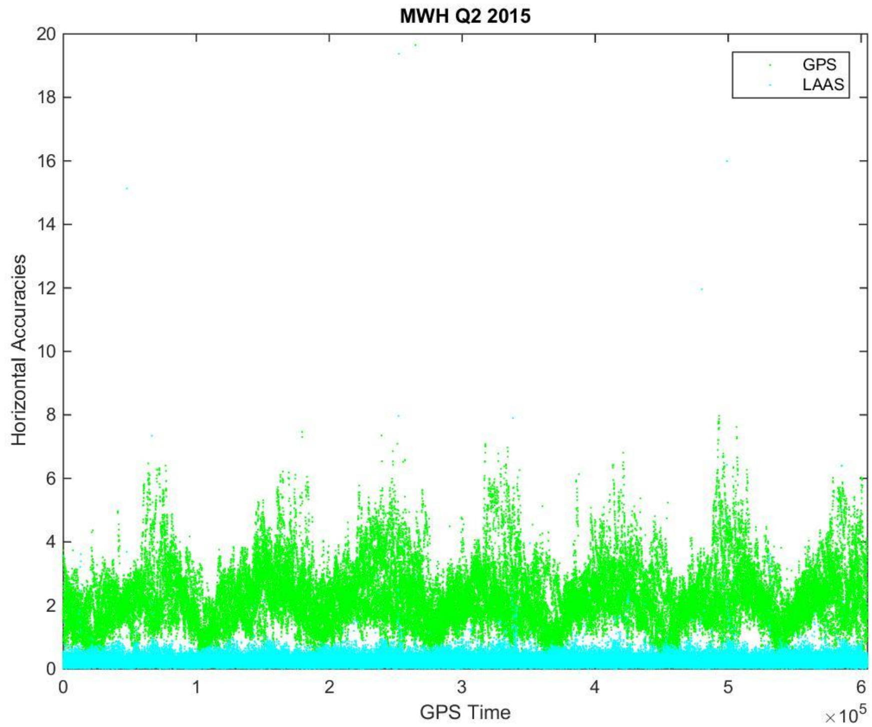


Figure 18 - MWH Horizontal Accuracy Ensemble Plot

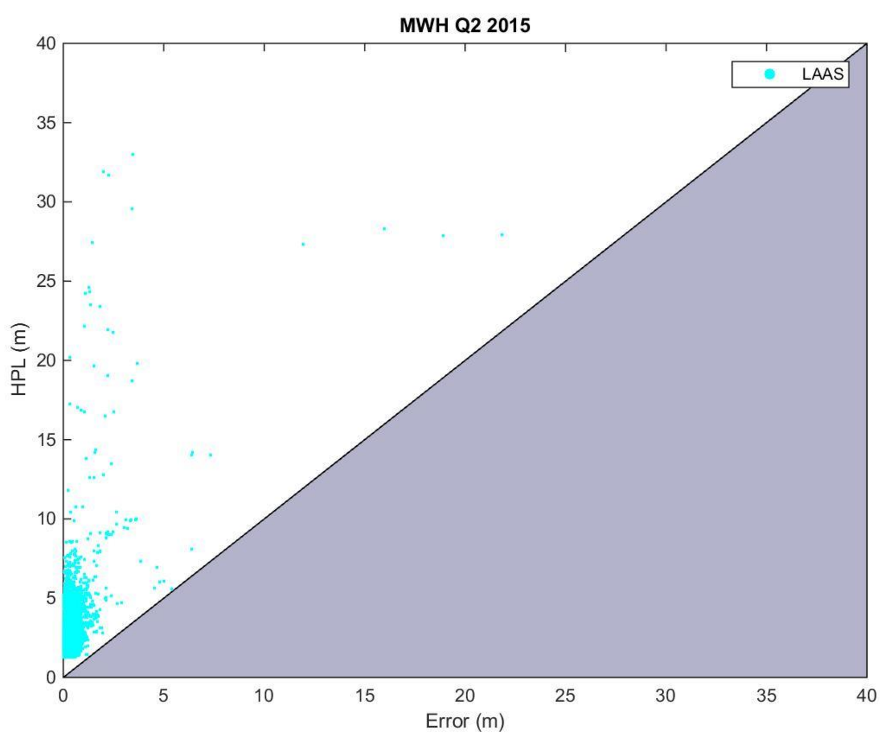


Figure 19 - MWH Horizontal Accuracy vs. Error Bounding Plot

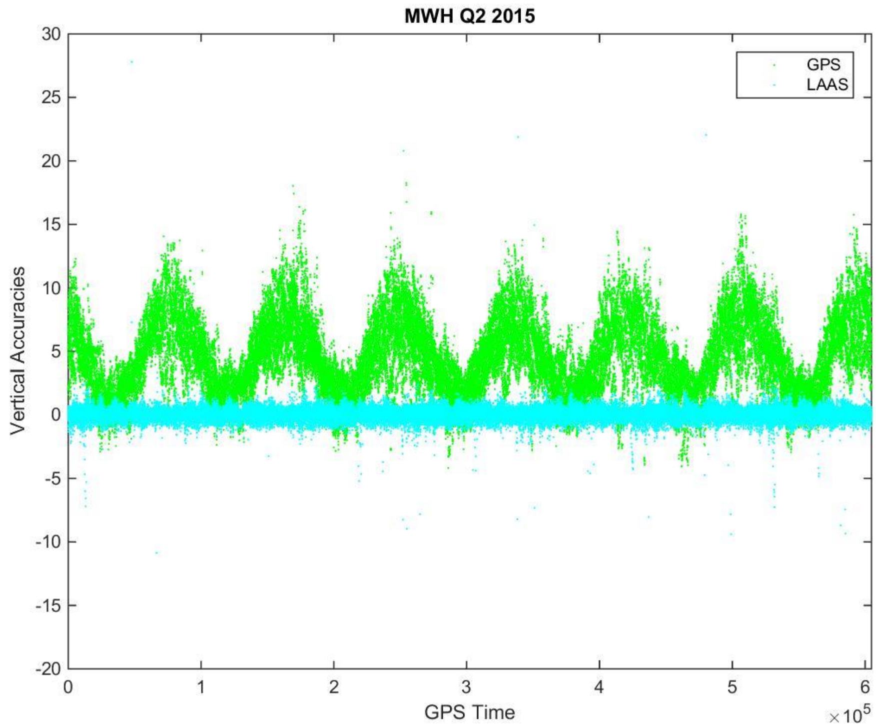


Figure 20 - MWH Vertical Accuracy

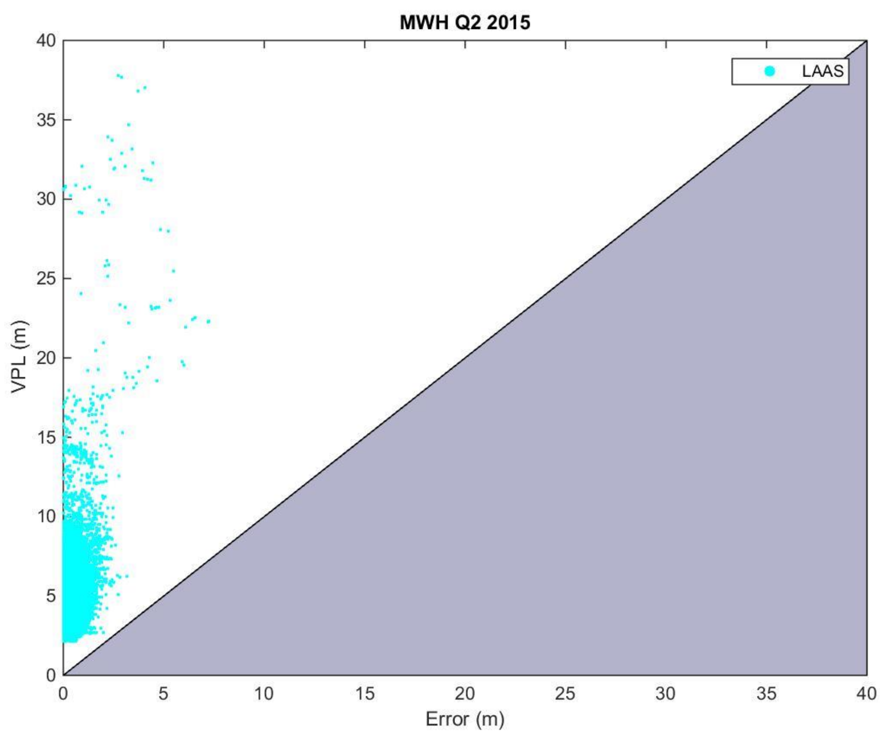


Figure 21 - MWH Vertical Accuracy vs. Error Bounding Plot

2.4 Rio de Janeiro Brazil

- GBAS is a Honeywell SLS-4000 operating in a CAT-I Block II prototype mode
- The antenna on the Brazil monitor is less robust than the other sites, therefore satellites below 11 degrees may not be tracked as consistently
- The data from this quarter only spans from April 1 - May 11, 2105 due to a router issue in Brazil

2.4.1 Real Time Performance Data

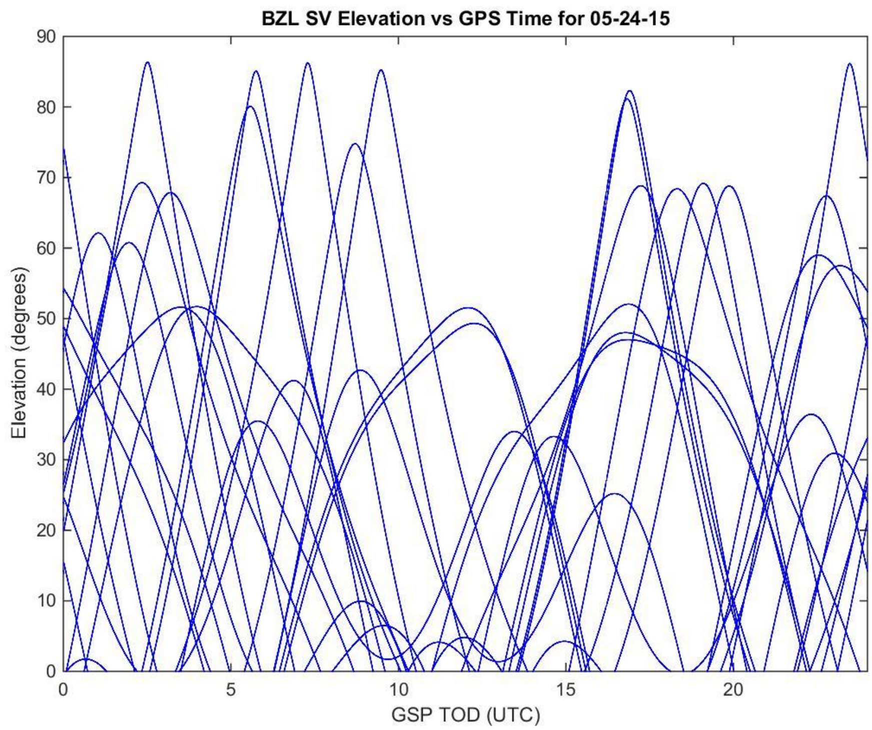


Figure 22 - BZL SV Elevation vs GPS time 05/24/15

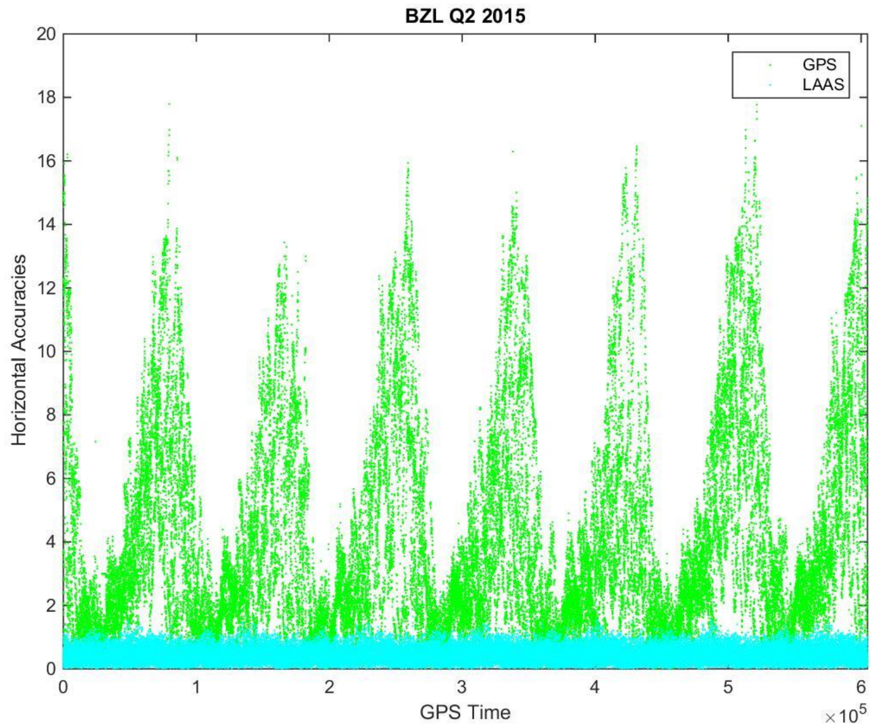


Figure 23 - BZL Horizontal Accuracy Ensemble Plot

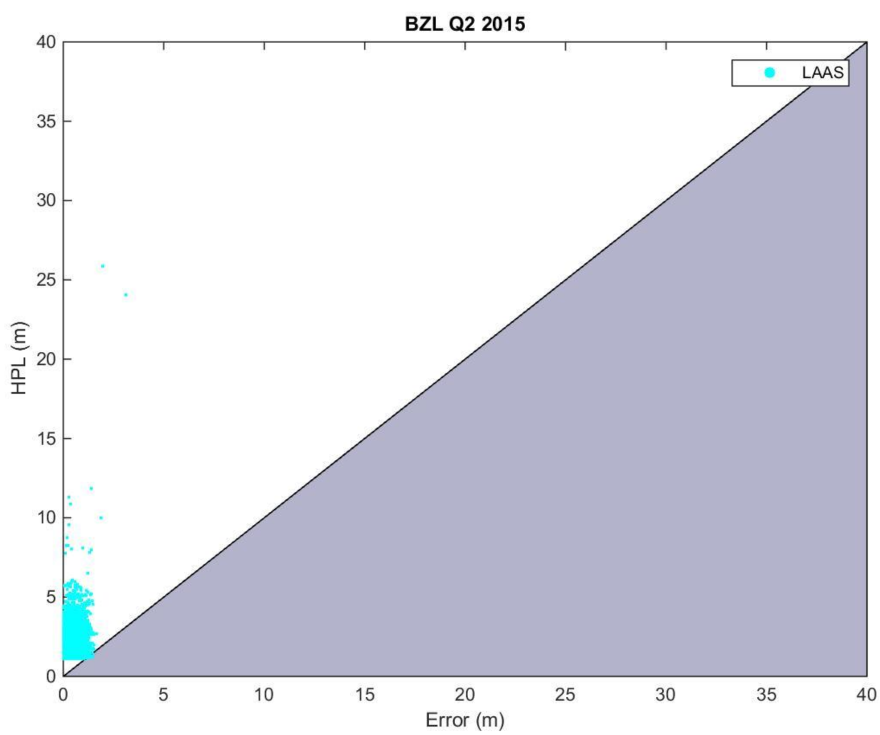


Figure 24 - BZL Horizontal Accuracy vs. Error Bounding Plot

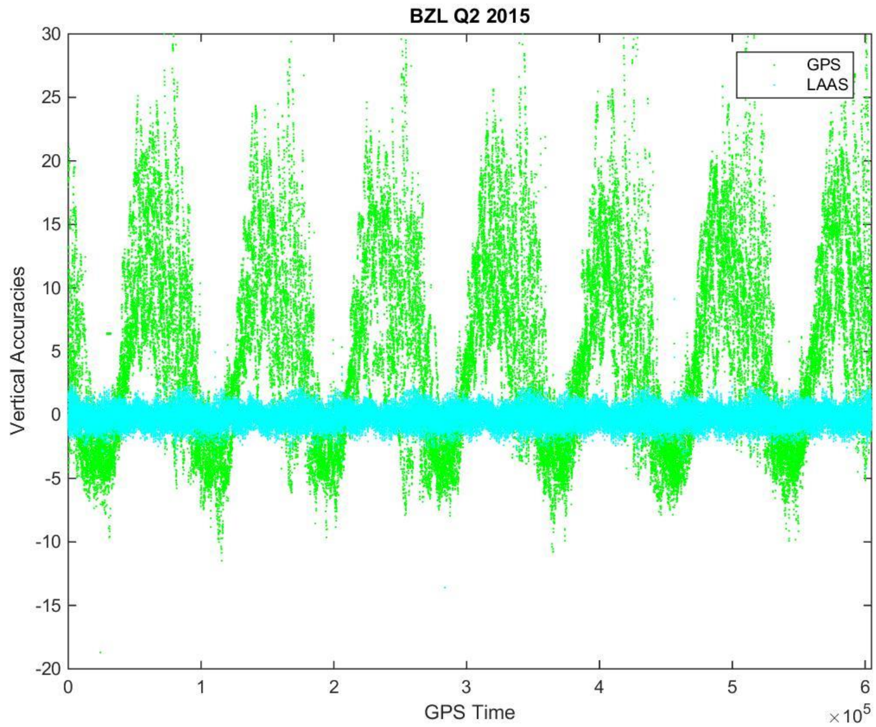


Figure 25 - BZL Vertical Accuracy

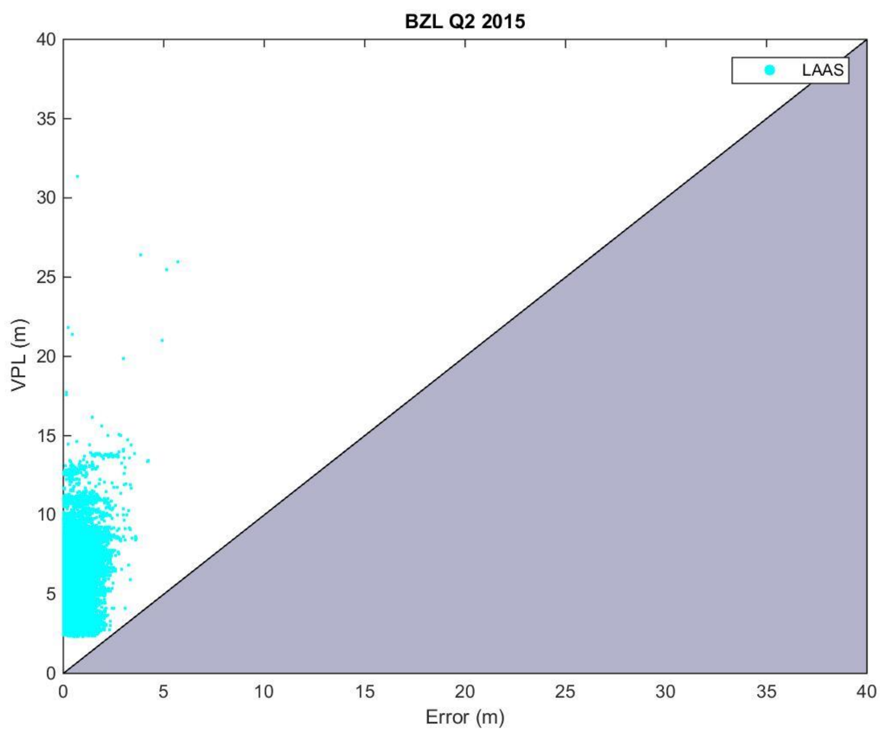


Figure 26 - BZL Vertical Accuracy vs. Error Bounding Plot

2.5 ACY SLS

- The SLS is currently configured for CAT-I Block II for Operational Evaluation and ICMS testing
- See sections 3.2 and 3.2.1 for additional details on the tests performed this quarter

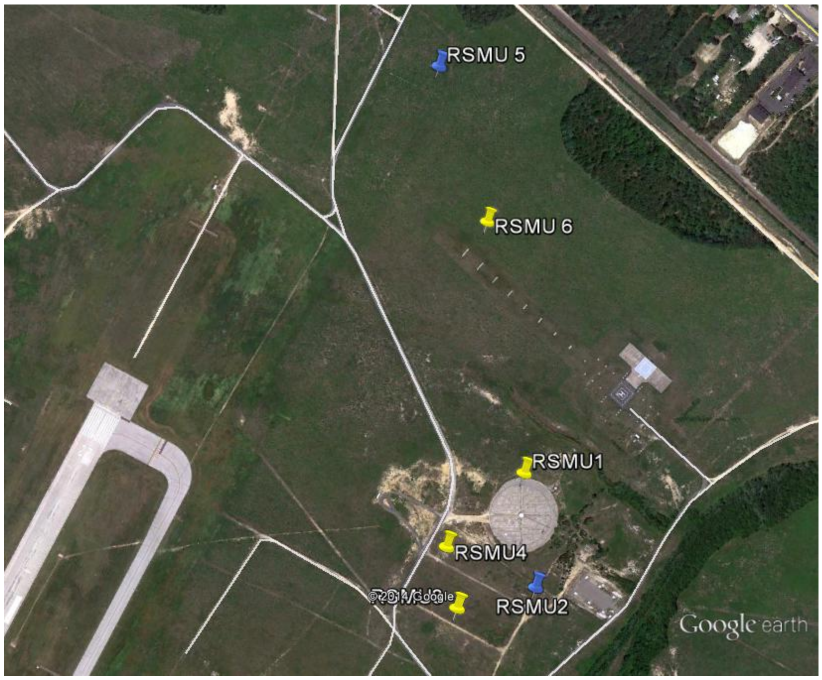


Figure 27 - ACY SLS-4000 Configuration

2.5.1 Real Time Performance Data

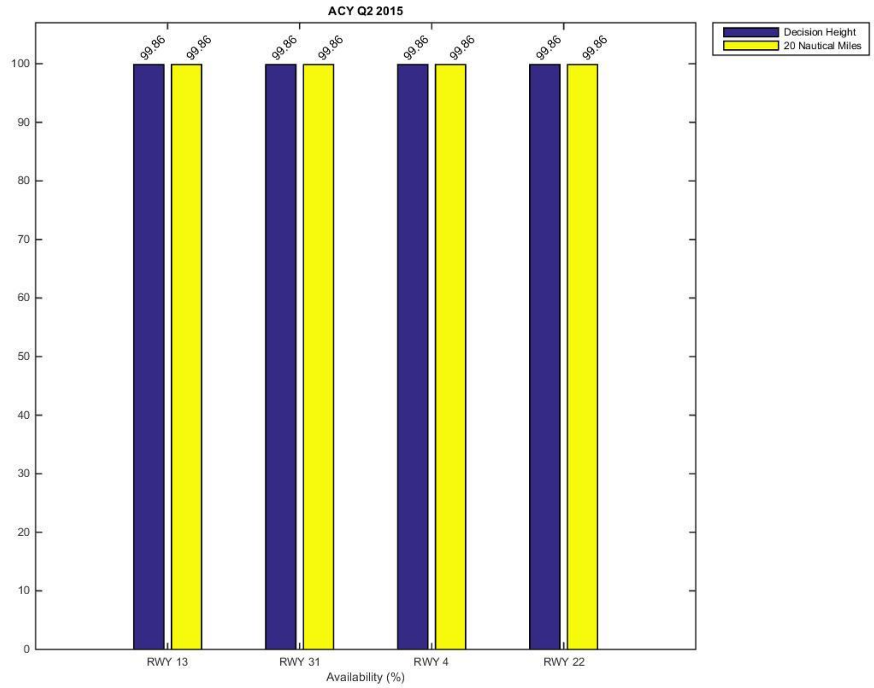


Figure 28 - ACY Availability - The data shown is based upon times when the SLS was transmitting corrections

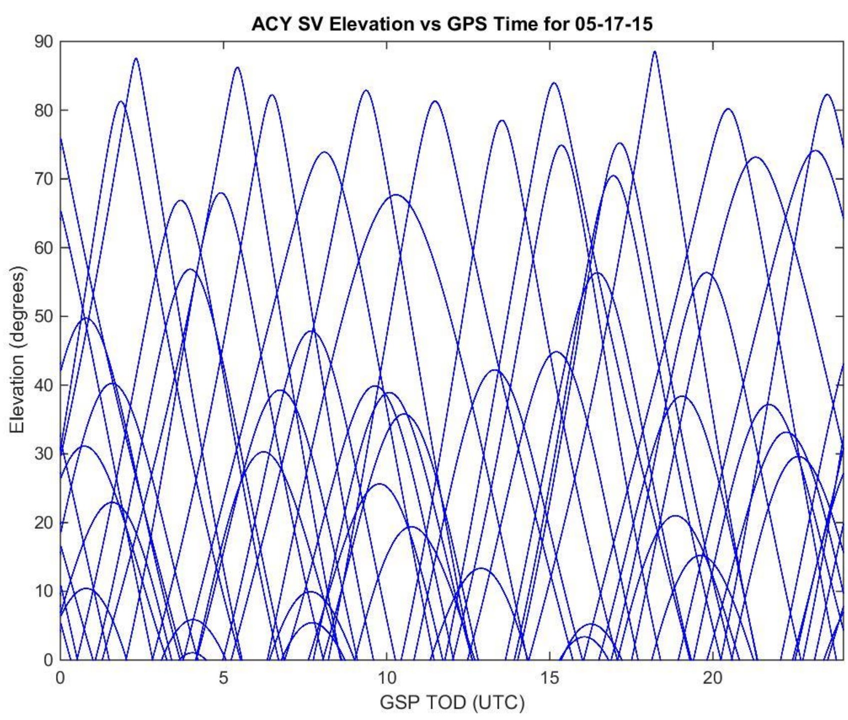


Figure 29 - ACY SV Elevation vs GPS time 05/17/15

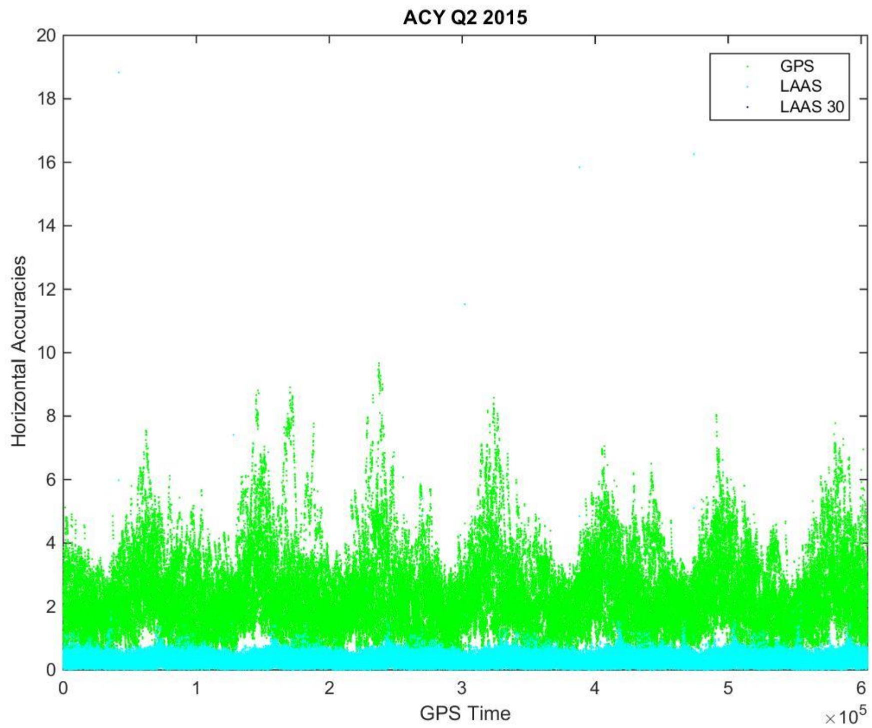


Figure 30 - ACY SLS Horizontal Accuracy Ensemble Plot

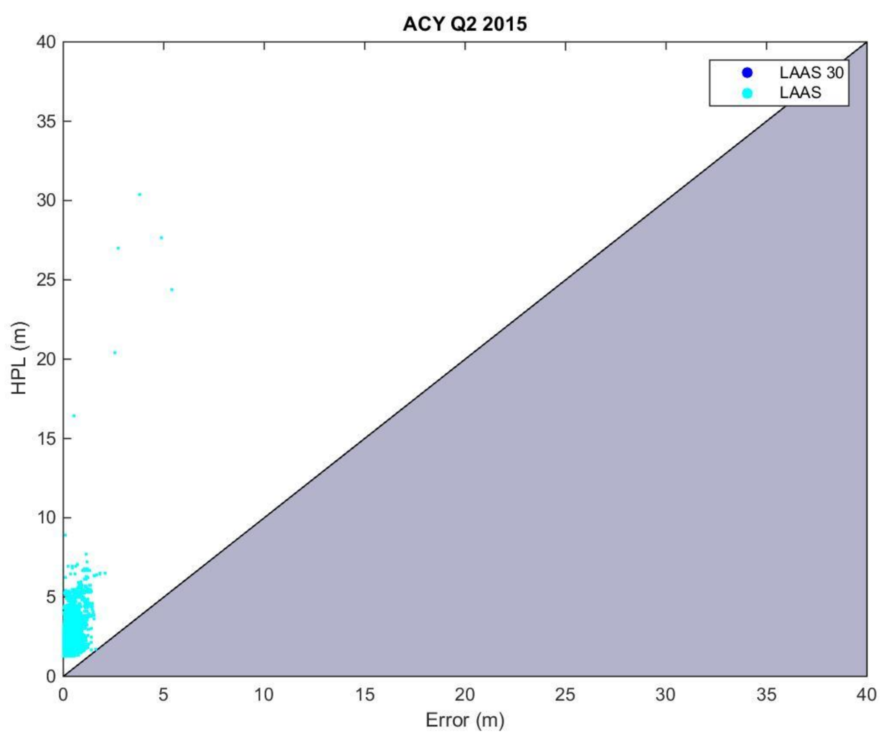


Figure 31 - ACY SLS Horizontal Accuracy vs. Error Bounding Plot

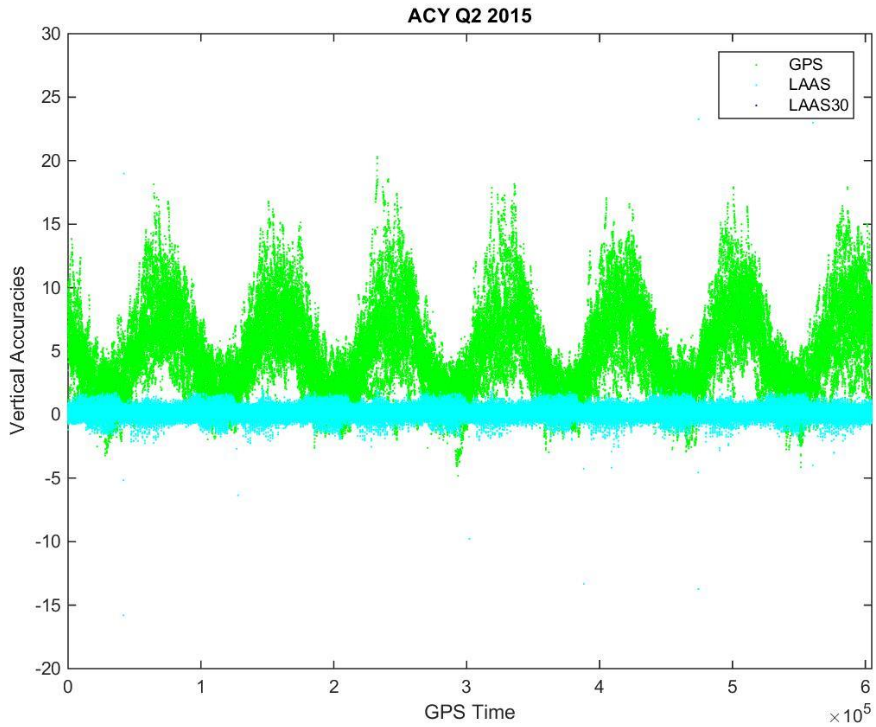


Figure 32 - ACY SLS Vertical Accuracy Ensemble

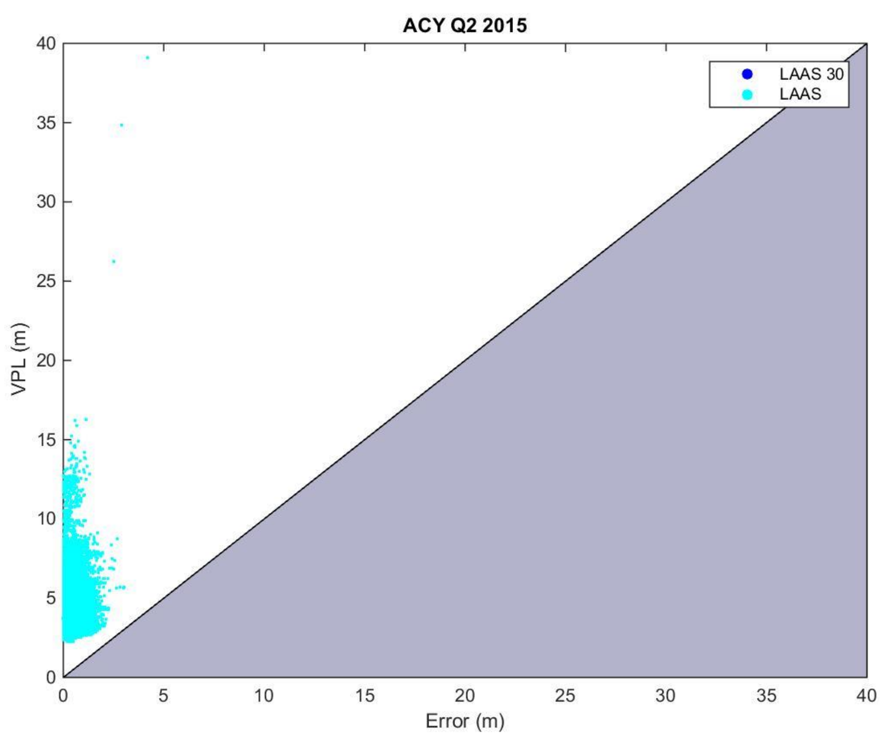


Figure 33 - ACY SLS Vertical Accuracy vs. Error Bounding Plot

2.6 LTP ACY

- The LTP has not been operational this quarter due to ongoing repairs
- See Appendix C for a full description of the LTP configuration

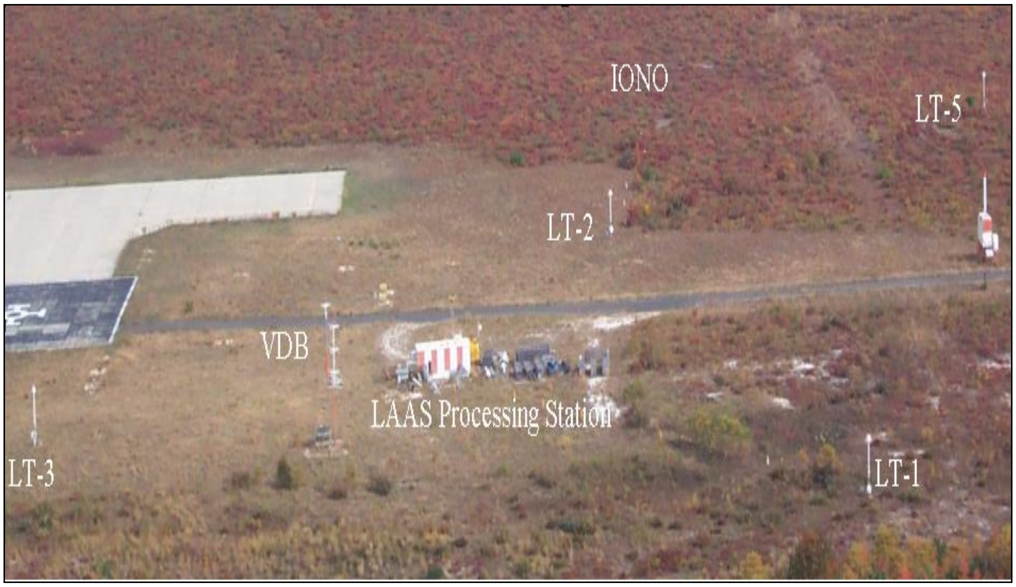


Figure 34 - Aerial View of LTP Configuration

3. Research, Development, and Testing Activities

3.1 System Verification Block-II SDA Activity

Test Procedure Conduct Audit
Location: Honeywell International Aerospace, Coon Rapids, Minnesota
Dates: May 5th through May 7th, 2015

Background:

During the opening period of the SDA conduct for the Block-II version of the SLS-4000 GBAS, which is ongoing, the FAA Systems Verification Team was responsible for reviewing and providing concurrence (or non-concurrence) for all System Segment Specification (SSS) line items on three Stages of Involvement (SOI).

1. Requirement Review
2. Test Case Review
3. Test Procedure and Results Review

All stages are critical to review, for instance if the requirement is faulted so are the next two stages. That said, however, the final proof whether it be an; analysis, a test/demo, or an inspection, all results are evidenced from the Test Procedure Result files. Analysis or inspection type procedures are easily verified through computer generated or other documented artifacts. A test/demo type procedure, in this case, is generally nothing more than an ASCII results file based on a series of manual and/or semi-automated input/outputs that the FAA reviewer never had the opportunity to witness. This makes a Test Procedure Conduct Audit desirable.

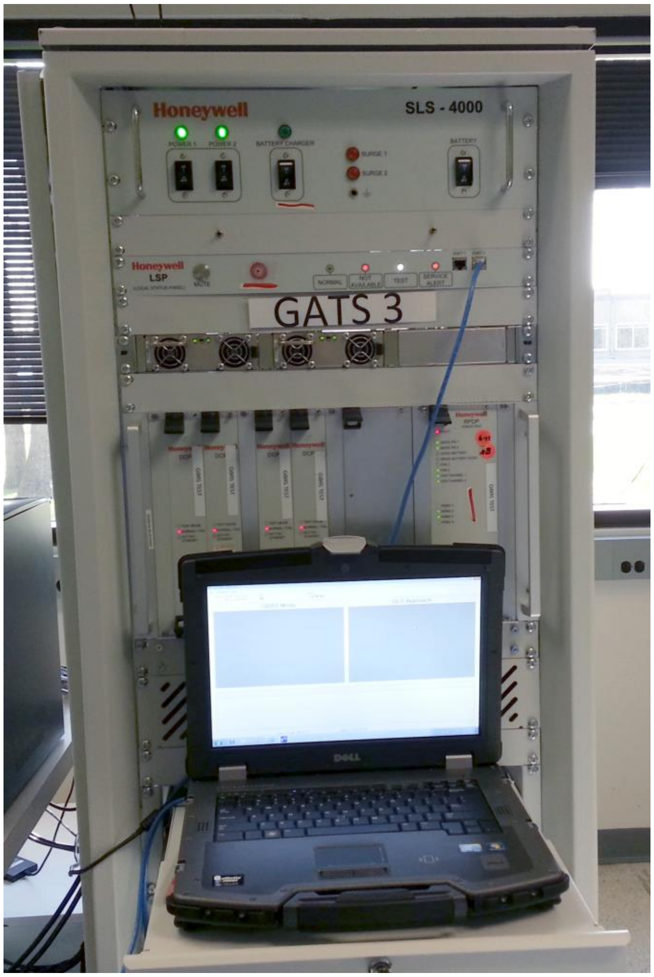
Planning:

Since the FAA SDA team performs an Operational Evaluation (Op-Eval) and Flight Testing against the candidate Block-II software on its own SLS-4000 GBAS at ACY it was unnecessary to have the Honeywell team perform many of the test/demo Test Procedures while in Coon Rapids. The FAA team instead focused on the test procedures that are difficult, if not impossible, to adequately replicate in a field setting.
These included scenarios involving;

1. Maximum Ranging Sources (18)
2. Excessive RFI (Multiple)
3. Code Carrier Divergence (Multiple)
4. Scintillation Monitor
5. Carrier Rate (Multiple)
6. Auto HSI w/ SBAS Simulator
7. Sector/Reception Masking (Multiple)
8. Bubble Time Scheduling (Multiple)
9. Excessive Acceleration (Multiple)
10. Sigma Events
11. CHI Squared
12. 2- B-Values / (ADD-11)

Test Conduct and Environment:

Testing was performed on a conforming Block-II candidate configured SLS-4000 test station using playback data that either had the necessary characteristics required for a given test, or had been simulated or altered for the purposes of a given test.



A total of 26 Test Procedures were run in the 3 day period. One procedure was particularly lengthy (most took about 15 minutes to a ½ hour) and had to be run overnight; this was an RSMU 1 and 2 sector masking routine referred to as TP01244. This procedure was troublesome and failed on multiple attempts, but was found to have a bug in the adaptation file and was easily remedied afterward. All the other 25 Test Procedures passed with little to no incident.

3.2 GBAS Operational Evaluation Testing

The Operational Evaluation was intended to analyze the operation of the Honeywell SLS-4000 system CAT-I Block II configuration (Part Number YG4031EA03), which was installed, operated, and evaluated, based on the manufacturer's Commercial Instruction Book (Document #10165326-103).

Procedural testing was conducted at the Honeywell facility in Coon Rapids, MN, with some tests witnessed from May 5th-7th, 2015. Procedures were also conducted using the GBAS installed at the William J. Hughes Technical Center from May 4-15th. Results from these tests were shown to PASS.

Flight Testing was also performed from May 18th-29th to demonstrate coverage and test other configuration changes, and any effects on airborne receivers (MMR and INR). Analysis was also done to observe outputs in regards to displays and annunciations outside of DMAX for purposes of Extended Service Volume (ESV) discussions, and receiver operation versus requirements.

As part of the testing, the system was required to satisfy a 14-day Stability Test, under normal configuration and conditions. Data was collected and analyzed, with a resultant report generated.

3.2.1 ICMS Testing

Testing was conducted at the William J. Hughes Technical Center from June 8th-10th, 2015.

The goal of the testing was to verify the updates to the ICMS PSA were satisfactory in handling changes to the Honeywell SLS-4000 in version Block 2 configuration, as well as backwards-compatible with Block 1. While in the Block 2 SW configuration, the testing also included verification when the SLS-4000 had Satellite Based Augmentation System (SBAS) enabled, as well as periods that SBAS was disabled. The testing also verified the able to manage the maximum number of Aircraft Approach Blocks that the GBAS would transmit. A maximum number of 48 Final Approach Segments (FAS) in Block 2, and 26 FAS in Block 1, can be installed and broadcast by the SLS-4000 GBAS.

The test was conducted using both the primary and secondary networks connected to individual Ethernet switches. A laptop was connected to both networks simulating an ICMS consolidator. The consolidator simulated inputs and outputs from several other typically found devices on the same network. In addition, a second laptop was connected to the network that simulated an ICMS display.

During the testing, normal operation and fault conditions were both checked to make sure proper colors and wording appeared on the ICMS display.

Honeywell SLS-4000 Block 2 SW with SBAS Enabled: PASS
Honeywell SLS-4000 Block 2 SW with SBAS Disabled: PASS
Honeywell SLS-4000 Block 1 SW: PASS

3.3 GBAS GAST-D Validation Status Update

The changes made to the ICAO SARPS to support GAST-D (i.e. GBAS approach service to CAT-III minima using augmentation of the GPS L1 signal) were conditionally accepted at an April 2015 ICAO NSP (Navigation Systems Panel) meeting. More validation work is required for several requirements relating to ionospheric gradient monitoring and VDB compatibility with other systems. Ad-hoc groups have been formed to address these issues, and are meeting regularly via teleconference. The goal is to wrap up the necessary work by late fall and to obtain final acceptance of the GAST-D SARPS at the December 2015 ICAO NSP meeting. ANG-C32 will take part in these calls, and support validation efforts where possible.

The FAA's initial planned efforts to support validation of the GAST-D ICAO SARPS relied heavily on two prototyping contracts, both with Honeywell International (HI), to produce a GAST-D capable ground system and GAST-D avionics. The avionics prototyping contract was complete as of January 2013; the ground system prototyping contract was completed on May 22 of this quarter. All deliverables from this contract have now been received. Honeywell will continue to work GAST-D under their own System Design Approval (SDA) program, and continues to contribute to the ongoing validation work at ICAO and participate in RTCA meetings.

3.4 Notice Advisory to Navstar Users (NANUs)

The GPS constellation is designed to provide adequate coverage for the continental United States for the majority of the sidereal day. A NANU is a forecasted or reported event of GPS SV outages, and could cause concern if the SV outage(s) creates an insufficient geometry to keep the protection levels below the alert limits. See **Table 4** below for a list of NANU types.

NANUs that caused an interruption in service where Alert Limits are exceeded will be highlighted within the NANU summary (see **Table 5**). Although such an interruption is unlikely, the GBAS team closely tracks the NANUs in the event that post-data processing reveals a rise in key performance parameters.

NANU Acronym	NANU Type	Description
FCSTDV	Forecast Delta-V	Satellite Vehicle is moved during this maintenance
FCSTMX	Forecast Maintenance	Scheduled outage time for Ion Pump Ops / software testing
FCSTEXTD	Forecast Extension	Extends a referenced "Until Further Notice" NANU
FCSTSUMM	Forecast Summary	Gives exact time of referenced NANU
FCSTCANC	Forecast Cancellation	Cancels a referenced NANU
FCSTRESCD	Forecast Rescheduled	Reschedules a referenced NANU
FCSTUUFN	Forecast Unusable Until Further Notice	Scheduled outage of indefinite duration
UNUSUFN	Unusable Until Further Notice	Unusable until further notice
UNUSABLE	Unusable	Closes an UNUSUFN NANU with exact outage times
UNUNOREF	Unusable with No Reference NANU	Resolved before UNUSUFN issued
USABINIT	Initially Usable	Set healthy for the first time

LEAPSEC	Leap Second	Impending leap second
GENERAL	General Message	General GPS information
LAUNCH	Launch	Recent GPS Launch
DECOM	Decommission	Removed From constellation

Table 1 - NANU Types and Definitions

NANU	TYPE	PRN	Start Date	Start Time (UTC)	End Date	End Time (UTC)
2015024	FCSTDV	16	04/15/2015	15:30	04/16/2015	03:30
2015025	FCSTSUMM	16	04/15/2015	16:08	04/15/2015	21:20
2015026	FCSTDV	05	04/21/2015	20:45	04/22/2015	08:45
2015027	FCSTDV	18	04/24/2015	00:00	04/24/2015	12:00
2015028	USABINIT	26	04/20/2015	22:22	N/A	N/A
2015029	FCSTSUMM	05	04/21/2015	21:29	04/22/2015	03:49
2015030	FCSTCANC	18	04/24/2015	00:00	N/A	N/A
2015031	FCSTDV	18	04/30/2015	23:30	05/01/2015	11:30
2015032	GENERAL	08	04/30/2015	N/A	N/A	N/A
2015033	FCSTSUMM	18	05/01/2015	00:31	05/01/2015	05:33
2015034	FCSTDV	02	05/12/2015	18:00	05/13/2015	06:00
2015035	FCSTSUMM	02	05/12/2015	18:09	05/13/2015	01:46
2015036	UNUSUFN	04	05/19/2015	12:46	N/A	N/A
2015037	UNUSABLE	04	05/19/2015	12:46	05/19/2015	14:38
2015038	FCSTDV	09	05/28/2015	13:30	05/29/2015	01:30
2015039	LEAPSEC	N/A	N/A	N/A	N/A	N/A
2015040	FCSTSUMM	09	05/28/2015	14:00	05/28/2015	19:15
2015041	FCSTDV	21	06/05/2015	03:00	06/05/2015	15:00
2015042	UNUNOREF	27	06/03/2015	06:03	06/03/2015	06:06
2015043	FCSTMX	25	06/11/2015	14:15	06/12/2015	02:15
2015044	FCSTDV	31	06/11/2015	09:20	06/11/2015	21:20
2015045	FCSTSUMM	21	06/05/2015	03:27	06/05/2015	08:57
2015046	FCSTMX	27	06/15/2015	13:00	06/16/2015	01:00
2015047	FCSTSUMM	31	06/11/2015	09:52	06/11/2015	15:04
2015048	FCSTSUMM	25	06/11/2015	14:52	06/11/2015	18:12
2015049	FCSTMX	24	06/17/2015	11:00	06/17/2015	23:00
2015050	FCSTMX	26	06/19/2015	00:00	06/19/2015	12:00
2015051	FCSTSUMM	27	06/15/2015	13:32	06/15/2015	16:55
2015052	FCSTMX	06	06/19/2015	20:00	06/24/2015	08:00
2015053	FCSTMX	30	06/25/2015	16:00	06/26/2015	04:00
2015054	FCSTDV	20	06/26/2015	02:30	06/26/2015	14:30
2015055	FCSTSUMM	24	06/17/2015	11:29	06/17/2015	14:46
2015056	FCSTSUMM	26	06/19/2015	00:47	06/19/2015	03:46
2015057	UNUNOREF	31	06/22/2015	19:19	06/22/2015	19:23
2015058	FCSTSUMM	06	06/23/2015	20:54	06/24/2015	01:15
2015059	FCSTMX	03	06/30/2015	17:00	07/01/2015	05:00
2015060	FCSTMX	09	07/01/2015	19:30	07/02/2015	07:30
2015061	FCSTSUMM	30	06/25/2015	16:58	06/25/2015	20:40
2015062	FCSTSUMM	20	06/26/2015	02:40	06/26/2015	08:40
2015063	FCSTSUMM	03	06/30/2015	18:12	06/30/2015	22:27

Table 2 - NANU Summary

4. GBAS Meetings

4.1 Executive Summary of the International GBAS Working Group

Executive Summary of GBAS Working Group Meeting 16
WJH FAA Technical Center, Atlantic City, NJ, USA
June 1-4, 2015

The 16th International GBAS Working Group (IGWG) was hosted by the FAA at the William J Hughes Technical Centre (WJHTC) in Atlantic City, NJ, USA. The meeting was chaired by FAA and EUROCONTROL (John Warburton, FAA and Andreas Lipp, EUROCONTROL). IGWG Secretaries are Dieter Guenter, FAA (NAVTAC) and Lendina Smaja, EUROCONTROL. About ninety-five (95) participants from fifteen (15) nations, international service providers, industry, airlines and aircraft manufacturers attended the meeting and working sessions.

In her welcome, Shelly Yak, acting director of the FAA WJHTC noted the progress made since the start of GBAS activities at the WJHTC and the extent of analysis and testing capabilities at the Center. She also remarked on the importance of GBAS in the precision approach aid mix and the fact that it is now considered part of the operational systems, given the growing experience with the Houston and Newark installations.

This meeting marked the announcement of a new update of the Honeywell GBAS system, due July 2015, significantly relaxing current operational constraints. Some systems, such as the one in Sydney, are logging over 90 approaches per day. Other airports, notably those in Scandinavia receive up to 30% traffic with GBAS capabilities; as a consequence, Oslo is investigating the transformation of the initially planned experimental system into an operational one. In Russia, the first approaches have been published, notably at Moscow Sheremetjevo. Russia has announced the first GBAS operational flight in December 2014.

The commitment to GBAS development and implementation by participants was impressive, and visible by motivated airline presentations from Delta Airlines, United Airlines and Cathay Pacific. An increased number of GBAS acquisition plans notably at locations in the USA, London Heathrow/UK and confirmation of the Dubai/UAE project were reported. Boeing and Airbus remain strongly committed to GLS and reported an increasing GLS customer base and increased number of GLS equipped aircraft sales, with the number of GLS aircraft having nearly doubled with respect to 2013.

The national updates and SESAR project briefings demonstrated strong continued commitment and activities in implementation of GBAS CAT I; GBAS CAT II/III validation activities and increased research in the potential impact of future multi constellation and dual frequency environment. All of the nations represented have GBAS related activities in one form or another from concept development, research activities to actual implementation.

Airline operations are steadily increasing, United Airlines flies an average of 70 GBAS operations per month at the Houston and Newark facilities. Since the last IGWG Delta Airlines has received operational approval, conducted approaches into Newark and Houston and is evaluating GBAS operations for several US airports. Other operators, among them British Airways, Emirates, Cathay Pacific and Lufthansa also perform GLS approaches on a regular basis to the US installations. In Sydney, Qantas and other operators have integrated GLS into their standard operations. Lufthansa, QANTAS, Emirates and other carriers are flying GLS approaches to Frankfurt. A EUROCONTROL flight-plan analysis shows that over 5% of European approaches are flown using GBAS equipped aircraft, with some airports indicating significantly higher proportions, strongly depending on the interest of the home carrier.

The status reports of service provider plans, users and manufacturers on the first day of the meeting were important and informative. Participants appreciated the possibility to get a concentrated overview of the worldwide state of the activities in a single day. The key value of the GBAS working group continues however to reside in the parallel strings of technical and operational sessions on day two and three, where data collection and evaluation, siting experience and interference mitigation, ionospheric activities, operational plans and future operations are not only exchanged but actively coordinated.

The trend toward operational aspects noticed during the last meetings continued. More than 2/3 of the participants attended the operational working sessions in this meeting. The presence of representatives of regulatory organizations and a large number of active pilots was noted as beneficial to the discussions.

In the operational sessions (CAT I Post Approval Activities and GBAS Future Operations) all aspects of use of the GBAS signals were discussed. A recurring topic was the RNP-GLS transition which is key to address operational improvements and the needs of airports and operators in terms of flight efficiency and environment while maintaining the precision approach capability. CAT II operations on a GAST-C system again emerged as promising for operational benefit.

Several presenters underscored the need to go beyond ILS capabilities and rapidly exploit GBAS potential in noise reduction, shorter approach paths, but also extending the service volume, to which a special working session was dedicated. The capability to provide steeper and multiple approach paths for runway ends - as is possible with GBAS - can be immediately beneficial for noise reduction and wake turbulence avoidance.

The technical sessions (Data and Testing, Ionosphere, Siting, Interference and Ground Monitoring) focused on the transition to operations, with significant feedback experiences in monitoring, notably of the ionosphere, interference, overflights and tools used for GBAS performance assessment. The investigation in effects of ionospheric events remained an important subject, with intensive discussion of GAST-D ionospheric monitoring and the first results towards validation of a Europe-wide threat model. In several areas the work will be continued between I-GWG sessions to progress on the exchange of methods and experiences on more detailed subject matters.

SESAR reported significant progress on its technical and operational efforts with validation results from the GAST-D prototypes now having been recognized by ICAO and the intensifying of work on GBAS dual frequency and multi constellation architecture. The SESAR work now continues into 2016 with the two installed GBAS prototypes and concentrated on increasing coverage and robustness at large, complex airports. A new SESAR project on advanced procedures using GBAS has provided the first results.

All participants were extremely satisfied with the outcome of the working group meeting, especially the members of the pilot community who noted the large amount of time devoted to operational aspects. The I-GWG visibly continued to fulfil a recognized function in GBAS implementation and the format seems well adapted to the participants' needs. This working group addresses relevant issues for the development and implementation of GBAS, and exchanges data and information, which can effectively be used by the participants in formulating their business strategies and implementation plans.

The next meeting will take place in Europe. While the exact location is still open, several options are being reviewed and need to be confirmed. It is currently targeted for February/March 2016.

4.2 ICAO Navigation System Panel (NSP) Summary - Montreal, April 2015

The ICAO Navigation Systems Panel (NSP) agreed to accept final validation for the GAST-D (Category II/III) SARPs, with the exception of the few requirements that still have validation issues and remain open. Those remaining open are the ionospheric gradient mitigation (15 requirements) and the VDB separation criteria related to ILS, VOR and VHF Communications (2 requirements). A total of 700 GBAS and GBAS related SARPs requirements in Annex 10 were reviewed by the Category II/III Subgroup (CSG) and Validation Subgroup (VSG).

The CSG developed a work plan to address the ionospheric gradient mitigation issues, which includes identification of several areas for further analysis. There was also a joint meeting between the CSG and Spectrum Subgroup (SSG) to review the VDB issues. A work plan was developed to address these issues over the next several months. The plan is to attempt to close validation of the 17 open requirements by the December NSP meeting.

The NSP also agreed to the need for a GBAS extended service volume. Operational feedback obtained during the meeting was that GBAS approach services should behave as much like ILS as possible. The plan is that concepts for the extended service volume would be further developed by RTCA SC-159 Working Group 4 in the near term.

Appendix A – GBAS Overview

A.1 GBAS Operational Overview

A GBAS is a precision area navigation system with its primary function being a precision landing system. The GBAS provides this capability by augmenting the GPS with real-time broadcast differential corrections.

A GBAS ground station includes four GPS Reference Receivers (RR) / RR antenna (RRA) pairs, and a Very High Frequency (VHF) Data Broadcast (VDB) Transmitter Unit (VTU) feeding an Elliptically Polarized VDB antenna. These sets of equipment are installed on the airport property where a GBAS is intended to provide service. The LGF receives, decodes, and monitors GPS satellite pseudorange information and produces pseudorange correction (PRC) messages. To compute corrections, the ground facility compares each pseudorange measurement to the range measurement based on the survey location of the given RRA.

Once the corrections are computed, integrity checks are performed on the generated correction messages to ensure that the messages will not produce misleading information for the users. This correction message, along with required integrity parameters and approach path information, is then sent to the airborne GBAS user(s) using the VDB from the ground-based transmitter. The integrity checks and broadcast parameters are based on the LGF Specification, FAA-E-3017, and RTCA DO-253D (Airborne LAAS Minimum Operational Performance Standards or MOPS).

Airborne GBAS users receive the broadcast data and use it to compute standardized integrity results. When tuning the GBAS, the user also receives the approach path for navigation with integrity assured. The GBAS receiver applies corrections to GPS measurements and then computes ILS-like deviations relative to the uplinked path providing guidance to the pilot. Airborne integrity checks compare protection levels, computed via the integrity parameters, to alert levels. Protection levels were determined based on allowable error budgets. The horizontal alert limit is 40m and the vertical is 10m at the GAST-C decision height of 200m. If at any time the protection levels exceed the alert limits, calculated deviations are flagged and the approach becomes unavailable. With the current constellation horizontal protection levels are typically 2.3m and vertical protection levels are typically < 5m with resulting availability of 100%.

One key benefit of the GBAS, in contrast to traditional terrestrial navigation and landing systems (e.g., ILS, MLS, TLS), is that a single GBAS system can provide precision guidance to multiple runway ends, and users, simultaneously. Only the local RF environment limits this multiple runway capability. Where RF blockages exist, Auxiliary VDB Units (AVU) and antennas can be added to provide service to the additional runways.

Figure 42 is provided as an illustration of GBAS operation with major subsystems, ranging sources, and aircraft user(s) represented.

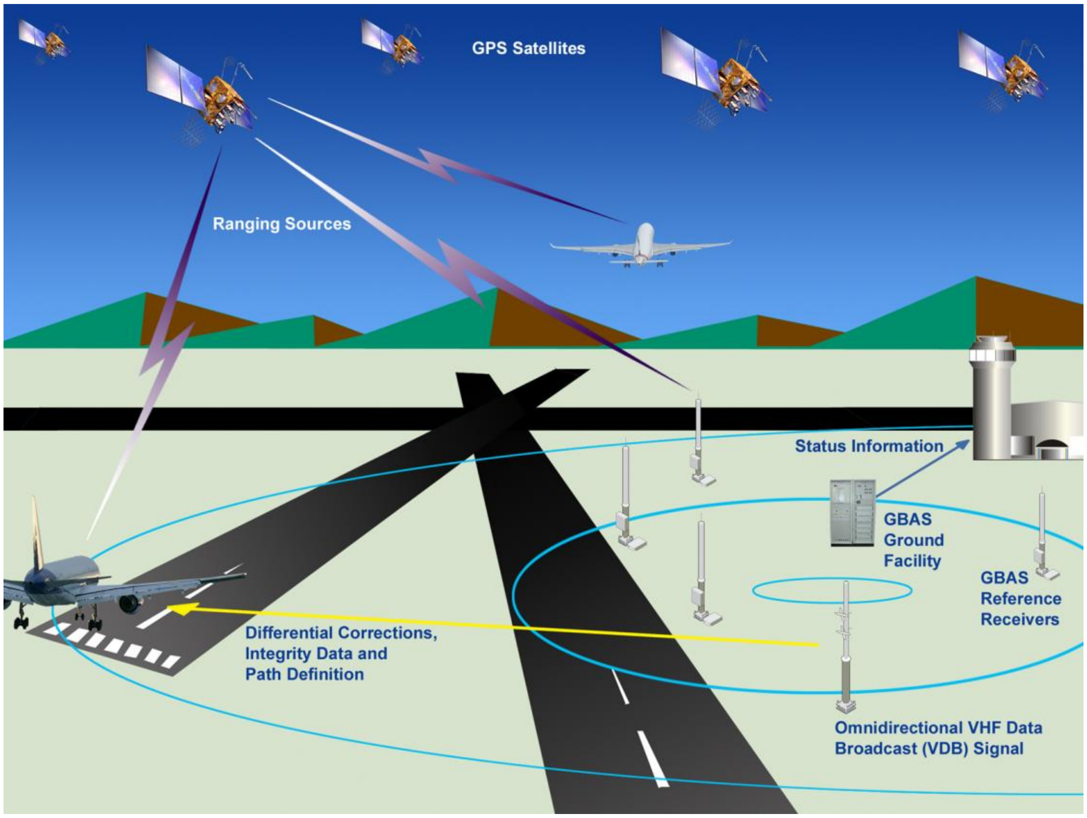


Figure 35 - GBAS Architecture Diagram

Appendix B - GBAS Performance and Performance Type

B.1 Performance Parameters and Related Requirements Overview

The GPS Standard Positioning Service (SPS), while accurate, is subject to error sources that degrade its positioning performance. These error sources include ground bounce multipath, ionospheric delay, and atmospheric (thermal) noise, among others. The SPS is therefore insufficient to provide the required accuracy, integrity, continuity, and availability demands of precision approach and landing navigation. A differential correction, with short baselines to the user(s), is suitable to provide precision guidance.

In addition to accuracy, there are failures of the SPS that are possible, which are not detected in sufficient time and can also cause hazardous misleading information (HMI). GBAS provides monitoring of the SPS signals with sufficient performance levels and time to alarm to prevent HMI.

The relatively short baselines between the user and the GBAS reference stations, as well as the custom hardware and software, is what sets GBAS apart from WAAS. Use of special DGPS quality hardware such as employment of MLA's serves to mitigate the multipath problems, while the GBAS software monitors and corrects for the majority of the remaining errors providing the local user a precision position solution.

The LAAS Ground Facility is required to monitor and transmit data for the calculation of protection parameters to the user. The GBAS specification also requires monitoring to mitigate

Misleading Information (MI) that can be utilized in the position solution. These requirements allow the GBAS to meet the accuracy, integrity, availability, and continuity required for precision approach and landing navigation.

There are three Performance Types (PT) defined within the LAAS Minimum Aviation System Performance Standards (MASPS). The three performance types, also known as Categories, (i.e., Cat I, and Cat II/III), all have the same parameters but with different quantity constraints. For the purposes of this report, the LTP assumes Cat I Alert Limits and hardware classification.

B.2 Performance Parameters

This section highlights the key parameters and related requirements used to depict GBAS system performance in this report. In order to provide the reader a clearer understanding of the plots provided, a little background is being provided below.

Cat I precision approach requirements for GBAS are often expressed in terms of Accuracy, Integrity, Availability, and Continuity. For clarity the use of these four terms, in the context of basic navigation, are briefly described below:

- **Accuracy -** is used to describe the correctness of the user position estimate that is being utilized.

- **Integrity –** is the ability of the system to generate a timely warning when system usage should be terminated.

- **Availability** - is used to describe the user’s ability to access the system with the defined Accuracy and Integrity.

- **Continuity** - is used to describe the probability that an approach procedure can be conducted, start to finish, without interruption.

B.2.1 VPL and HPL

Vertical and Horizontal Protection Levels (VPL and HPL) parameters are actively monitored since the GBAS is required to perform with a worst case constellation and geometry scenario. VPL / HPL parameters are directly tied to constellation geometry and when combined with pseudorange errors affect the SPS position estimate and time bias. Monitoring the VPL and HPL in the GBPM gives a valid picture of what the user is experiencing. The protection levels are compared against the alert limits of the appropriate GBAS service level (GSL). In the event the protection levels exceed the alert limit, an outage will occur (See section 6 for GBAS site specific outages).

B.2.2 B-Values

B-values represent the uncorrectable errors found at each reference receiver. They are the difference between broadcasted pseudorange corrections and the corrections obtained excluding the specific reference receiver measurements. B-values indicate errors that are uncorrelated between RRs. Examples of such errors include multipath, receiver noise, and receiver failure.

B.2.5 Performance Analysis Reporting Method

For a given configuration, the LTP's 24-hour data sets repeat performance, with little variation, over finite periods. The GBAS T&E team can make that statement due to the continual processing of raw LTP data and volume of legacy data that has been analyzed from the LTP by the FAA and academia. Constellation and environmental monitoring, in addition to active performance monitoring tools such as the web and lab resources provide the GBAS T&E team indications for closer investigation into the presence, or suspicion, of uncharacteristic performance.

Data sets from the LTP ground and monitoring stations are retrieved on a weekly basis and processed immediately. A representative data-day can then be drawn from the week of data to be formally processed. The resultant performance plots then serve as a snapshot of the LTP's performance for the given week. These weekly plots are afterward compared to adjacent weeks to select a monthly representative set of plots.

Appendix C - LTP Configuration and Performance Monitoring

C.1 Processing Station

The LTP Processing Station is an AOA-installed operational GBAS system. It is continually operational and is used for flight-testing, in addition to data collection and analysis summarized in this report. As an FAA test system, the LTP is utilized in limited modified configurations for various test and evaluation activities. This system is capable of excluding any single non-standard reference station configuration from the corrections broadcast. The performance reporting of the system is represented only from GBAS standard operating configurations.

C.1.1 Processing Station Hardware

The processing station consists of an industrialized Central Processing Unit (CPU) configured with QNX (a UNIX-type real time OS). It then collects raw reference station GPS data messages while processing the data live. It also collects debugging files and special ASCII files utilized to generate the plots found in this report. These collected files are used for component and system level performance and simulation post processing.

The CPU is also configured with a serial card that communicates in real time with the four reference stations through a Lantronix UDS2100 serial-to-Ethernet converter. The reference stations continuously output raw GPS messages to the CPU at a frequency of 2 Hz. Data to and from the reference station fiber lines is run through media converters (fiber to/from copper). The CPU then generates the GBAS corrections and integrity information and outputs them to the VDB.

The VDB Transmitter Unit (VTU) is capable of output of 80 watts and employs a TDMA output structure that allows for the addition of auxiliary VDBs (up to three additional) on the same frequency for coverage to terrestrially or structure blocked areas. The LTP's VTU is tuned to 112.125 MHz and its output is run through a band pass and then through two cascaded tuned can filters. The filtered output is then fed to an elliptically polarized three bay VHF antenna capable of reliably broadcasting correction data the required 23 nautical miles (see Protection Level Maps at http://laas.tc.faa.gov for graphical representation).

Surge and back-up power protection is present on all active processing station components.

C.1.2 Processing Station Software

Ohio University (OU) originally developed the GBAS code through an FAA research grant. Once the code reached a minimum of maturity, OU tested and then furnished the code to the FAA (circa 1996). It was developed using the C programming language under the QNX operating system. QNX was chosen because of its high reliability and real-time processing capability. This LTP code has been maintained by the GBAS T&E team since that time and has undergone numerous updates to incorporate evolving requirements, such as the inclusion of Cat III.

The software stores the precise survey data of the four GBAS reference station antennas (all RRA segments). Raw GPS data (i.e., range and ephemeris info) is received via four GPS receivers. The program cycles through the serial buffers and checks for messages, if one is found, it gets passed to a decoding function. From there, it is parsed out to functions according to message type and the information from the messages is extracted into local LTP variables. Once the system has received sufficient messages, the satellite positions are calculated in relation to the individual reference receivers. Type 1, 2, 4, 11 messages containing differential corrections, integrity values, GS information, and approach path data are then encoded and sent to the VDB via a RS-232 connection. Each of the four message types are encoded separately and sent according to DO-246D standards.

C.2 Reference Stations

There are four reference stations included in the FAA's LTP as required in the GBAS specification. The LTP's reference stations are identified as LAAS Test (LT) sites; there were originally five LT sites (LT1 through LT5), excluding LT4. LT4 was originally used for the L1/L2 site (**Figure 43**).

Each reference station consists of two major component systems. The first is a high quality, GNSS antenna (ARL-1900) manufactured by BAE Systems. The second is the reference receiver.

Figure 36 - The BAE GNSS Multipath Limiting Antenna (MLA)

C.2.1 The BAE ARL-1900 GNSS Multipath Limiting Antenna (MLA)

The BAE Systems ARL-1900 is an innovative, single feed, GNSS antenna that is approximately 6 feet high, and weighs about 35 pounds. The receiving elements are configured in an array, and when combined allow reception of the entire GNSS (Global Navigation Satellite System) band. This antenna is also capable of the high multipath rejection as required by the LAAS specification.

Multipath is a phenomenon common to all Radio Frequency (RF) signals and is of particular concern in relation to DGPS survey and navigation. It is simply a reflection of a primary signal that arrives at a user's equipment at a later time, creating a delay signal that can distort the primary if the reflection is strong. Reflected multipath is the bouncing of the signal on any number of objects including the local water table. Signals that reflect off the earth surface are often referred to as ground-bounce multipath. In all cases, the path length is increased. This path length is critical in GPS since the ranging is based on the signal's Time of Arrival (TOA). This causes a pseudorange error, for the SV being tracked, proportional to the signal strength. The BAE provides at least 23 dB of direct to indirect (up/down) pattern isolation above 5 degrees elevation. These multipath induced pseudorange errors can translate directly into a differential GPS position solution, which would be detrimental to applications such as GBAS. Multipath limiting antennas, such as the BAE Systems ARL-1900, were therefore developed to address the multipath threat to differential GPS and attenuate the ground multipath reducing the error. The ARL-1900 antenna characteristics also mitigate specular reflections from objects. The antenna's polarization (right hand circular polarized, or RHCP), provides a pattern advantage and reflective LHCP signals, which is left hand circular polarized.

C.3 Multi-Mode Receiver (MMR) Monitoring Station

The GBAS team maintains an MMR on a precise surveyed GPS antenna to monitor ground station performance and evaluate MMR software updates. The MMR drives a dedicated Course Deviation Indicator (CDI). The CDI is a cockpit instrument that indicates fly left/right and up/down information with respect to the intended flight path. A virtual runway was constructed such that the approach path goes through the MMR GPS antenna point. With the configuration, the CDI should always be centered when the MMR is tuned to the virtual runway that coincides with the antenna's survey position. **Figure 44** is a representation of a typical FAA fabricated MMR test/flight user platform. The version of MMR firmware for this reporting period was Flight Change (FC) 31.

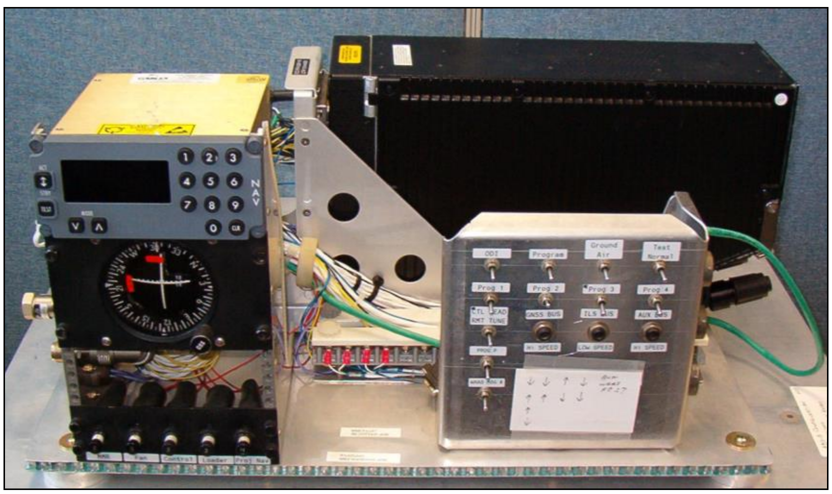


Figure 37 - MMR User Platform

Appendix D - GBPM Configuration and

The Ground Based Performance Monitor is the primary performance monitoring tool for the LTP and the Honeywell SLS-4000 systems. The system uses the received VDB broadcast type 1, 2, 4, and 11 messages from the ground station being monitored along with raw GPS data in order to compute the position of the monitor station. The position calculated from this data is compared to the position of the precision-surveyed GBAS grade GPS antenna, which is used to identify positioning errors.

The GBPM's Novatel OEM-V receiver logs range and ephemeris messages, which provide the necessary pseudorange and carrier phase measurements, as well as satellite position information. VDL messages are then received and separated into each of the DO-246D GBAS message types and decoded.

Data is collected in 24-hour intervals and saved to a .raw file without interruption. This data is used to post-evaluate system performance. In addition to the raw file, live data is transferred from each offsite monitor once per minute to our local database. Users can then access the data through an interactive website by means of tables, charts, and graphs hosted by the Navigation Branch at the FAA. The web address for this service is http://laas.tc.faa.gov.

Analysis of GBPM data is critical for closely observing the LTP and SLS performance behavior. The GBPM data output package contains several plots that can quickly illustrate the overall performance picture of the GBAS. The most useful plots available for performance summary purposes are *Vertical and Horizontal User Error versus Time*. These two plots are often used for preview performance analysis because the "user" GPS sensor position is known and stationary. The known position (precision survey) of the GBPM GPS sensor is compared directly to the computed user position. Typical LTP Vertical and Horizontal user error has an average well within the +/- 1-meter range.

Figure 45 is one of the GBPM's that was built by the Navigation Branch. Some of the major components include a retractable KVM to check the current status of the monitor, CISCO router with a T1 line back to our lab at ACY for data collection and maintenance, Power Distribution Unit (PDU) for a means remote access to bring power outlets back up if they become unresponsive, Novatel GPS Receiver, Becker VDB Receiver, QNX CPU, and an uninterruptable power supply.

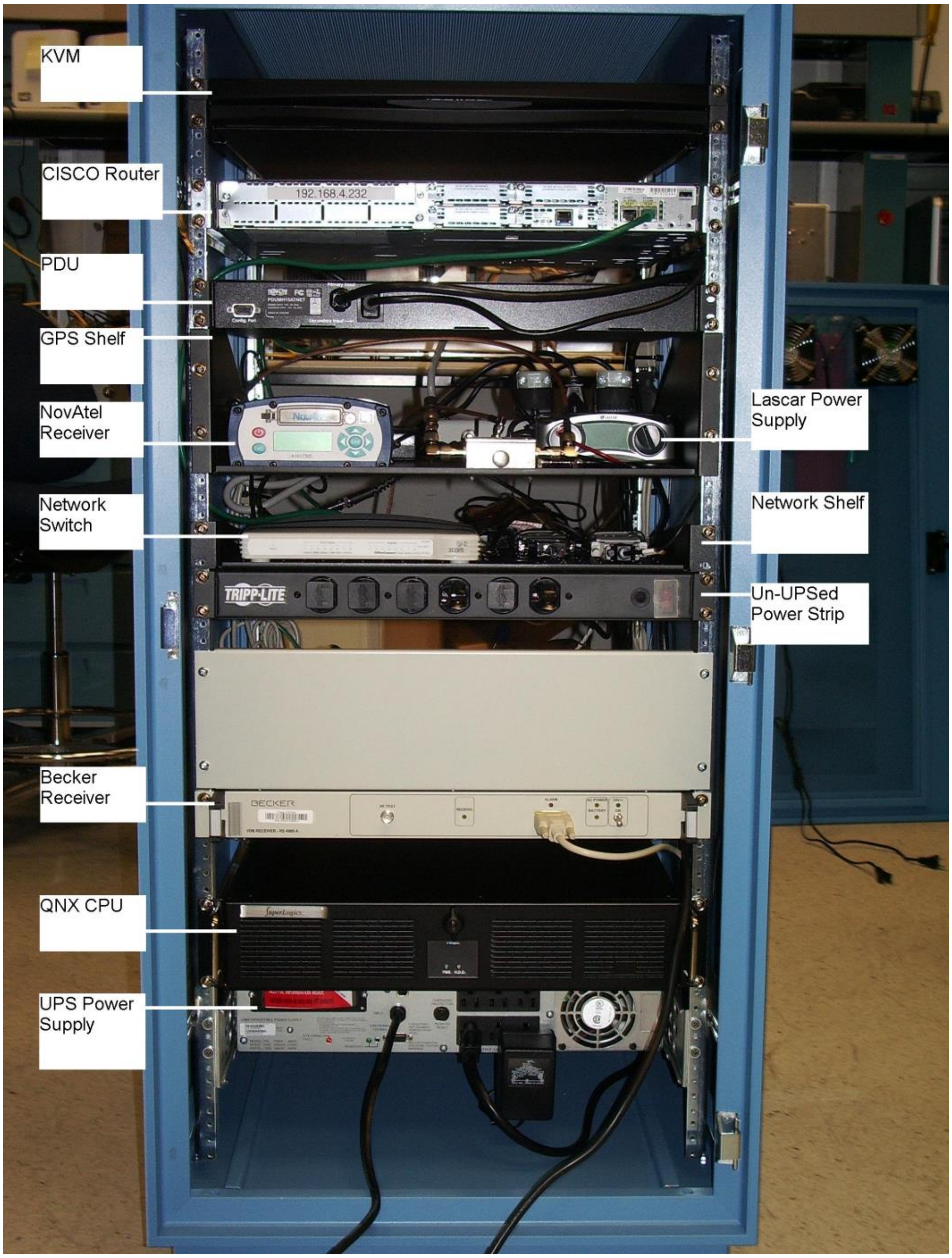


Figure 38 - Ground Based Performance Monitor (GBPM)

Glossary of Terms

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Key Contributors and Acknowledgements

Babel, Julian	609-485-4589	Julian.ctr.Babel@faa.gov
Beauchamp, Shelly	609-485-8358	Shelly.Beauchamp@faa.gov
Casler, Shawn	609-485-6914	Shawn.Casler@faa.gov
Cassell, Rick	571-271-2197	rcassell@systems-enginuity.com
Dennis, Joseph	703-841-4131	Joseph.ctr.Dennis@faa.gov
Dickenson, Mark	609-485-6993	Mark.Dickinson@faa.gov
Dudley, David	609-485-5886	David.ctr.Dudley@faa.gov
Gale, Marie	609-485-6270	Marie.ctr.Gale@faa.gov
Gillespie, Joseph	609-485-4579	Joseph.Gillespie@faa.gov
Guenter, Dieter	703-841-2261	Dieter.ctr.Guenter@faa.gov
Joannou, Dean	609-485-6771	Dean.Joannou@faa.gov
Kemp, Chad	609-485-6308	Chad.Kemp@faa.gov
Key, Randy	405-954-9169	Randy.Key@faa.gov
Motley, Campbell	703-841-2664	Campbell.ctr.Motley@faa.gov
Tedeschi, Carmen	609-485-7165	Carmen.Tedeschi@faa.gov
Velez, Ruben	609-485-5452	Ruben.Velez@faa.gov
Warburton, John	609-485-6782	John.Warburton@faa.gov
Wolf, Chris	609-485-6915	Christopher.Wolf@faa.gov