Federal Aviation Administration

Ground Based Augmentation System

Performance Analysis and Activities Report

Reporting Period: April1st – June30th, 2017

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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 GBAS ILS/VDB interference testing, supporting system design approval activities for Honeywell's future CAT-III capable SLS-5000, International GBAS Working Group (IGWG), Tech Center Tuesday, LAAS Integrity Panel (LIP), ICAO GBAS Working Group (GWG), and maintaining six Ground Based Performance Monitors (GBPMs) and a prototype GAST-D Honeywell Smartpath Landing System 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 in the quarter
d) To offer background information on GBAS

2. GBAS Updates by Site

The Ground Based Performance Monitor (GBPM) was designed and built by ANG-C32 to monitor the performance of GBAS installations. There are currently six GBPMs in use. They are located in Newark New (EWR), Houston (IAH), Moses Lake Washington (MWH), Rio de Janeiro Brazil (GIG), and two in Atlantic City New Jersey (ACY). The GBPM is used to monitor the integrity, accuracy, availability, and continuity of the FAA's LAAS Test Prototype (LTP) and Honeywell's SLS-4000.

The plots in each of the following sections utilize a compilation of data collected at one minute intervals.

Note on Plots:

The first plot shows the site's availability, i.e. the user's ability to use the system for the defined procedures. An outage, or loss in availability, occurs when the protection levels (LPL and VPL) exceed the alert limit, or when the system is down for reasons other than planned maintenance. The satellite constellation data used to generate the data shown in this plot is derived from the Almanac.

The second plot shows satellite elevation versus time (UTC) for the site on a single day of the quarter. Typically, a day that falls within the middle of the quarter is chosen to represent this plot for each of the sites.

The next two plots show the site's lateral accuracies and lateral protection level (LPL) versus error respectively. The first plot compares the lateral accuracies for GBAS and GPS. For the lateral protection level (LPL) versus error plot, data points should ***never*** appear in the dark area of the plot; this would indicate that the error exceeds the protection levels. The data used to generate these plots is from the GPS receiver in the FAA-owned Ground-Based Performance Monitor (GBPM) on-site.

The final two plots show the site's vertical accuracies and vertical protection level (VPL) versus error respectively. The first plot compares the vertical accuracies for GBAS and GPS. For the vertical protection level (VPL) versus error plot, data points should ***never*** appear in the dark area of the plot; this would indicate that the error exceeds the protection levels. The data used to generate these plots is from the GPS receiver in the FAA-owned Ground-Based Performance Monitor (GBPM) on-site.

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. The ground station is currently configured in CAT I – Block I mode.

Figure 1 - EWR SLS-4000 Configuration

2.1.1 Real Time Performance Data

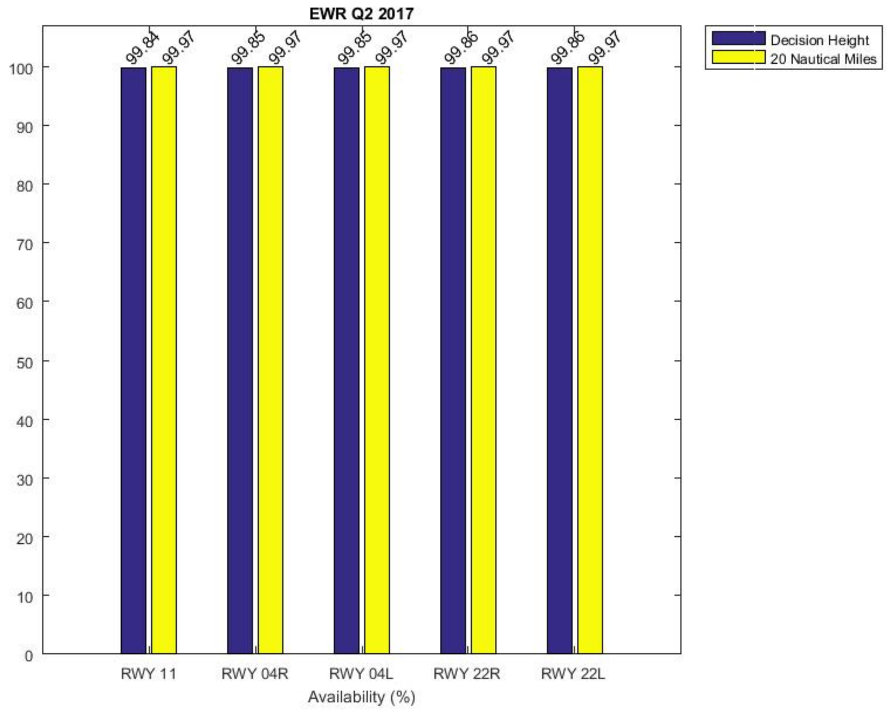

Figure 2 - EWR Availability

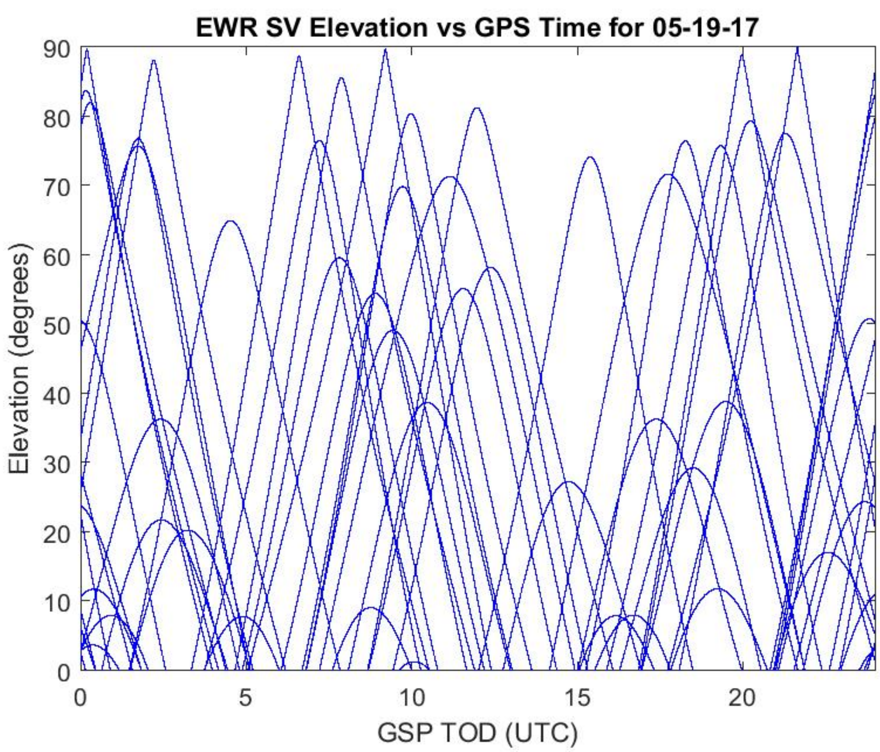

Figure 3 - EWR SV Elevation vs GPS time 05/19/17

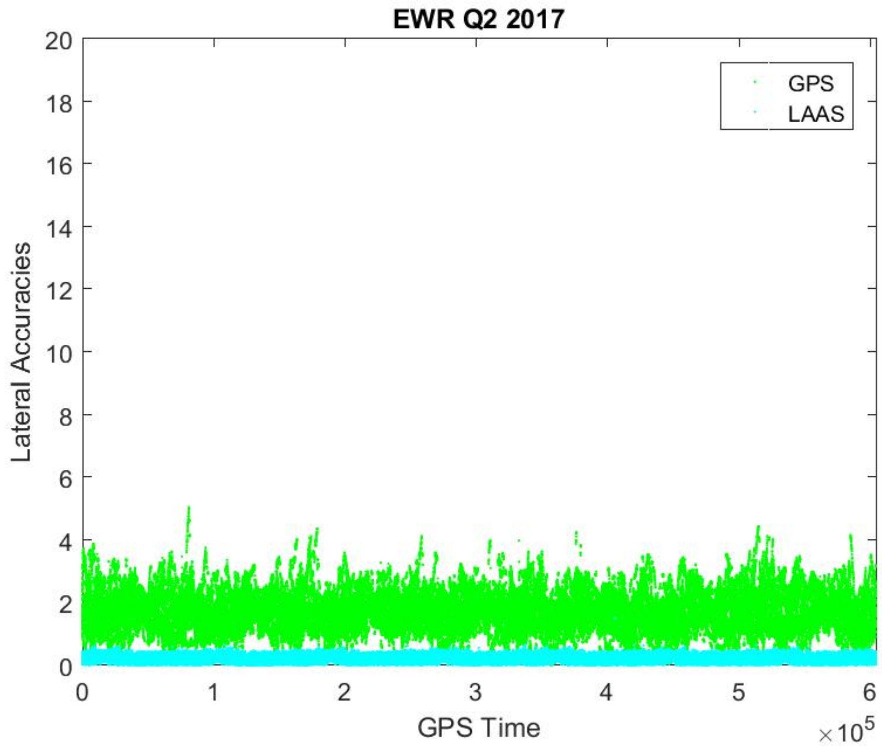

Figure 4 - EWR Lateral Accuracy

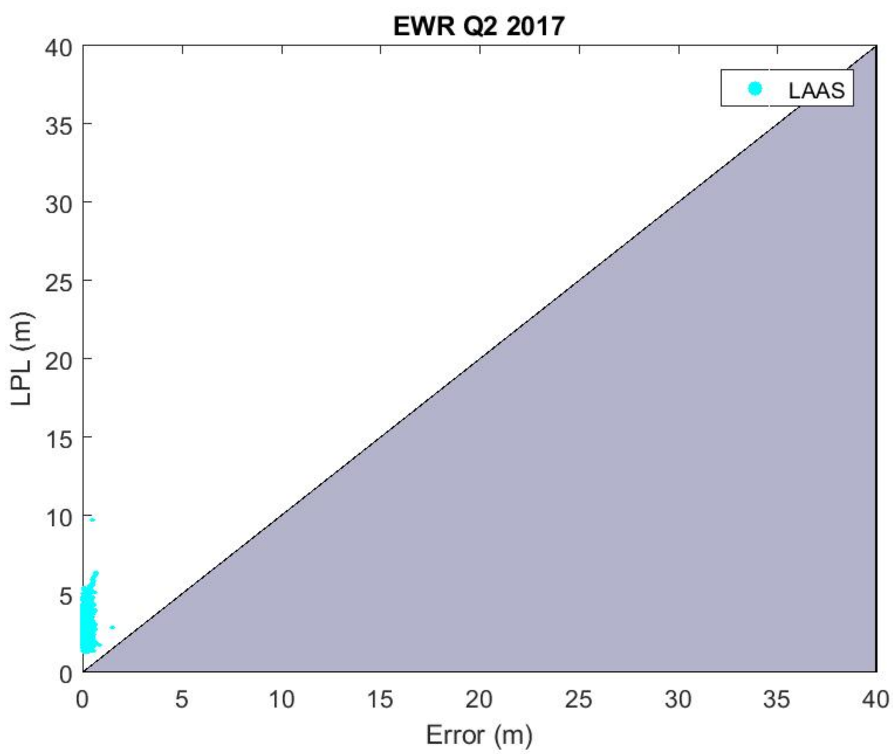

Figure 5 - EWR Lateral Protection Level (LPL) vs. Error

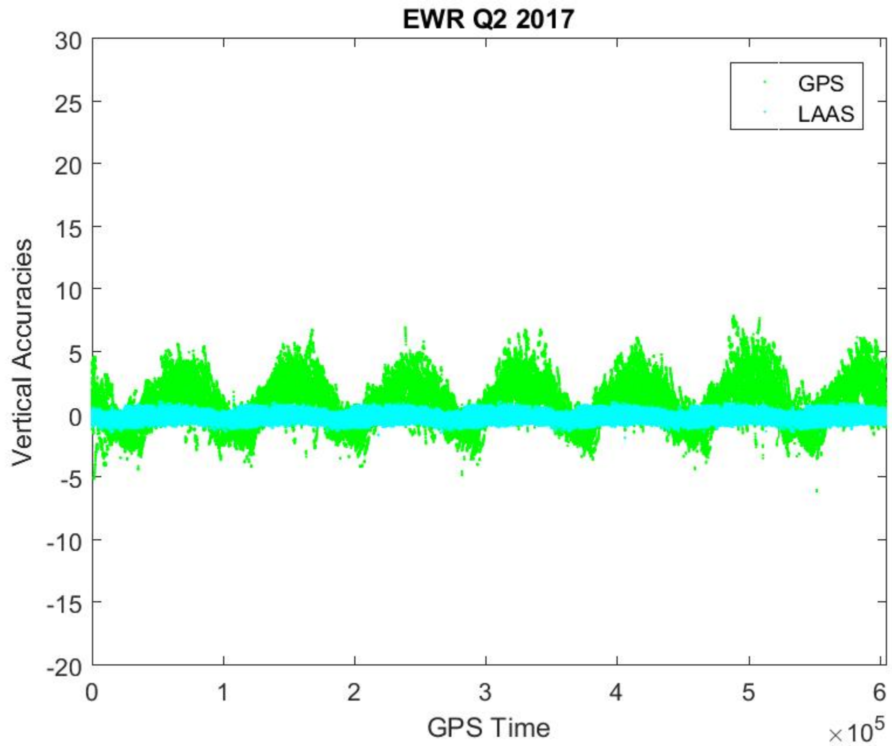

Figure 6 - EWR Vertical Accuracy

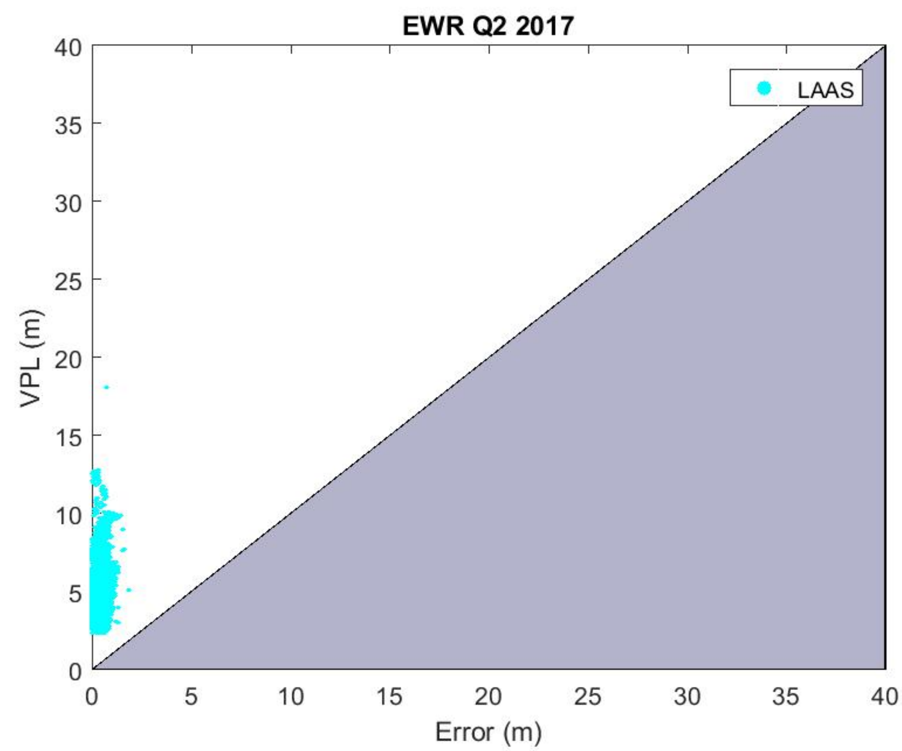

Figure 7 - EWR Vertical Protection Level (VPL) vs. Error

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. The ground station is currently configured in CAT I – Block I mode.

Figure 8 - IAH SLS-4000 Configuration

NOTE: IAH Real Time Performance Data lateral and vertical accuracy plots are not included for this quarter due to intermittent GPS receiver communication issues that have developed. A lack of consistent satellite data from the Novatel receiver to the CPU makes it impossible to accurately calculate position, and thus accuracy. This issue impacts only the GBPM, and does not indicate any issue with the SLS-4000. Update: As of August, this issue has been resolved and should be reflected by improved performance which will be presented in Q3.

2.2.1 Real Time Performance Data

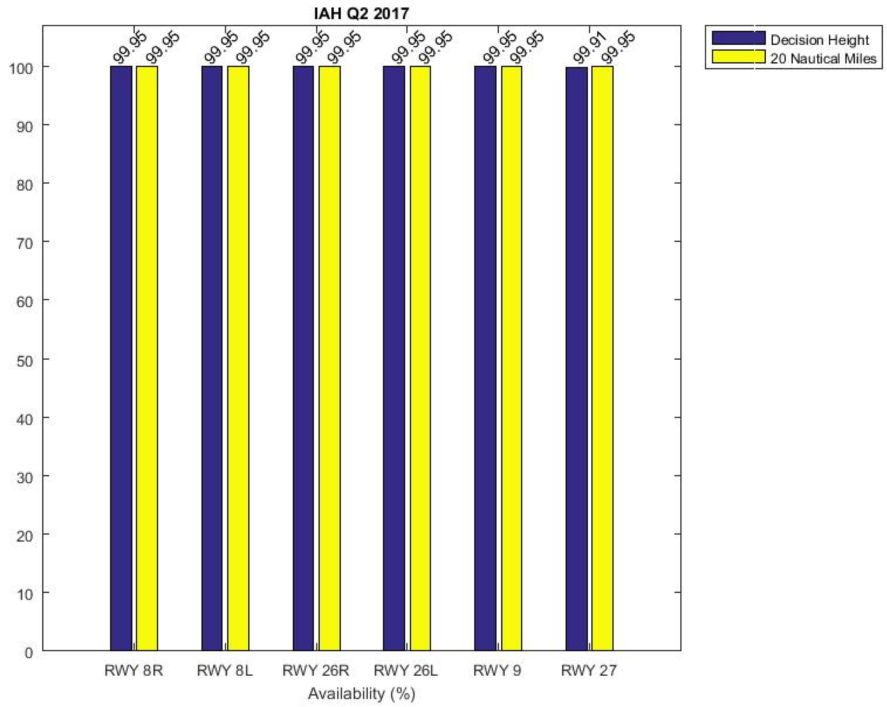

Figure 9 - IAH Availability

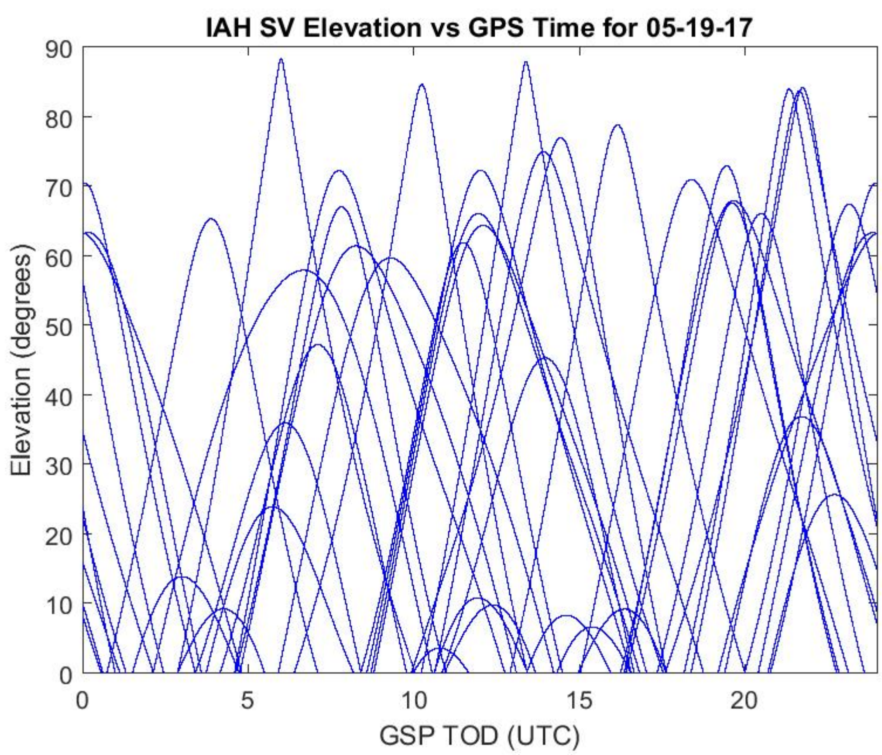

Figure 10 - IAH SV Elevation vs GPS time 05/19/17

2.3 MWH SLS

- Grant County Int'l Airport in Moses Lake, WA has a private-use Honeywell SLS-4000 owned by Boeing that was granted operational approval on January 9, 2013. The ground station is currently configured in CAT I – Block I mode
- 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 Int'l Airport (MWH) is a public use airport, it has no commercial flights
- This system requires a significant amount of multipath masking which can affect the constellation geometry at times, causing inflated protection levels, and a decrease in system availability

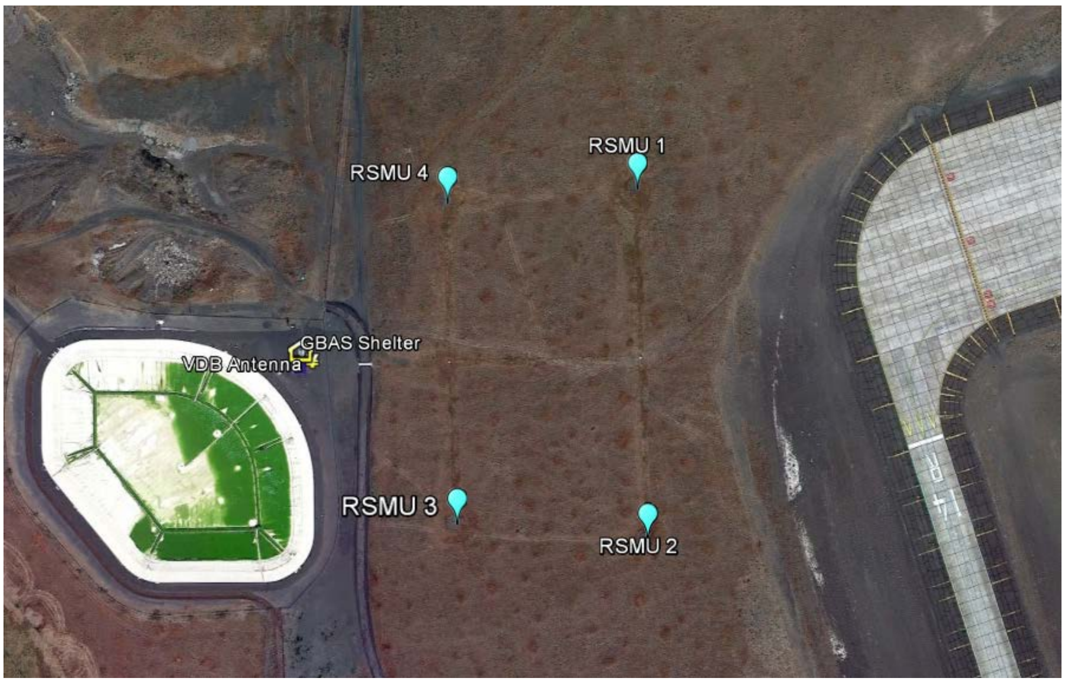

Figure 11 - MWH SLS-4000 Configuration

NOTE: MWH Real Time Performance Data plots are not included for this quarter due to the GBPM being offline during this time. As of June 23rd, 2017 this issue has been mitigated and will be reflected in the Q3 report. As with IAH, this issue impacts only the GBPM, and does not indicate an issue with the SLS-4000.

2.4 Rio de Janeiro Brazil

- An SLS-4000 Block II system is installed at Galeao Int'l Airport in Rio De Janeiro, Brazil. The system is operating but not operationally approved, as a safety case for use of the GBAS in low-latitude ionospheric environments is not yet complete.
- The GPS antenna on the Brazil GBPM is less robust than the other sites, therefore satellites below 11 degrees may not be tracked as consistently, impacting the accuracy and protection levels calculated using the data from the GBPM GPS receiver

2.4.1 Real Time Performance Data

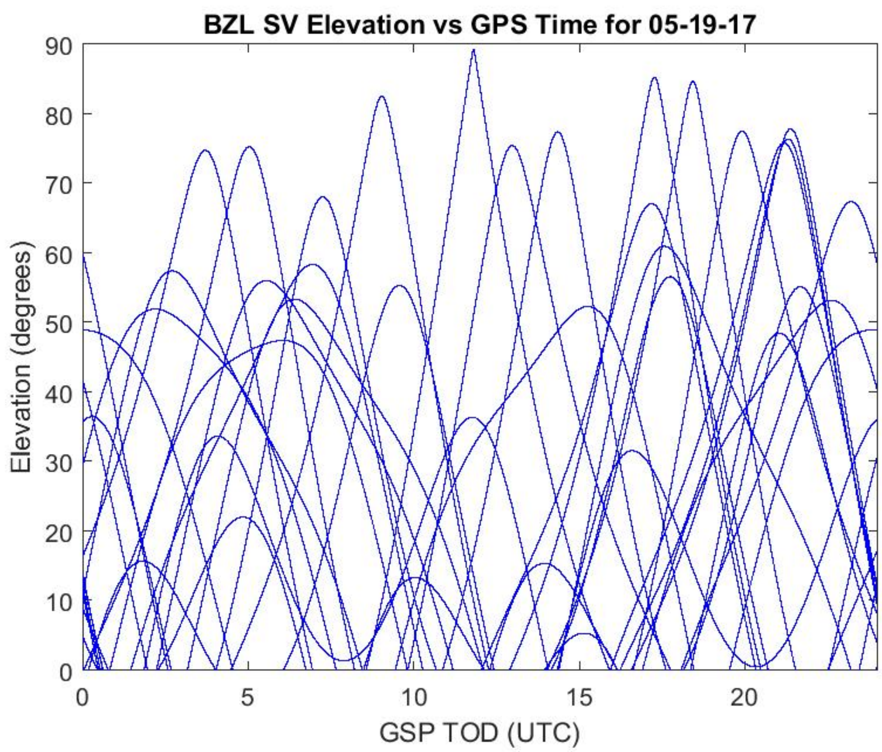

Figure 12 – BZL SV Elevation vs GPS time 05/19/17

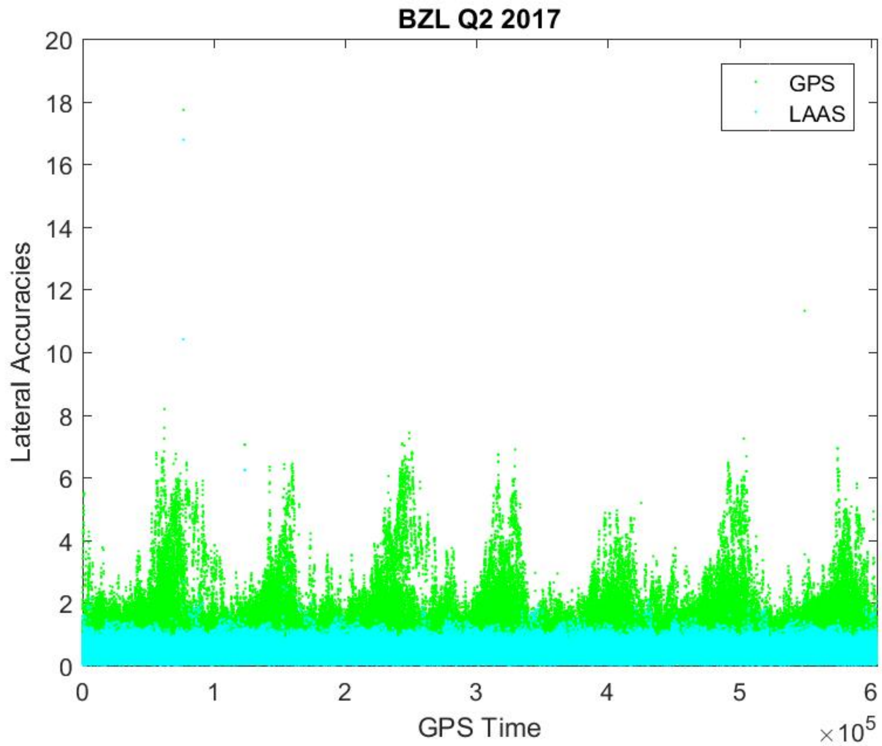

Figure 13 – BZL Lateral Accuracy

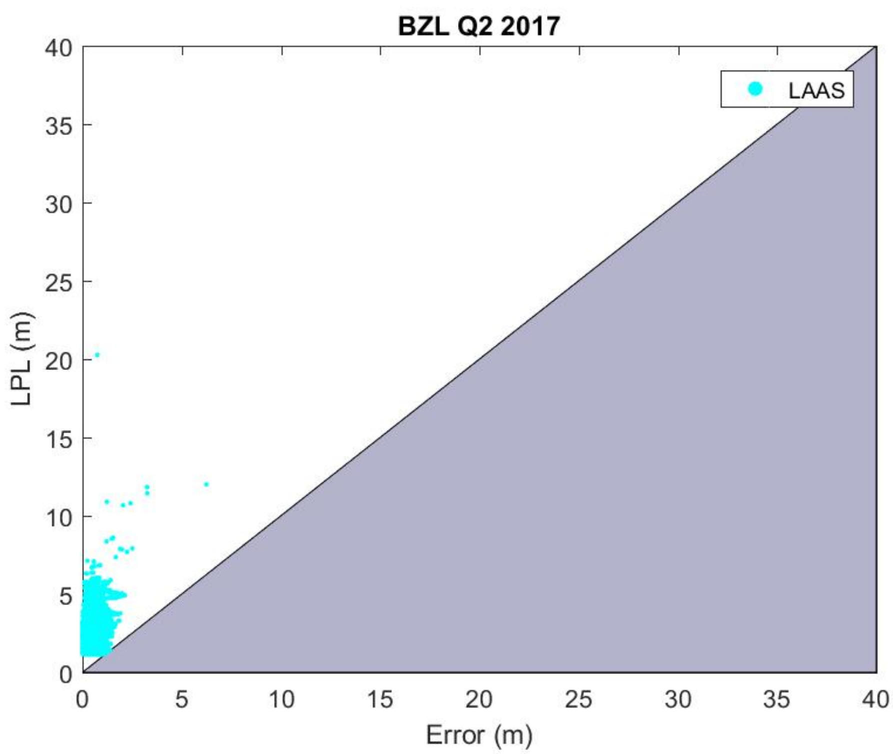

Figure 14 – BZL Lateral Protection Level (LPL) vs. Error

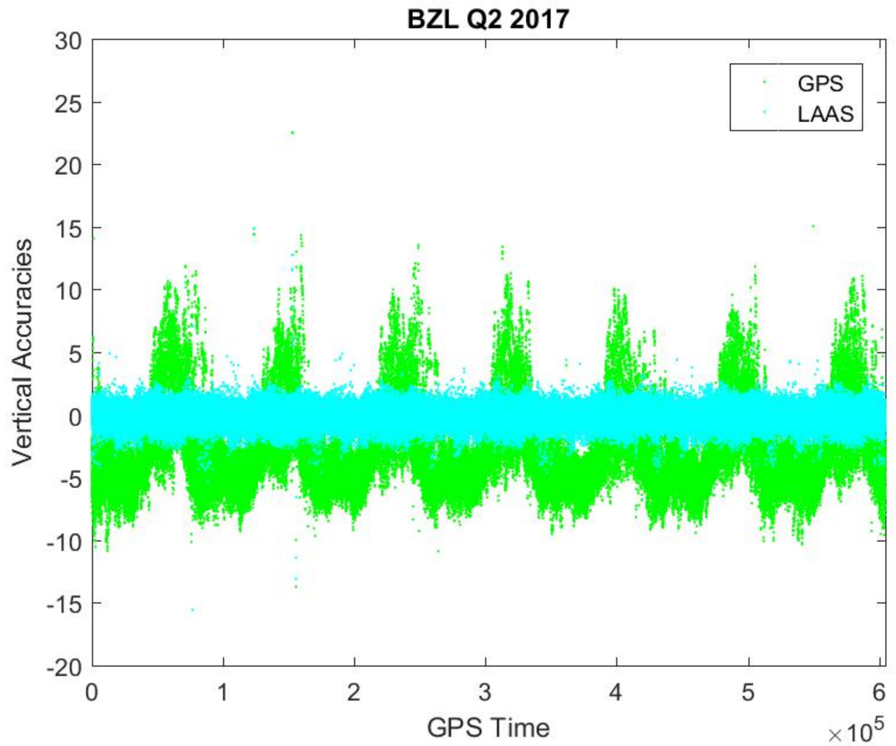

Figure 15 – BZL Vertical Accuracy

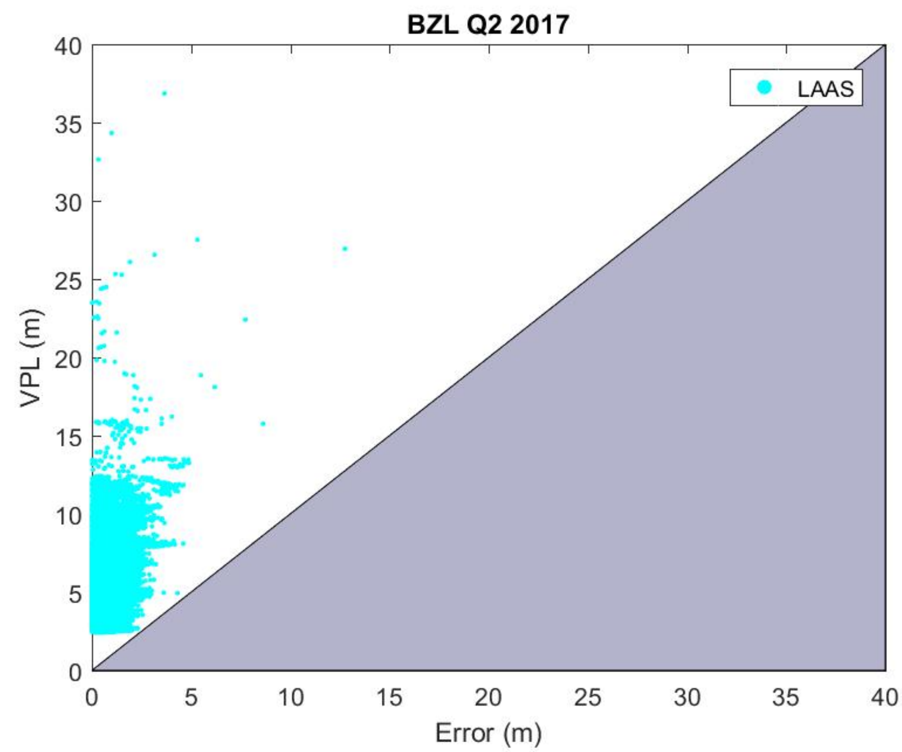

Figure 16 – BZL Vertical Protection Level (VPL) vs. Error

2.5 ACY SLS

- The KACY SLS-4000 ground station operates in either CAT-I Block II mode, or in CAT-III prototype mode. This is a test site and is not operationally approved.
- RSMUs 5 & 6 are not used in CAT-I mode and are part of the GAST-D/CAT-III prototype system.
- **NOTES**. Periods of data removed include:
    - June 7th thru 13th due to VDB hardware maintenance and repair.
- See **Section 4** for additional details on the tests performed at ACY this quarter.

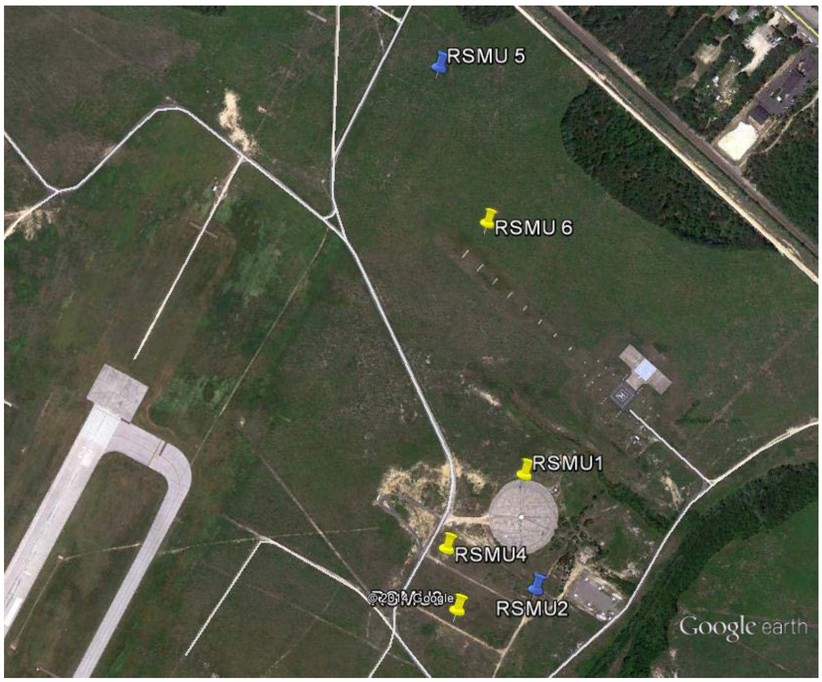

Figure 17 - ACY SLS-4000 Configuration

2.5.1 Real Time Performance Data

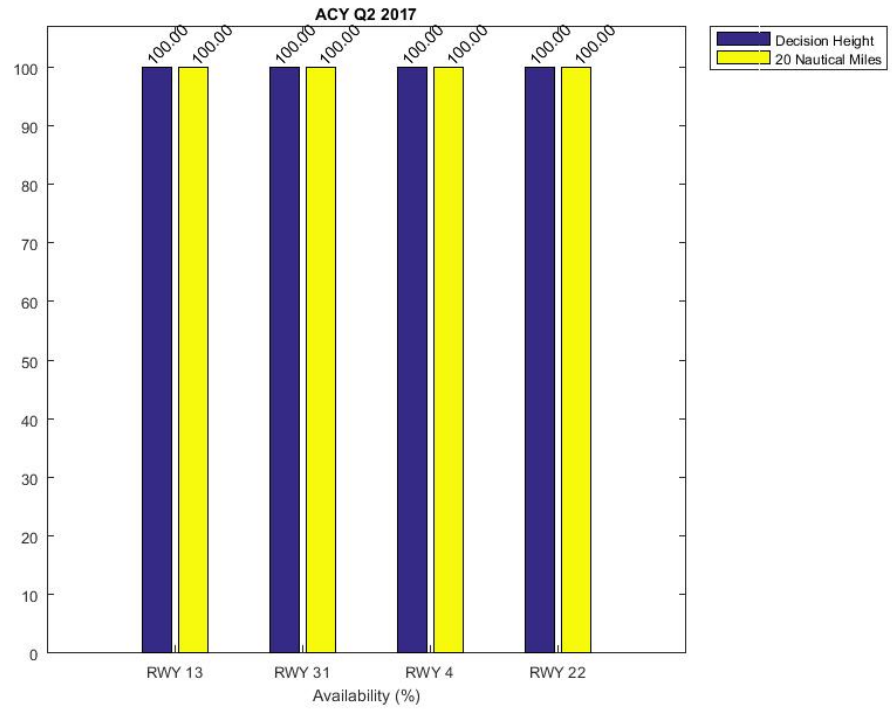

Figure 18 – ACY SLS Availability

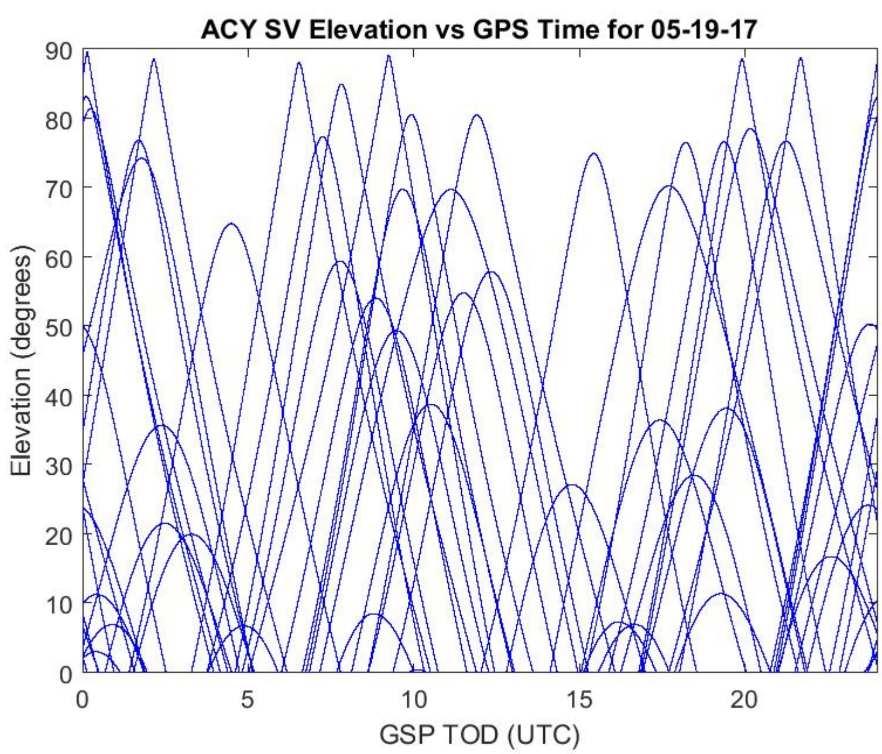

Figure 19 – ACY SV Elevation vs. GPS time 05/19/17

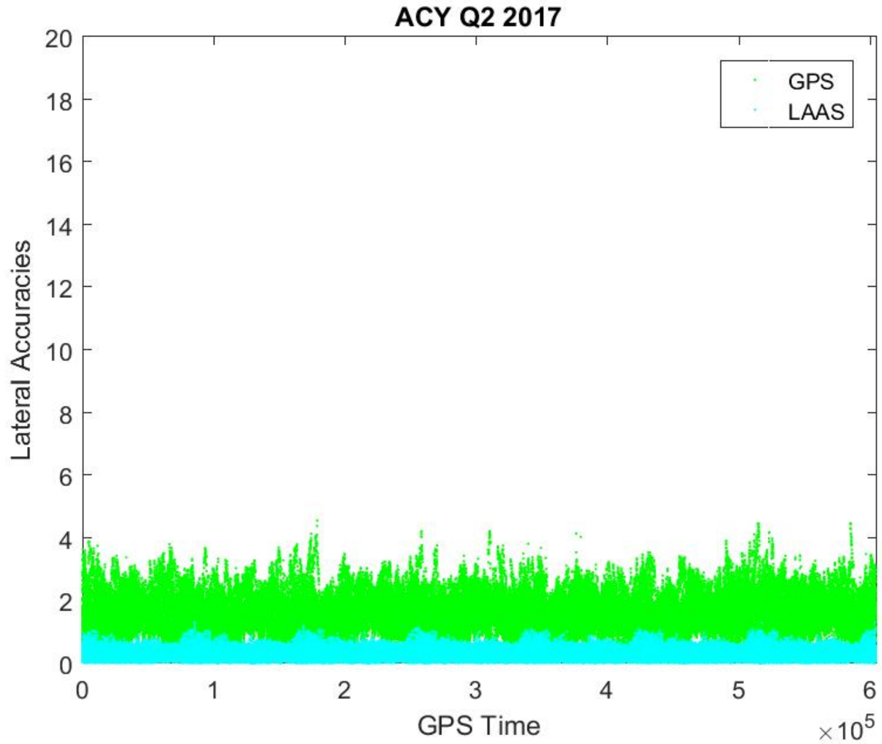

Figure 20 – ACY SLS Lateral Accuracy

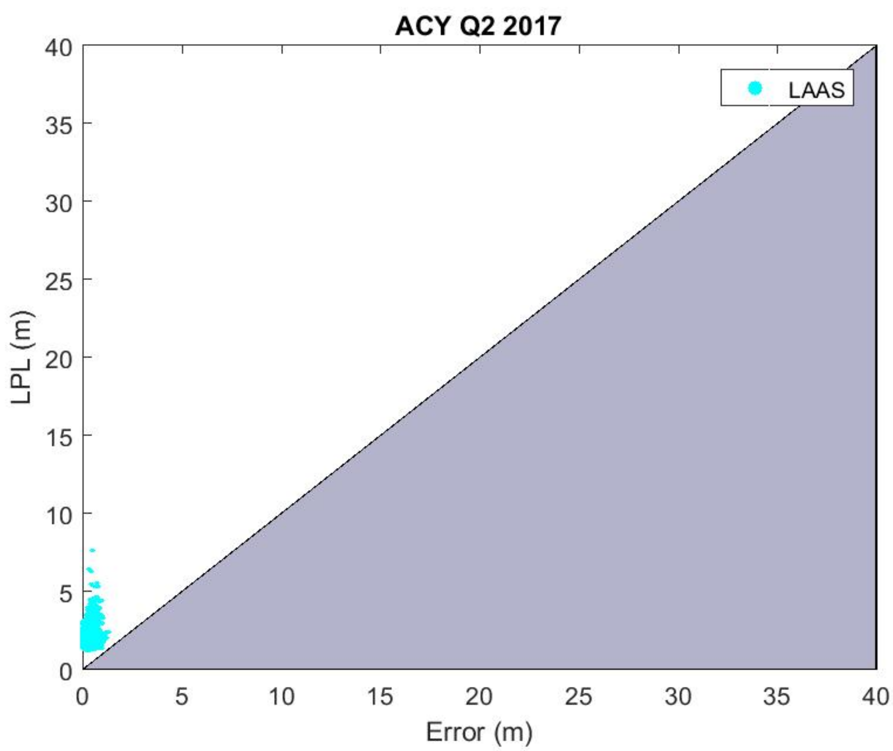

Figure 21 – ACY SLS Lateral Protection Level (LPL) vs. Error

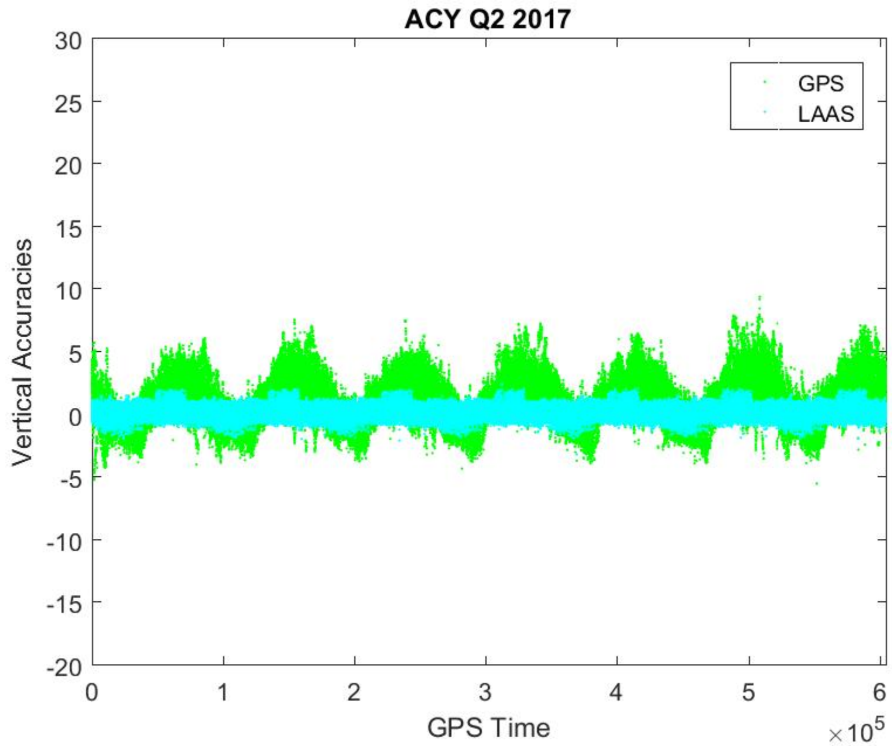

Figure 22 – ACY SLS Vertical Accuracy

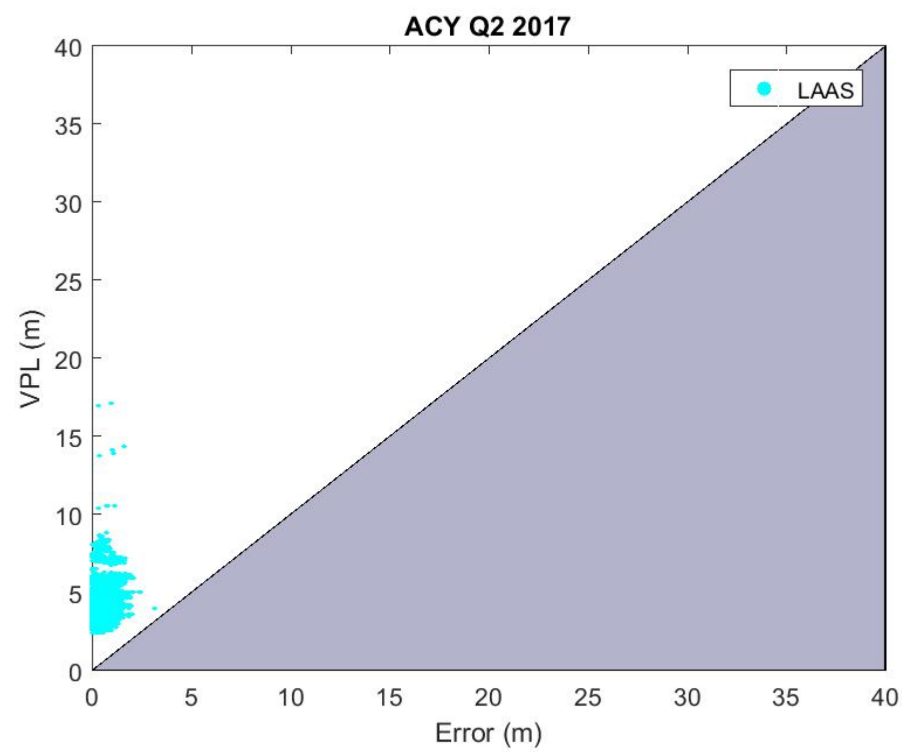

Figure 23 – ACY SLS Vertical Protection Level (VPL) vs. Error

2.6 ACY LTP

- At the time of this reporting, the LTP is being used in limited capacity for testing purposes only.
- The LTP was used to broadcast the Undesired Signal during the VDB Interference Flight Testing at the FAA William J. Hughes Technical Center. VDB testing continued into Q1 2017. See **Section 4.4** for additional details.
- See Appendix C for a full description of the LTP configuration.

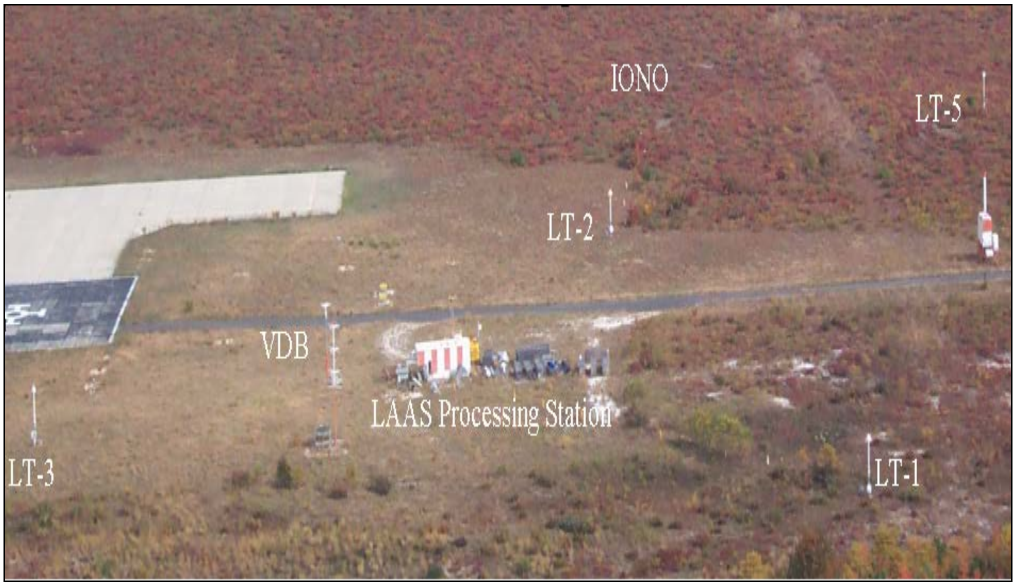

Figure 24 – Aerial View of LTP Configuration

3. Operational Implementation Updates

3.1 Domestic Operations

- Since the EWR SLS-4000 received operational approval in 2012, there have been a total of 1922 GBAS approaches conducted at EWR. Airline carriers include United Airlines (Boeing 737, 787), British Airways (Boeing 787), and Lufthansa (A380 Airbus).

	LANDINGS THRU 2016	2017 (Only)	Apr-17	May-17	Jun-17
EWR	**1788**		**2008**	**2073**	**2158**
United		278	72	45	26
Delta		0	0	0	0
BA (787)		21	7	5	3
DLH (747-8)		56	7	15	9
*Flight Chk L60					1
EWR SUB		370	**86**	**65**	**86**

Table 1 – Breakdown of Landings by Airline at EWR

*Periodic Flight Inspection of the GBAS at Newark International airport was completed successfully on June 1st.

- Since the IAH SLS-4000 received operational approval in 2013, there have been a total of 2006 GBAS approaches conducted at IAH. Airline carriers include United Airlines (Boeing 737, 787), British Airways (Boeing 787), Cathay Pacific (Boeing 747-8), Emirates (A380 Airbus), Carlgolux (B747-8) and Lufthansa (A380 Airbus).

	LANDINGS THRU 2016	2017 (Only)	Apr-17	May-17	Jun-17
IAH	**1864**		**2051**	**2138**	**2191**
United B737		217	31	71	41
United B787		7	0	1	2
Delta		0	0	0	0
Emirates (A380)		0	0	0	0
LH (A-380)		31	6	5	1
Cathay (747-8)		41	6	8	4
BA (787)		11	0	0	0
Cargolux (747-8)		26	2	2	5
IAH SUB		333	**45**	**87**	**53**

Table 2 – Breakdown of Landings by Airline at IAH

*Periodic Flight Inspection of the GBAS at Houston International airport (IAH) was completed successfully on April 25th, 2017.

3.2 Domestic Airlines Equipage

Aircraft Equipage	United
B737-800	22
B737-900/ER	111
B787-800	13
B787-900	20
Total	166

Table 3 – Q2 Aircraft Quantity for United

- 22% of United's worldwide fleet is GLS equipped.

Aircraft Equipage	Delta
B737-700	10
B737-800	2
B737-900ER	69
A321-200	15
Total	96

Table 4 – Q2 Aircraft Quantity for Delta

3.3 International Operations

- Australia's Melbourne Airport GBAS station is now installed and in full operation since May 25, 2017. This is the second GBAS to be installed in Australia, the first, successfully installed at Sydney Airport in 2014.

For more information, please refer to: Melbourne Airport Becomes Second in Southern Hemisphere to Install SmartPath

4. Research, Development, and Testing Activities.

4.1 ICAO Navigation Systems Panel (NSP) GBAS Working Group (GWG)

The NSP GWGmet in Montreal, Canada June 13th – 16th. The agenda item that received the most discussion concerned the VDB compatibility issue with ILS and VOR. There was a joint meeting with the Spectrum Working Group to review this issue. A work plan was reviewed and accepted by the joint working groups. Much progress has been made on analyzing the issue, including computer modeling and collection of flight inspection data in several countries. The critical operational scenarios have been identified. The most problematic appears to be the scenario where the ILS Localizer serving the opposite runway end is transmitting during a GBAS approach, and the aircraft flies over the Localizer. Some service providers turn off the Localizer for the opposite runway using an interlock system. However, some leave it turned on. The RTCA/GWG/SWG ad-hoc group continues to evaluate potential solutions, including defining more stringent adjacent channel performance by the airborne receiver. The plan is to have proposed SARPs and MOPS changes by spring 2018, and final approval at the November 2018 NSP meeting.

The IGM ad-hoc group continues to work on the development of additional material for Annex 10 regarding operation in low-latitude regions. A work plan was presented to the GWG and was approved.

Status information provided included the following: The GBAS installed at Melbourne, Australia is operational and approach procedures published. The CAT I GBAS in Frankfurt had several changes implemented related to the VDB coverage, enabling the system to meet all performance requirements. Russia has 110 GBAS stations that are operating and have been flight inspected. Over 20 have published approach procedures. The Honeywell SLS-4000 in Shanghai was upgraded to correct some technical issues. A second GBAS is installed at Tianjin, built by CETC (China Electronic Technical Corporation). The system will initially be approved for use in China. However, the intent is that it would be available for use outside of China. There was a question about what standard the system is being certified to. That information was not available.

4.2 VHF Data Broadcast (VDB) Adjacent channel signal strength testing

The Technical Center (ANG-C32) is supporting RTCA SC-159 WG4 and ICAO NSP through on-site test and data collection at Atlantic City International Airport (ACY). The VHF Data Broadcast (VDB) adjacent channel Desired to Undesired (D/U) signal strength requirements in the current MOPS (DO-253C) are under review to determine if the current values need to be increased. Some analytical studies presented at ICAO NSP meetings indicate there could be an interference problem under certain signal geometries with the current D/U values. The D/U values in the current RTCA MOPS will be unchanged in the revised DO253D MOPS when they are approved but changes could be recommended for a future revision.

To determine the effects on the VDB reception from strong VOR signals, which could be experienced in the airport environment, ground signal strength data was collected. To obtain the most realistic measurements one of the Technical Center R&D aircraft (N39) was used as a platform for the data collection equipment. The aircraft was taxied near the VOR and data was collected for VOR and VDB signals. The objective was to obtain a worst case scenario to help determine the full range of values that could be experienced by aircraft at an airport. Previous ANG-C32 flight test data was used to look at VDB performance in the presence of an on-airport VOR during approach and landing.

In the future GBAS may be used for guided take off and guided departure so the effects of flying over the ILS Localizer were examined. Previous ANG-C32 flight test data was used to look at the performance of the VDB link when flying over the ILS Localizer at 50 feet and while performing touch & go's. Localizer signal strength on roll out was a concern so the test aircraft taxied down the centerline of the active runway collecting ILS Localizer signal strength.
The results from these tests are being presented at the weekly RTCA SC-159 WG4 VDB Ad Hoc Working Group meetings. The test results present new data which had not been previously

collected and will be used to help validate the VDB/VOR/LOC signal strength model being developed at Boeing. The Boeing model will be used to provide input to RTCA and ICAO NSP which are considering whether the adjacent channel Desired to Undesired ratio (D/U) requirements need to be changed.

5. Meetings and Conferences

5.1 Radio Technical Commission for Aeronautics (RTCA)

RTCA SC-159 Working Group 4 committee have accepted the final review and comment (FRAC) of the LAAS GAST D MOPS (DO-253) and ICD (DO-246). These documents will be consistent with the ICAO SARPs for GBAS GAST D standards for Category III operations, which were approved by ICAO in December 2016.

5.2 International GBAS Working Group (IGWG)

The 18th International GBAS Working Group (IGWG) was hosted by US Federal Aviation Administration (FAA) and Delta Air Lines in Atlanta, Georgia. The meeting was chaired by FAA and EUROCONTROL (Shelly Beauchamp, FAA and Andreas Lipp, EUROCONTROL). IGWG Secretaries for the meeting were Dieter Guenter, FAA (NAVTAC) and Lendina Smaja, EUROCONTROL.

A record one hundred thirty (130) participants from twenty-three (23) nations, international service providers, industry, airlines and aircraft manufacturers attended the meeting and working sessions with many new participants. Notably, representatives from nine (9) major airlines attended the meeting.

In his welcome, Capt. Steve Dickson, Senior Vice President of Flight Operations for Delta Air Lines, noted Delta's investment in GLS technology, siting the company's continued commitment to customer satisfaction and the need for resilience in equipment to ensure operations continue safely and on time.

Continued commitment to GBAS development and implementation by participants was impressive, and visible in airline presentations from Delta Air Lines, United Airlines, Cathay Pacific, Ryanair, CargoLux, JAL and ANA. Ryanair, attending the IGWG for the first time, reported plans to be the largest GBAS-equipped fleet in Europe and to pursue GBAS installations for at least six of their destinations in the region. Additionally, Polish Air Navigation Service Provider (PANSA) announced plans for the installation of a new GBAS at Krakow, Poland, and SEATAC and the PANYNJ updated their progress towards installations in the U.S. Fraport announced the recent start of new 3.2 degree GLS approaches into Frankfurt, a step towards decreasing noise exposure to nearby communities. NPPF Spectr from Russia provided an update of their impressive GBAS implementation in Russia with 90 locations and 10 different aircraft types. CargoLux reported that they'd received approval to use a Russian GBAS station as an alternate.

A new session was added to address the various GBAS cost benefit analysis activities that are underway. Updates were briefed by both the FAA and EUROCONTROL for SESAR, as well as by several individual airports. These briefs led to extensive discussion on what would be appropriate assumptions to use in these analyses and what timelines benefits should be considered over. Participants stressed the importance of environmental impacts for CBA consideration, especially noise abatement.

Boeing and Airbus remain strongly committed to GLS and reported an increasing GLS customer base and increased number of GLS equipped aircraft sales. Boeing reported over 1900 equipped aircraft and over 100 airlines now taking delivery of GLS-equipped aircraft. Boeing also announced that the B-777X would be optionally GAST-D GLS equipped at entry to service in 2019 while GLS CAT I is part of the standard fit. Airbus reported that 45 customers were choosing the GLS option on aircraft, ten new customers since last year.

The status reports of service provider plans, users and manufacturer updates as presented 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 more in depth briefings can take place.

The increased interest in operational aspects noticed during the last meetings continued. More than two-thirds of the participants attended the operational working sessions at this meeting. Major aspects of the operational working groups were discussions on the newly coordinated means to allow enhanced service volumes, an important step for GBAS operations at airports with a requirement for extended final approach segments. Another topic of particular interest was the desire on progress towards approval of CAT-II operations on a GAST-C GBAS system. Both Honeywell and United Airlines briefed on their status towards achieving this goal. Progress was reported on RNP-to-GLS approvals in the U.S., Europe, and Asia. In one major SESAR project, several solutions are dedicated to pursuing enhanced arrival procedures enabled by GBAS. The operational focus was also visible in the desire of most participants to attend in Delta hosted after hours (7:30pm to 11:30pm) Delta Air Lines dispatch tours and simulator sessions, in which participants had an opportunity to experience hands-on GLS operations in the Boeing 737-900 and A 350 simulators.

The technical sessions, which included Data Collection and Evaluation, Siting and Ground Monitoring Topics, and Ionospheric Aspects, remained active. During the ionospheric aspects session, strategies used to complete validation of the GAST-D SARPS were briefed, as well as the completion of the Asia Pacific Threat Model and work on an independent Monte Carlo analysis tool. Other technical topics briefed included an update on EUROCONTORL'S PEGASUS data processing software, performance of the FAA's GLS service prediction tool, VDB compatibility work and GBAS implementation in Brazil.

Participants were extremely satisfied with the outcome of the working group meeting, and agreed that the IGWG continued to fulfil a recognized function in GBAS development and implementation work. The meeting's format seems well adapted to the participants' needs, allowing for coordination between ANSPs, airports, airlines and OEMs. The working group addresses relevant issues for GBAS, and enables exchanges of data and information which can be effectively used by participants in formulating their business strategies and implementation plans.

PANSA extended an offer to host the next International GBAS Working Group in Krakow, Poland in 2018. Final dates will be determined.

5.3 Air Traffic Controller Association (ATCA) Tech Center Tuesday

The GBAS group participated in the 3rd annual Tech Symposium at the William J Hughes Technical Center in Egg Harbor Township, NJ, Tech Center Tuesday during the May 12th -16th ATCA. As one of the many different research and development, test and evaluation groups, the GBAS group presented the technology, sharing their research and current work to the viewing public, including Congressmen Frank LoBiondo and John Larson.

Tech Center Tuesday features exhibits and presentations from various programs and organizations. The tech talks and demonstrations presented during this period benefit both the aviation industry and the FAA by giving officials the chance to get a second hand perspective from developers, scientists, engineers and various aviation colleagues.

5.4 LAAS Integrity Panel (LIP)

The FAA conducted a meeting of the LAAS Integrity Panel (LIP) on the Honeywell GBAS System Design Approval in Coon Rapids, MN, May 23-26. The meeting reviewed the progress and status of several elements of the Honeywell SLS-5000 GAST D system design. The topics reviewed included the ionospheric gradient monitor (IGM), Code-Carrier Divergence (CCD) monitor, Ephemeris monitor, Excessive Acceleration monitor, and RF interference.

The IGM discussions largely focused on the simulations used to determine compliance with the ICAO performance requirements for detection of anomalous ionospheric gradients. The simulations take into account the gradient detection performance of the two ground monitors (IGM and CCD) and the airborne DSIGMA monitor. The discussions included the methodology employed in terms of determination of the worst case performance using Monte Carlo simulations. Work continues by the FAA Key Technical Advisors (KTAs) to define the methodology that should be used. During the LIP there was also a presentation given by the Korea Advanced Institute of Science and Technology (KAIST) on the IGM simulation tool that was developed to assist in evaluating various methodologies.

6. Relevant GPS Events

6.1 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 1** 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 2**). 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 5 - NANU Types and Definitions

NANU	TYPE	PRN	Start Date	Start Time (Zulu)	End Date	End Time (Zulu)
2017030	FCSTMX	19	04/19/2017	1400	04/19/2017	2200
2017031	FCSTSUMM	19	04/19/2017	1505	04/19/2017	1925
2017032	UNUSUFN	16	04/22/2017	1637	04/22/2017	
2017033	UNUSABLE	16	04/22/2017	1637	04/22/2017	1646
2017034	FCSTMX	14	05/04/2017	1900	05/04/2017	0300
2017035	UNUSUFN	27	04/27/2017	2327	04/27/2017	
2017036	UNUSABLE	27	04/27/2017	2327	04/27/2017	0448
2017037	FCSTDV	22	05/05/2017	0745	05/05/2017	1945
2017038	FCSTSUMM	14	05/03/2017	1945	05/03/2017	2307
2017039	FCSTSUMM	22	05/05/2017	0803	05/05/2017	1318
2017040	FCSTDV	12	05/18/2017	2335	05/18/2017	1135
2017041	FCSTMX	11	05/18/2017	1630	05/18/2017	0030
2017042	GENERAL					
2017043	FCSTSUMM	11	05/18/2017	1655	05/18/2017	2035
2017044	FCSTSUMM	12	05/19/2017	0008	05/31/2017	0601
2017045	FCSTMX	07	05/31/2017	1500	05/31/2017	2300
2017046	FCSTCANC	07	05/31/2017		05/31/2017	
2017047	FCSTDV	18	06/02/2017	0130	06/02/2017	1330
2017048	FCSTSUMM	18	06/02/2017	0141	06/02/2017	0701
2017049	FCSTMX	28	06/07/2017	1730	06/08/2017	0130
2017050	FCSTMX	18	06/13/2017	1400	06/13/2017	2200
2017051	FCSTSUMM	28	06/07/2017	1819	05/07/2017	2226
2017052	FCSTDV	15	06/15/2017	1820	06/16/2017	0620
2017053	FCSTMX	22	06/20/2017	2130	06/21/2017	0530
2017054	FCSTMX	13	06/21/2017	2345	06/22/2017	0745
2017055	FCSTSUMM	18	06/13/2017	1449	06/13/2017	1810
2017056	FCSTSUMM	15	06/15/2017	1842	06/16/2017	0059
2017057	FCSTSUMM	22	06/20/2017	2256	06/21/2017	0122
2017058	FCSTSUMM	13	06/22/2017	0031	06/22/2017	0306
2017059	FCSTMX	16	06/27/2017	1800	06/28/2017	0200
2017060	FCSTMX	20	06/29/2017	2300	06/30/2017	0700
2017061	FCSTSUMM	16	06/27/2017	1925	06/27/2017	2223
2017063	FCSTSUMM	20	06/29/2017	2329	06/30/2017	0201

Table 6 - NANU Summary

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

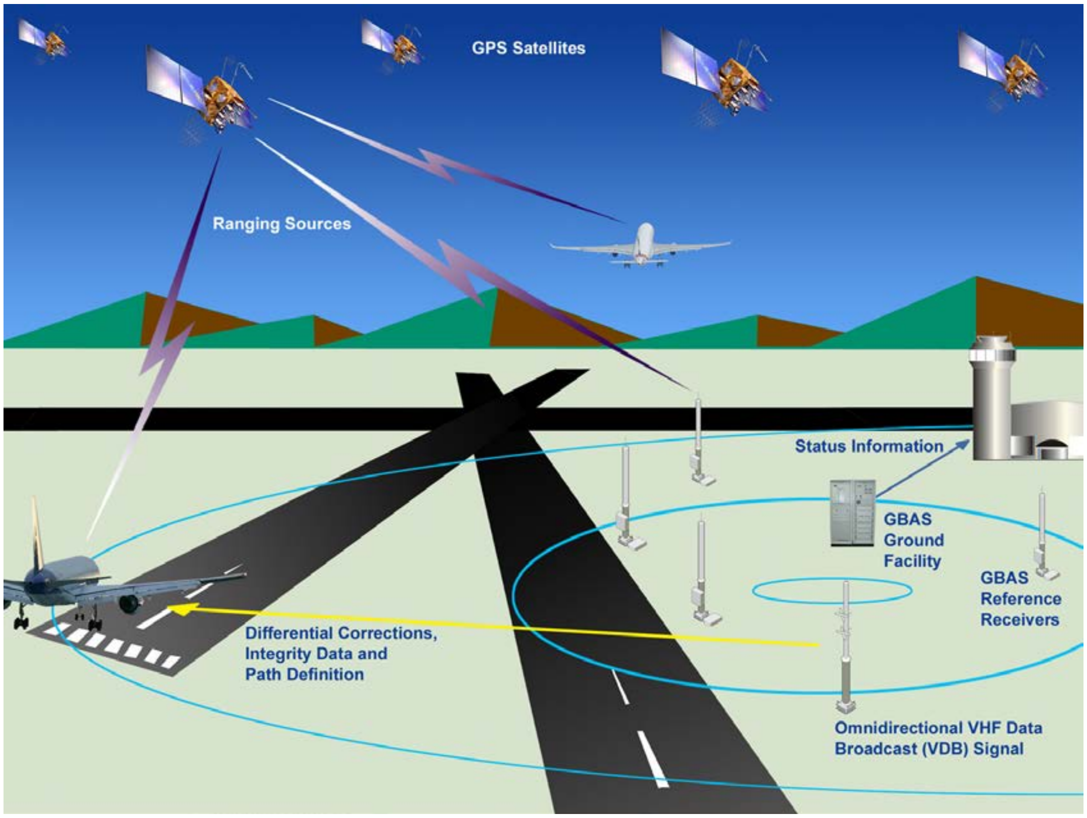

Figure 25 – GBAS Architecture Diagram

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) 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.2.3 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 sites; there were originally five LT sites (LT1 through LT5), excluding LT4. LT4 was originally used for the L1/L2 site (**Figure 32**).

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 26 – 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.

Appendix D - GBPM Configuration

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 33 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.

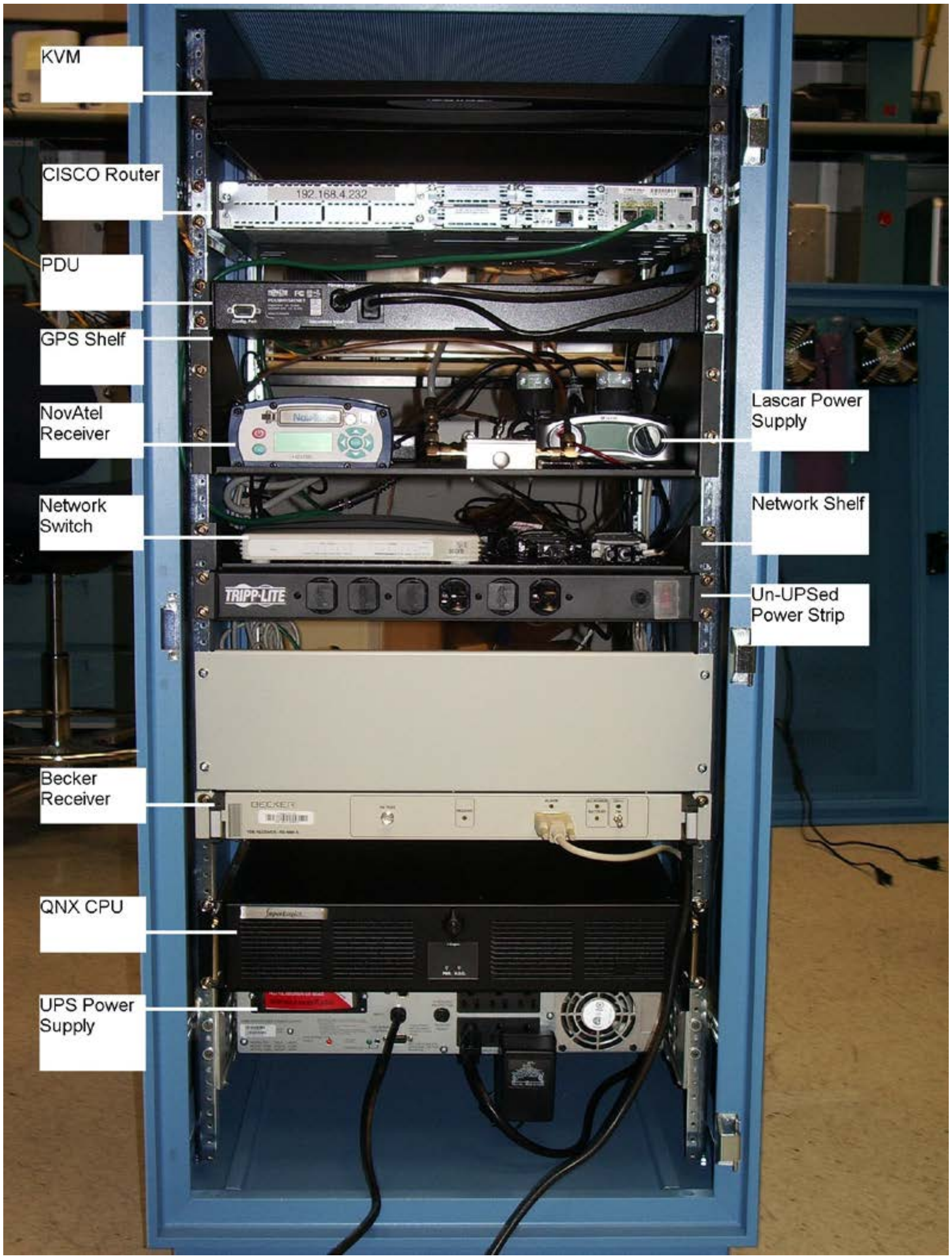

Figure 27 – Ground Based Performance Monitor (GBPM)

Glossary of Terms

Index of Tables and Figures

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