Federal Aviation Administration

Ground Based Augmentation System

Performance Analysis and Activities Report

Reporting Period: July 1 – October 31, 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 the validation of the GAST-D ICAO SARPs, GBAS ILS/VDB interference testing, supporting system design approval activities for an update to the CAT-I approved Honeywell International (HI) Satellite Landing System (SLS-4000) and future CAT-III capable SLS-5000, and maintaining six Ground Based Performance Monitors (GBPMs) and a prototype GAST-D Honeywell Satellite 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 this past quarter
d) To offer background information for GBAS

2. Operational & Implementation Updates

The Honeywell Block II-S upgrade for Newark International Airport (EWR) will begin in December 2017 (See Section 4.1 for more details), with George Bush International Airport (IAH) to follow shortly after.

The Port Authority New York and New Jersey (PANYNJ) will be installing Honeywell GBAS Block II-S systems at of John F. Kennedy Airport (JFK), LaGuardia Airport (LGA), and Teterboro Airport (TEB). 7460's have been submitted for JFK and LGA (See Section 5.2 for more information). San Francisco International Airport (SFO) and Seattle-Tacoma International Airport (SEATAC) are both in early planning stages of installing an SLS-4000 Block II-S.

Each month, the FAA receives a report from Newark and Houston Airports itemizing the number of GLS approaches done per airline. These are listed below in **Table1** and **Table 2**. In addition to the airlines listed below, ANA and Norwegian Air Shuttle are starting work to obtain ops spec to use US systems.

Since the EWR SLS-4000 received operational approval in 2012, there have been a total of 2540 GBAS approaches conducted at EWR. Airline carriers include United Airlines (Boeing 737, 787), British Airways (Boeing 787), Norwegian Air, and Lufthansa (A380 Airbus).

Newark Liberty International Airport (EWR)											
	Thru 2016	Jan-17	Feb-17	Mar-17	Apr-18	May-17	Jun-17	Jul-17	Aug-17	Sept -17	Oct-17
United	-	37	25	26	72	45	73	85	90	57	62
Delta	-	0	0	0	0	0	0	0	1	0	0
British Airways 787	-	11	4	6	7	5	3	10	12	4	13
DLH 747-8	-	9	8	8	7	15	9	8	13	13	12
Flight Check	-	0	0	0	0	0	1	0	0	0	0
Sub-Totals	-	57	37	40	86	65	86	103	116	74	87
Totals	1788	1845	1882	1922	2008	2073	2159	2262	2378	2452	**2539**

Table 1 – GLS Approaches at EWR

Since the IAH SLS-4000 received operational approval in 2013, there have been a total of 2356 GBAS approaches conducted at IAH. Airline carriers include United Airlines (Boeing 737, 787), British Airways (Boeing 787), Cathay Pacific (Boeing 747-8), Carlgolux (B747-8) and Lufthansa (A380 Airbus).

George Bush Intercontinental Airport (IAH)

	Thru 2016	Jan-17	Feb-17	Mar-17	Apr-18	May-17	Jun-17	Jul-17	Aug-17	Sept-17	Oct-17
United B737	-	29	25	20	31	71	41	18	39	14	22
Untied B787	-	2	1	1	0	1	2	0	0	0	2
DLH A-380	-	7	3	9	6	5	1	7	4	8	7
Cathay 747-8	-	6	7	10	6	8	4	11	8	7	3
British Airways 787	-	5	3	3	0	0	0	0	0	0	0
Cargolux 747-8	-	5	6	6	2	2	5	3	3	0	3
Sub-Totals	-	54	45	49	45	87	53	39	54	29	37
Totals	1864	1918	1963	2012	2057	2144	2197	2236	2290	2319	**2356**

Table 2 – GLS Approaches at IAH

Totals For All Operational GBAS Sites											
	Thru 2016	Jan-17	Feb-17	Mar-17	Apr-18	May-17	Jun-17	Jul-17	Aug-17	Sept-17	Oct-17
Grand Totals	3652	3763	3845	3934	4065	4217	4356	4498	4669	4772	**4895**

Table 3 – Total GLS Landings for Every Operational Site YTD

3. GBAS Updates by Site

The 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 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 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.

3.1 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

3.1.1 Real Time Performance Data

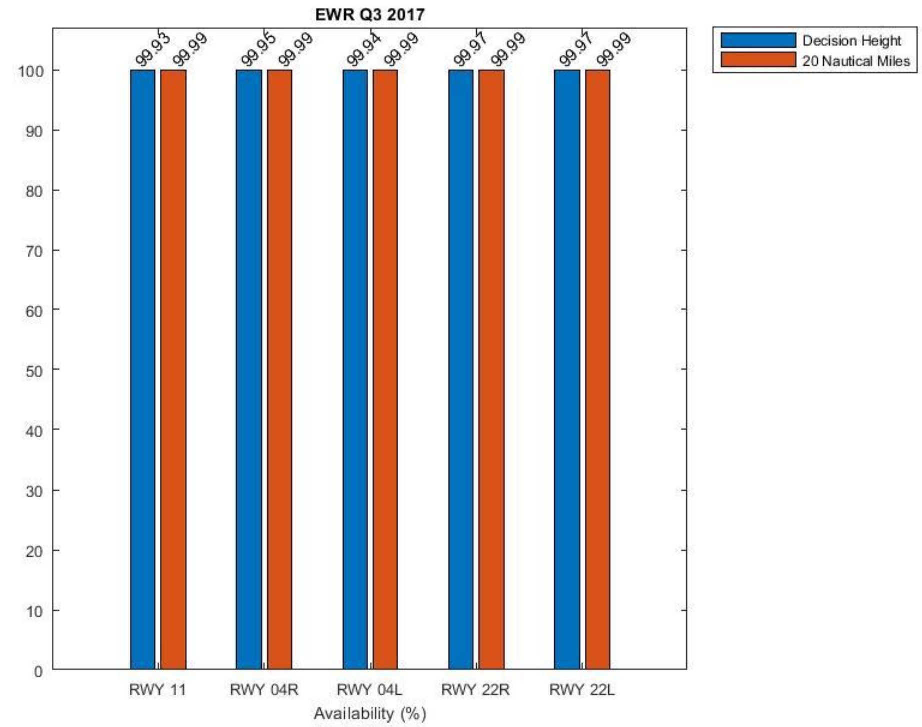

Figure 2 - EWR Availability

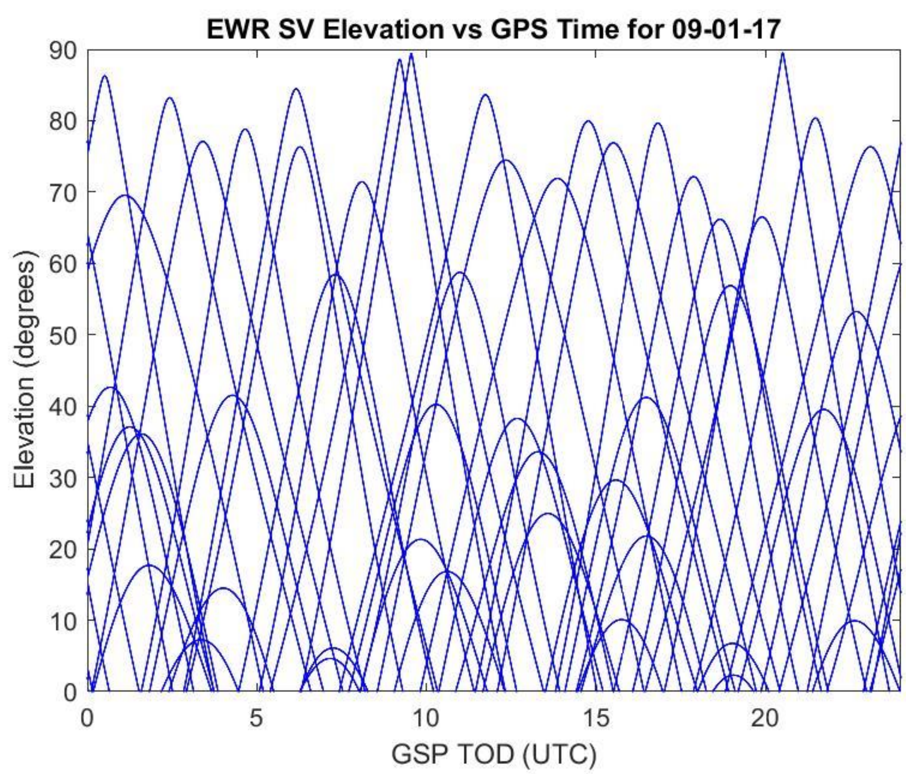

Figure 3 - EWR SV Elevation vs GPS time 08/17/16

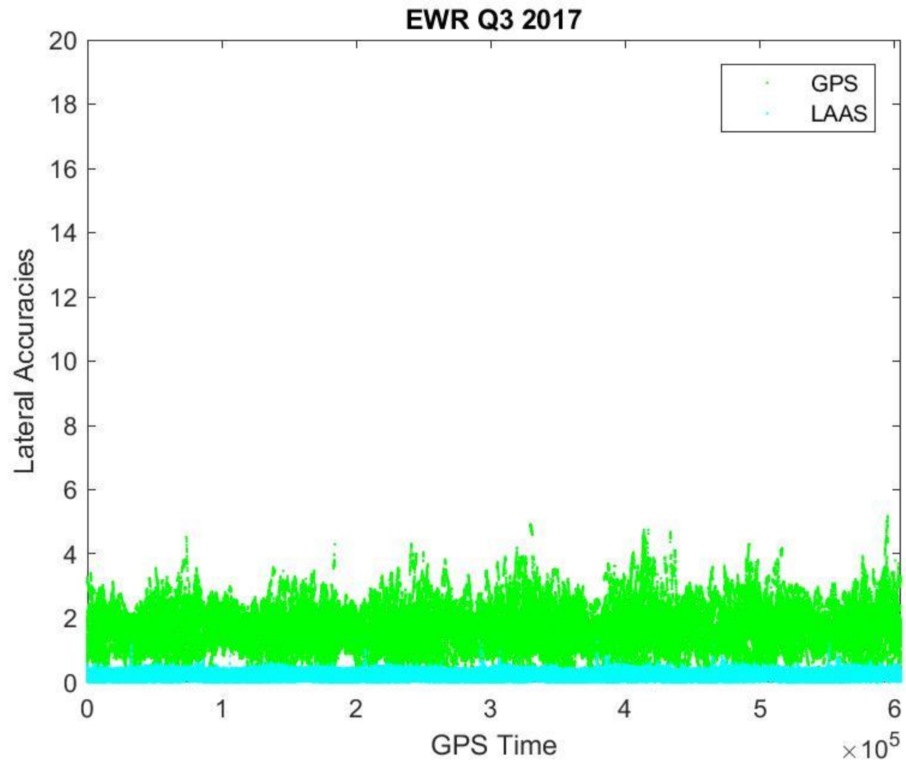

Figure 4 - EWR Lateral Accuracy

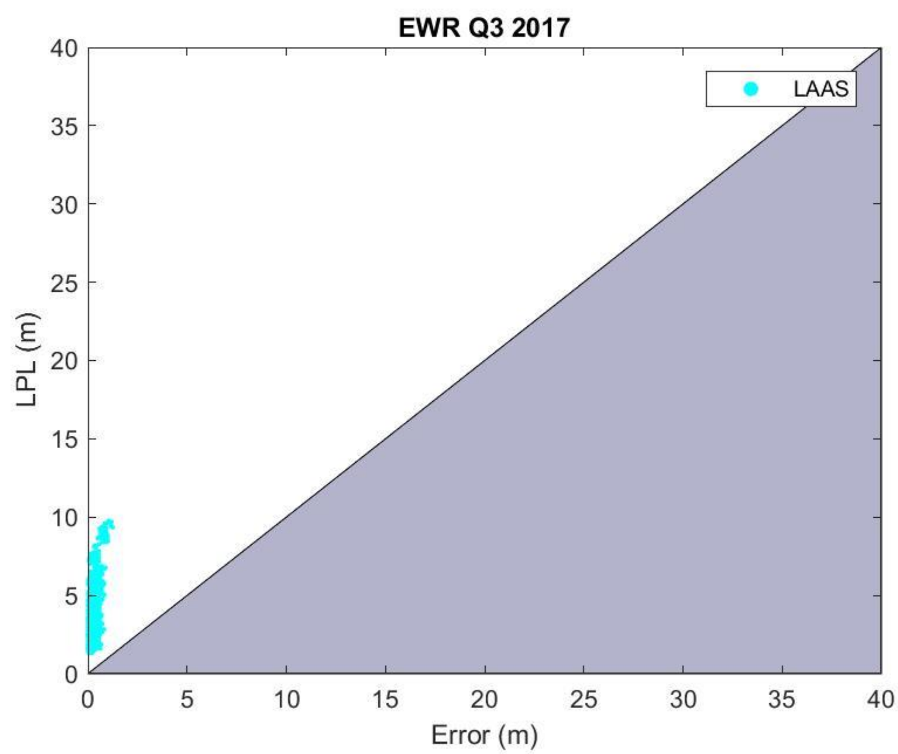

Figure 5 - EWR Lateral Protection Level (LPL) vs. Error

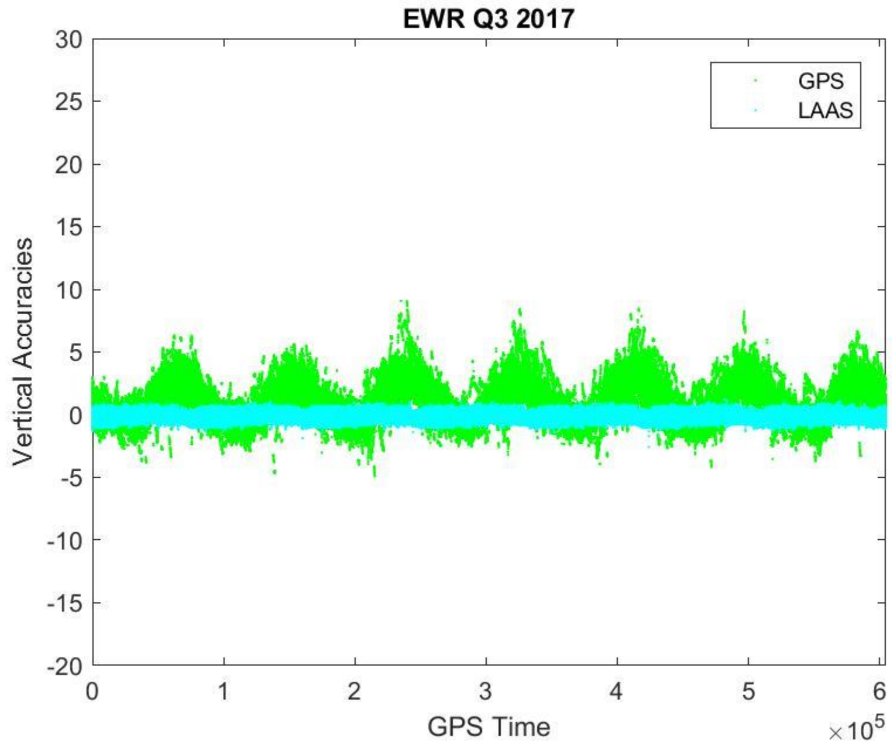

Figure 6 - EWR Vertical Accuracy

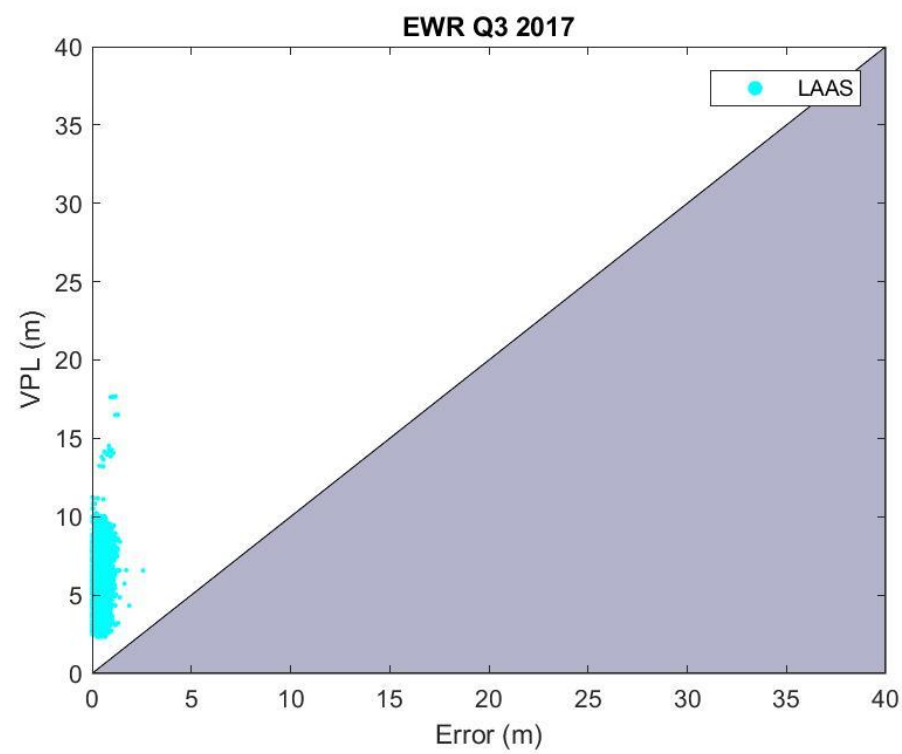

Figure 7 - EWR Vertical Protection Level (VPL) vs. Error

3.2 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

3.2.1 Real Time Performance Data

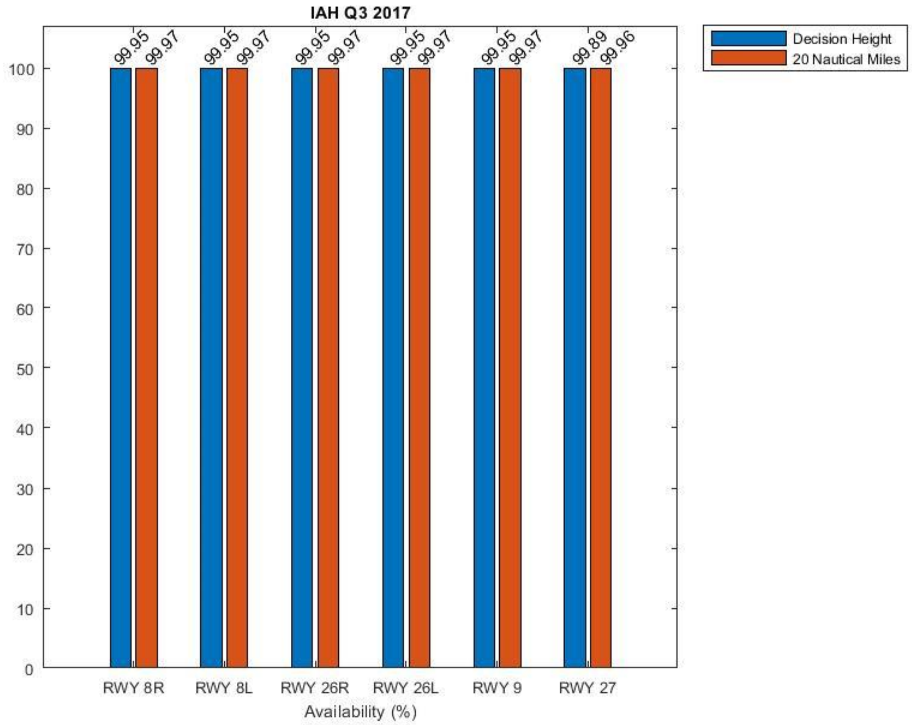

Figure 9 - IAH Availability

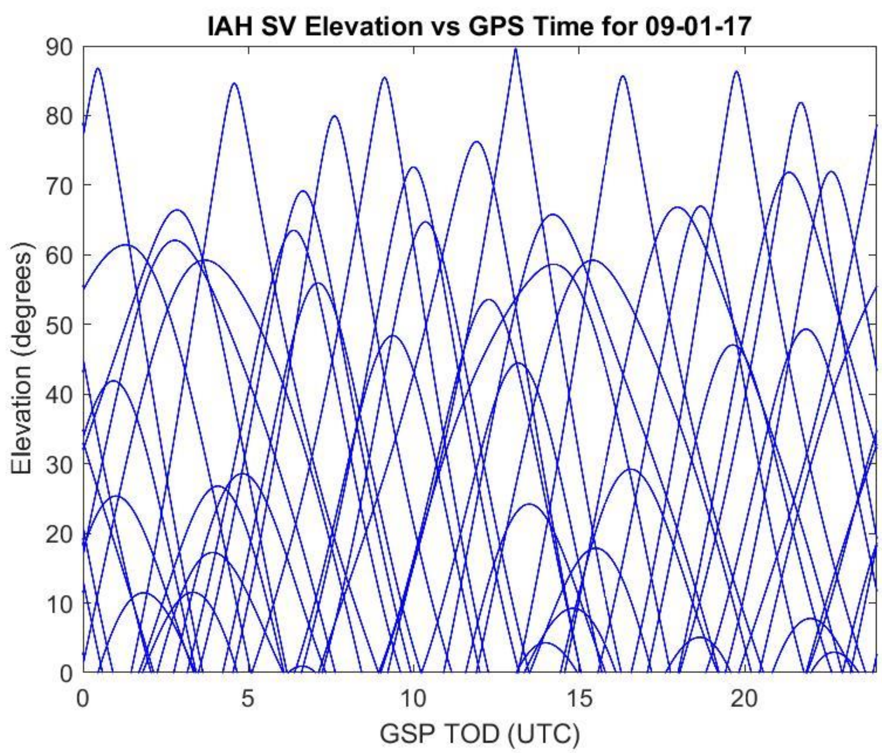

Figure 10 - IAH SV Elevation vs GPS time 08/17/16

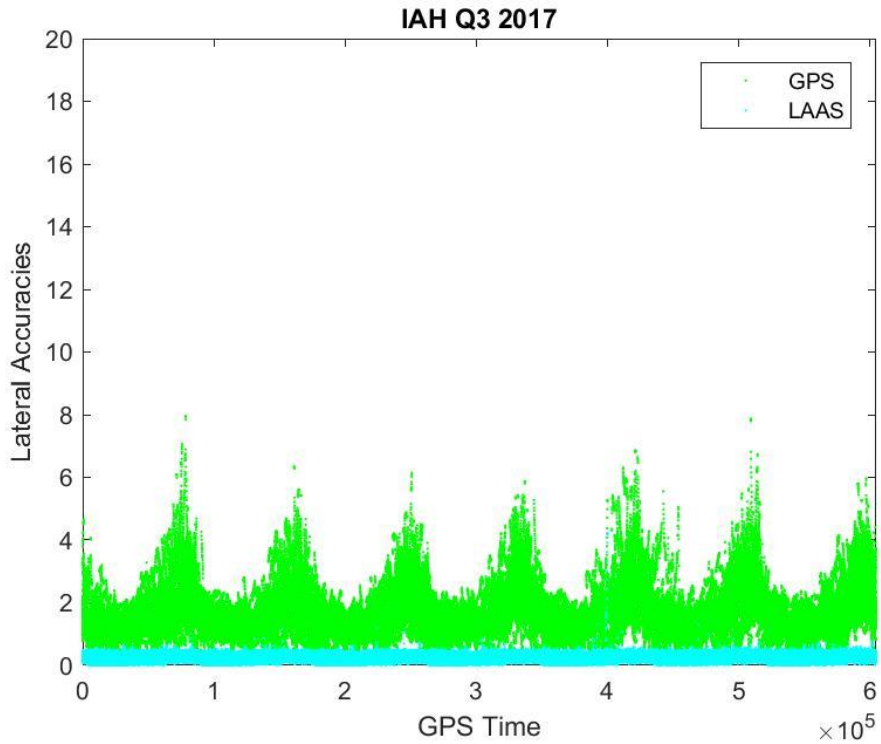

Figure 11 - IAH Lateral Accuracy

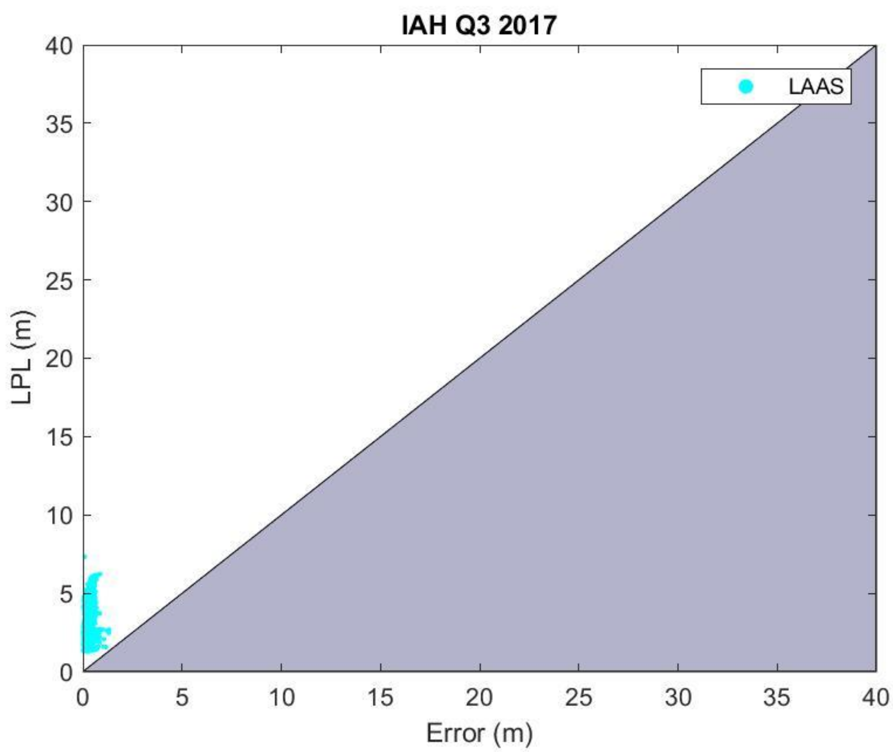

Figure 12 - IAH Lateral Protection Level (LPL) vs. Error

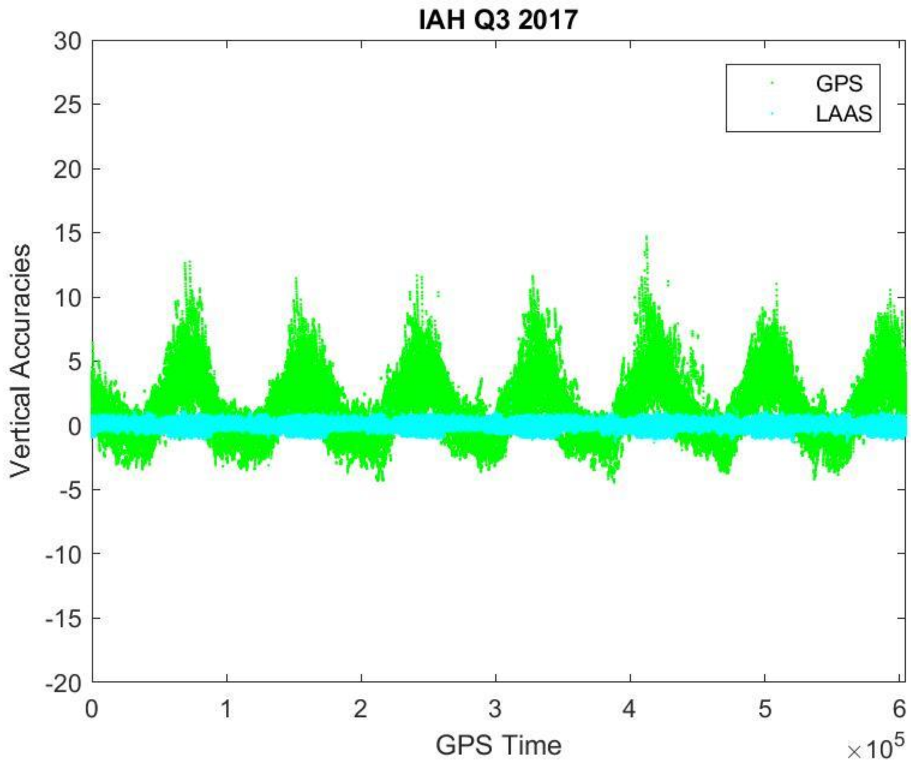

Figure 13 - IAH Vertical Accuracy

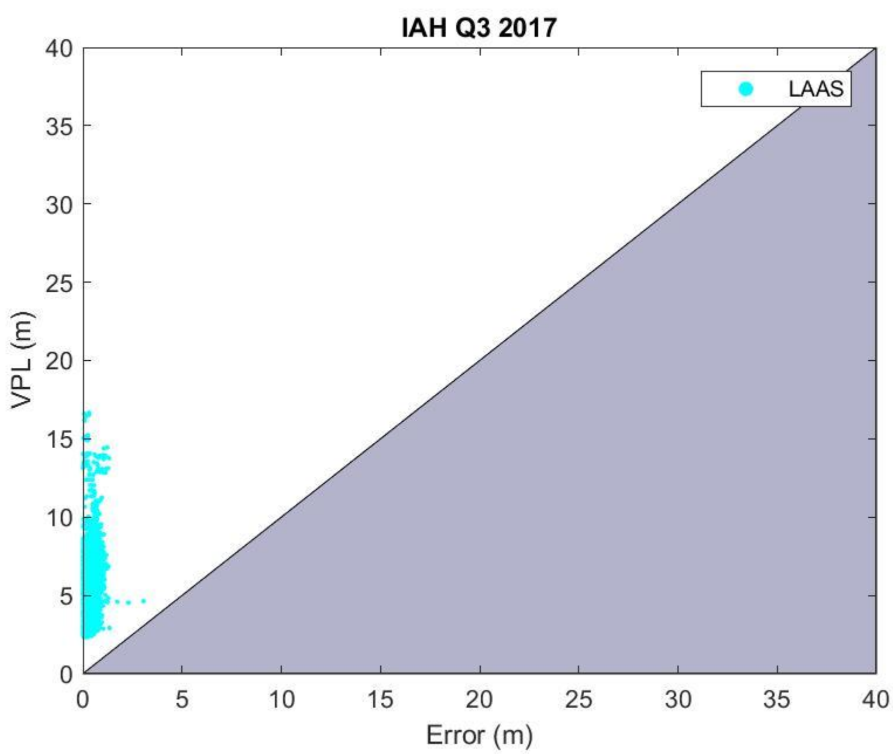

Figure 14 - IAH Vertical Protection Level (VPL) vs. Error

3.3 MWH SLS

- Grant County 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 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 error, and a decrease in system availability
- For the duration of this quarter, the availability is reduced in Moses Lake due to a bad reference receiver and limited satellite availability. A future update to the Block II software version of the SLS-4000 should alleviate these issues.

Figure 15 - MWH SLS-4000 Configuration

3.3.1 Real Time Performance Data

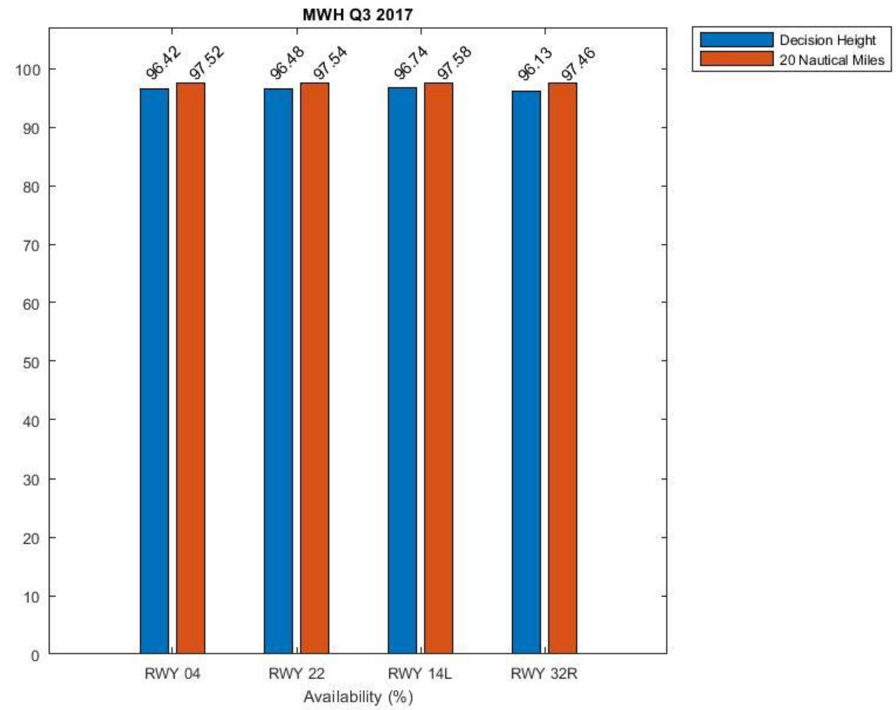

Figure 16 - MWH Availability

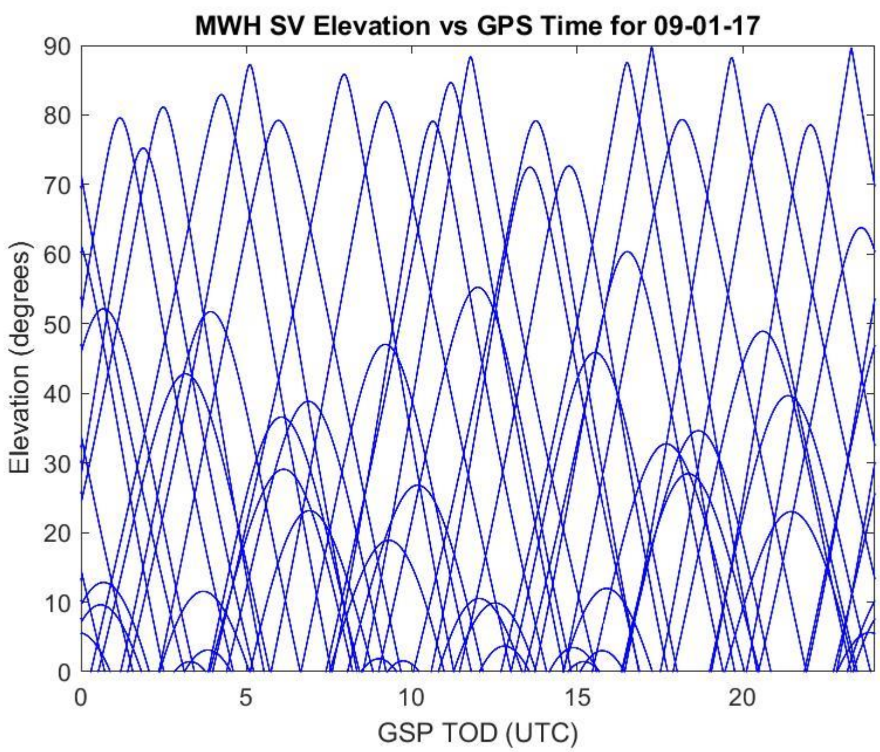

Figure 17 - MWH SV Elevation vs GPS time 08/17/16

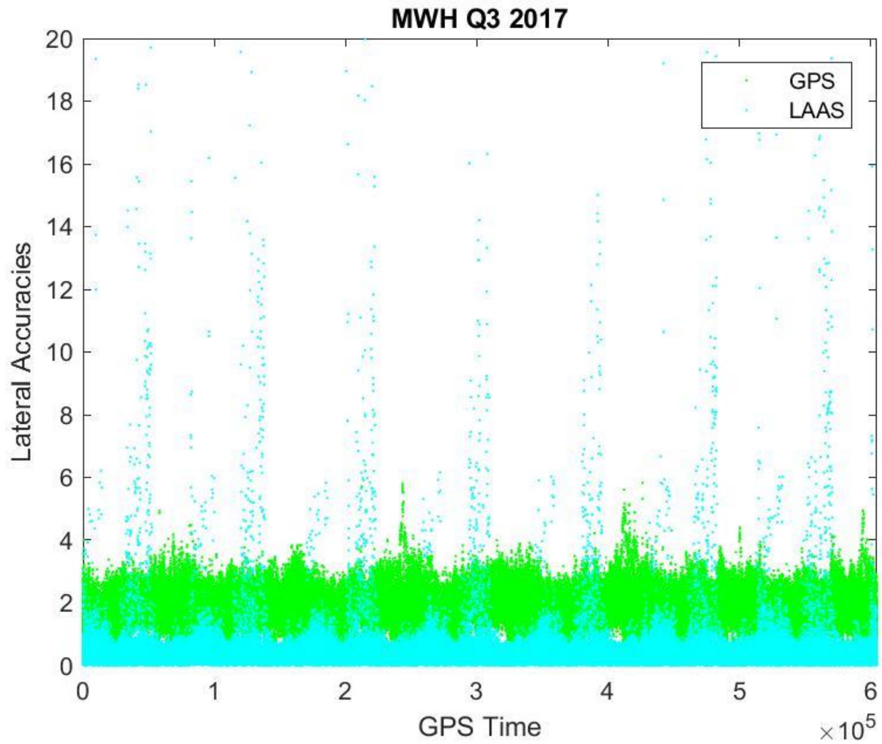

Figure 18 - MWH Lateral Accuracy - High errors occur at times where the VPL > 10 at DH and service would not be available

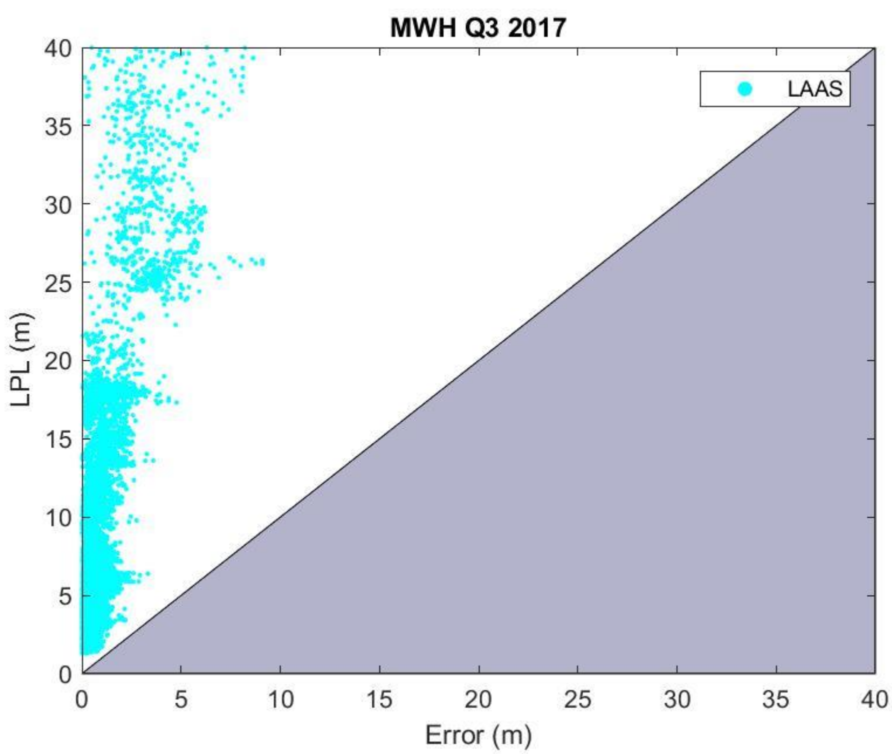

Figure 19 - MWH Lateral Protection Level (LPL) vs. Error

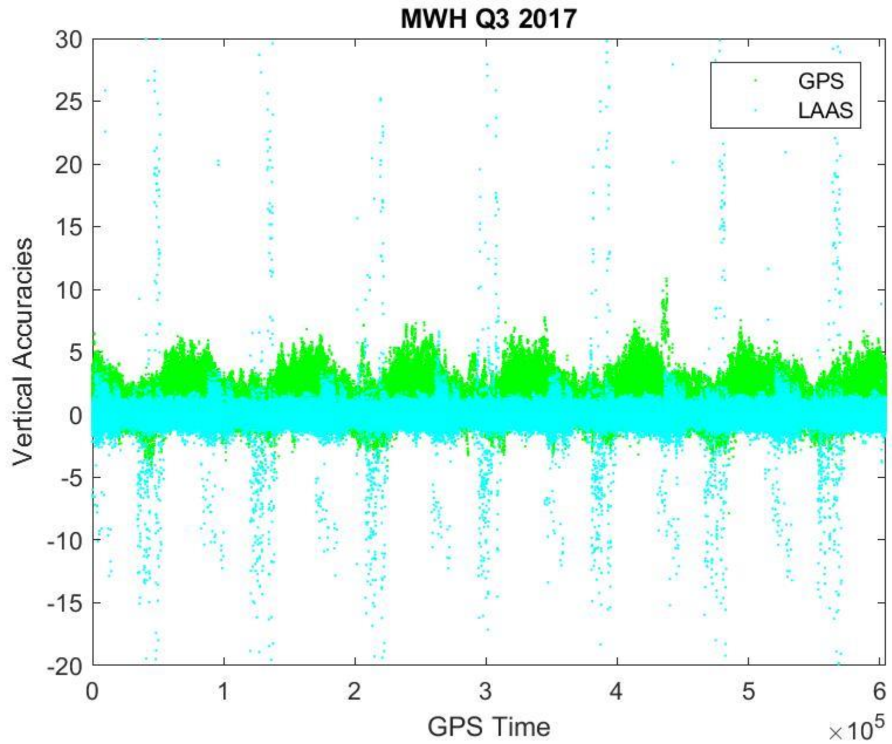

Figure 20 - MWH Vertical Accuracy - High errors occur at times where the VPL > 10 at DH and service would not be available

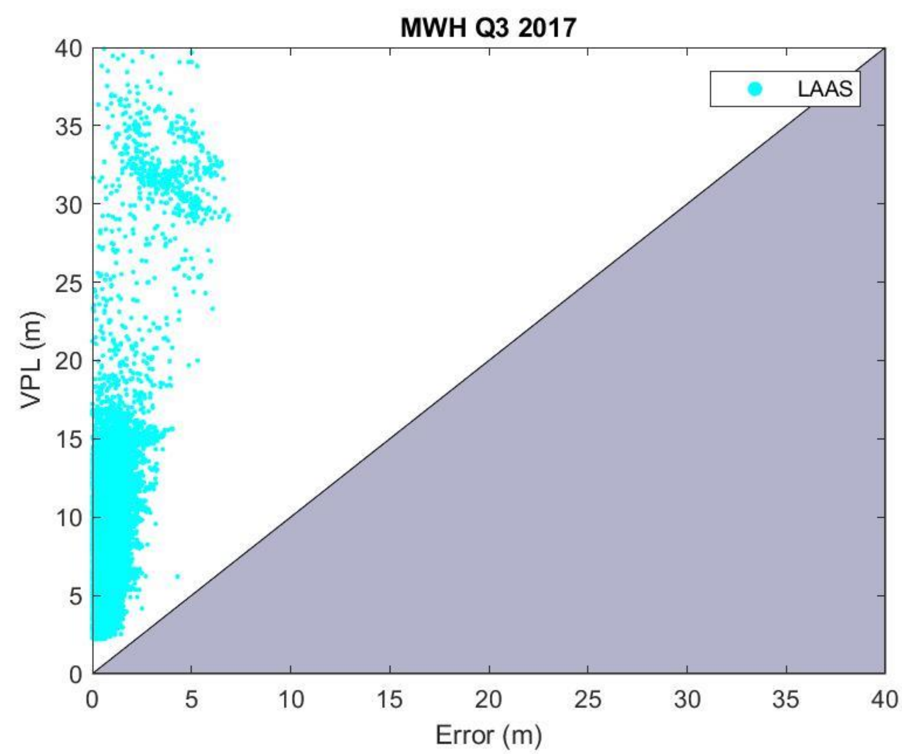

Figure 21 - MWH Vertical Protection Level (VPL) vs. Error

3.4 Rio de Janeiro Brazil

- The antenna on the Brazil GBPM is less robust than the other sites, therefore satellites below 11 degrees may not be tracked as consistently
- The FAA-owned Ground-Based Performance Monitor (GBPM) was unavailable for most of the third quarter 2017 due to a computer failure
- Repairs were made during a trip to Brazil under the GBAS Annex to the FAA/DECEA MOU in late October 2017
- Quarterly performance reports specifically for Brazil will be posted on the LAAS/GBAS website at http://laas.tc.faa.gov/ beginning March 2018.
- See *Section 5.2* for more details

3.5 ACY SLS

- The KACY ground station operates in either CAT-I Block II mode, or in CAT-III prototype mode.
- RSMUs 5 & 6 are not used in CAT-I mode and are part of the GAST-D/CAT-III prototype system.

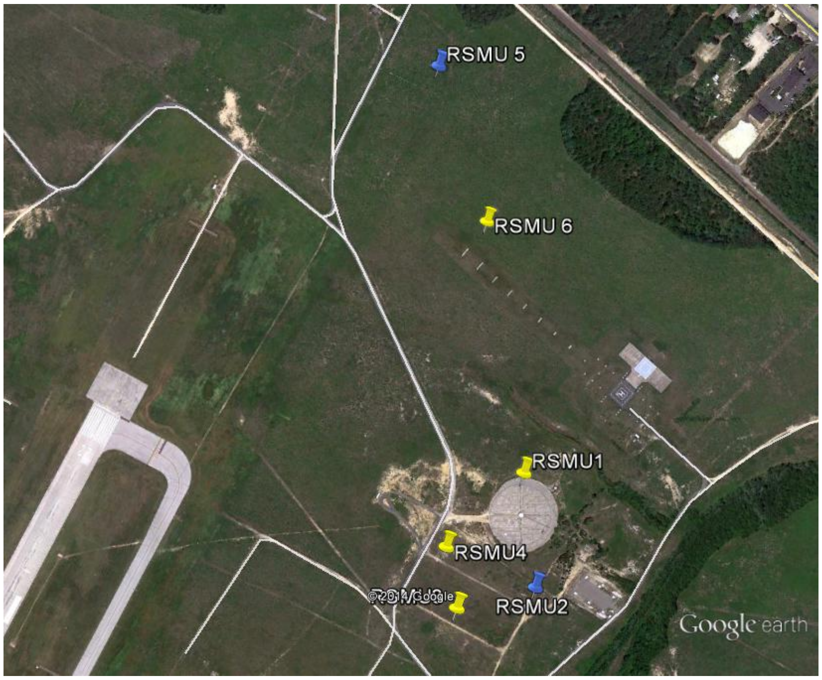

Figure 22 - ACY SLS-4000 Configuration

3.5.1 Real Time Performance Data

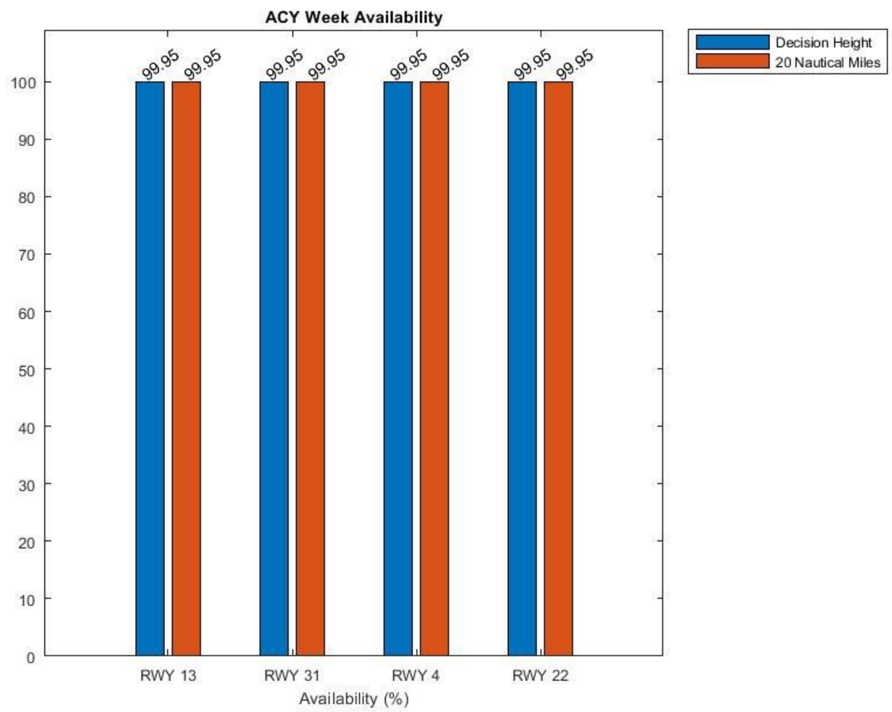

Figure 23 - ACY SLS Availability - The data shown is based upon times when the SLS was transmitting in a nominal mode

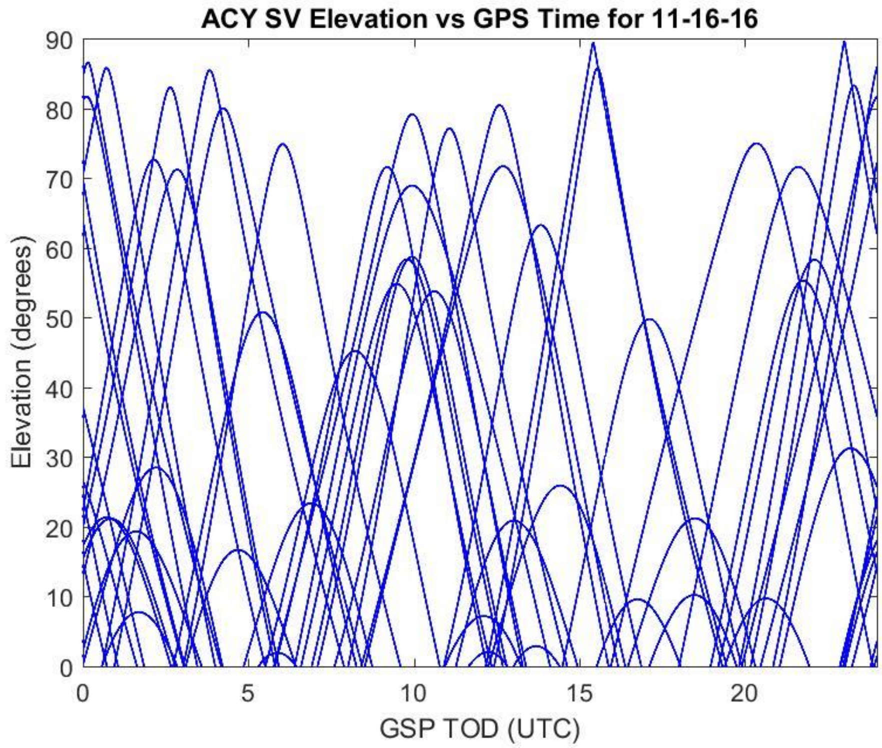

Figure 24 - ACY SV Elevation vs GPS time 08/17/16

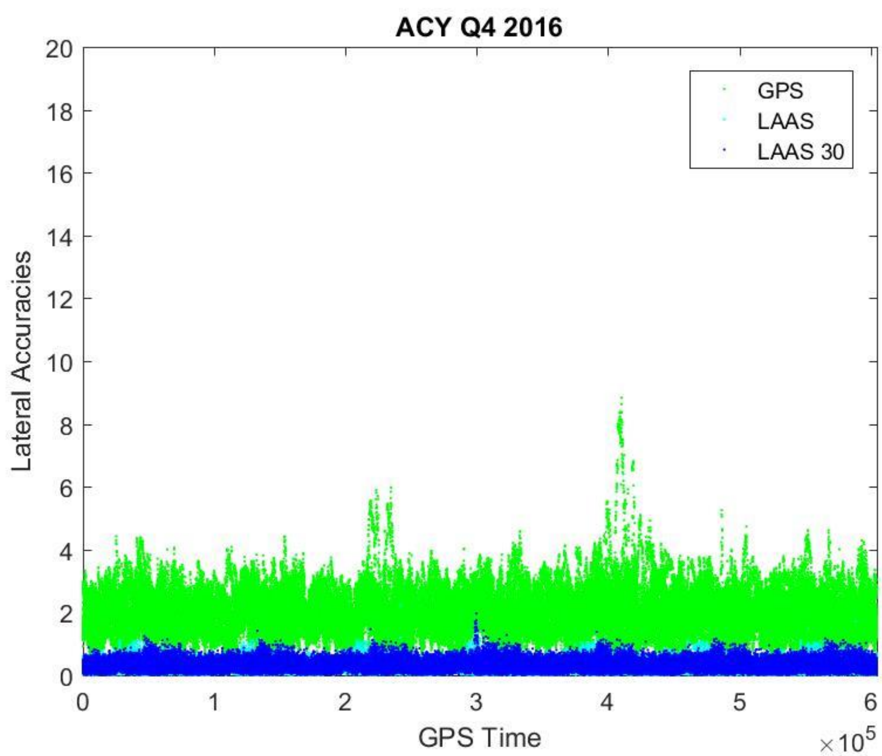

Figure 25 – ACY SLS Lateral Accuracy

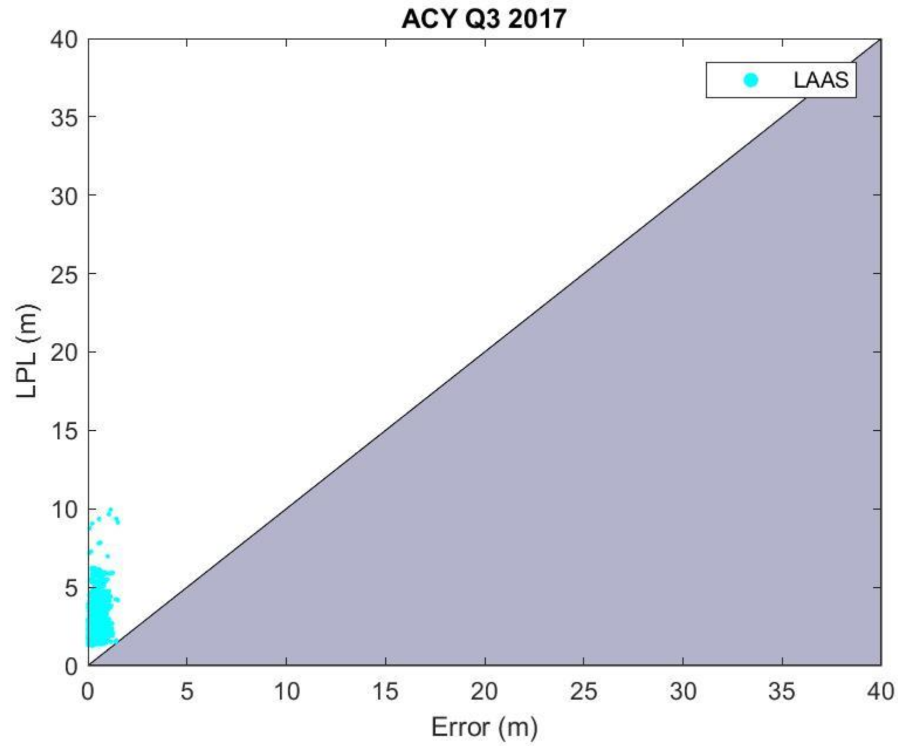

Figure 26 - ACY SLS Lateral Protection Level (LPL) vs. Error

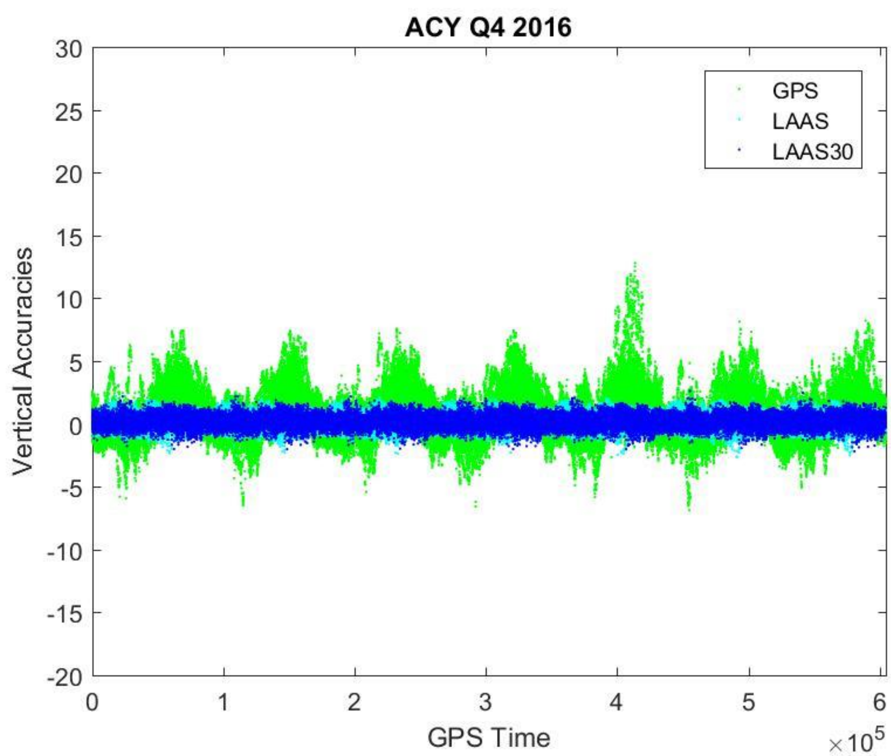

Figure 27 - ACY SLS Vertical Accuracy

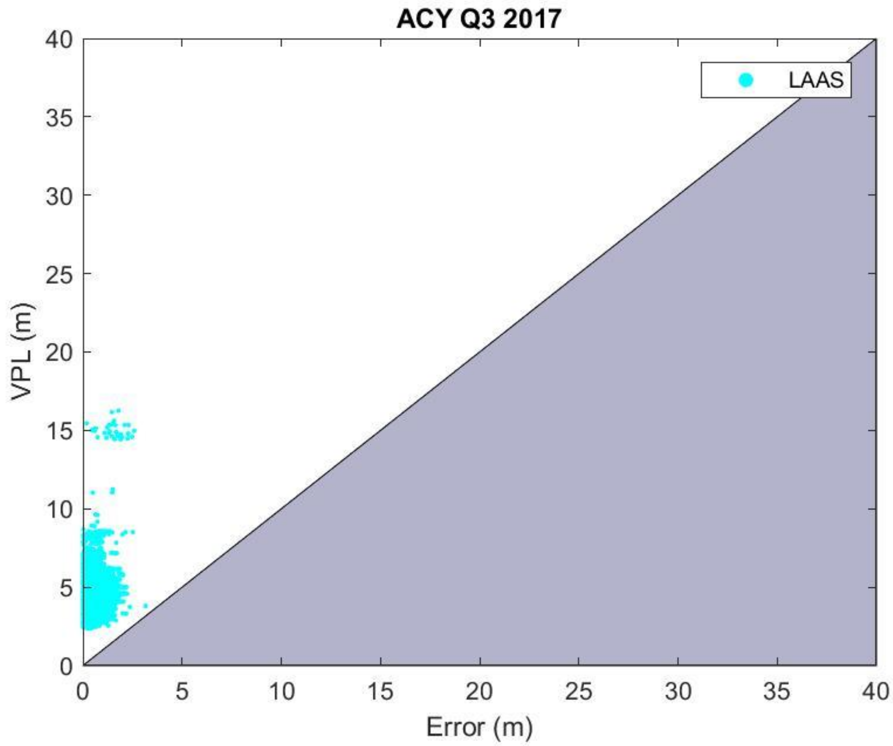

Figure 28 - ACY SLS Vertical Protection Level (VPL) vs. Error

4. Research, Development, and Testing Activities

4.1 Honeywell SLS-4000 Block II

A system design approval letter for Honeywell's Block II update to their approved CAT-I capable system, the SLS-4000, was issued in October 2015. This update is expected to provide greater system availability in CONUS via updates to the Signal Deformation Monitor (SDM) that will allow use of PRNs 11 and 23 and thru finer multipath masking. These changes should alleviate the majority of brief service outages seen with the Block I version of the system. This update also allows for optional SBAS integration requiring a hardware update consisting of a WAAS-capable receiver and antenna. Use of SBAS for real-time ionospheric monitoring will allow the GBAS to not assume it's operating in a worst-case ionospheric environment at all times. This change should further increase system availability by lowering Protection Limit (PL) values. Honeywell also believes that use of the SBAS option could pave the way towards approval of auto-land and CAT-II capabilities. In addition, updates have been made to accommodate the system's use in low-latitude regions, though these updates will not be used in CONUS.

Both PANYNJ and HAS are planning to update their SLS-4000 sites to Block II with the SBAS option, while Boeing plans to update to the base Block II option at its private site at Moses Lake, WA. These updates are likely to occur beginning in December 2017. Updates will require a minimum two-week down period of the SLS-4000 for stability testing, and non-federal maintainers and inspectors will require delta training prior to operational approval being reissued.

4.2 System Design Approval (SDA) - Honeywell SLS-5000 (GAST-D)

At an ICAO Navigation Systems Panel (NSP) GBAS Working Group (GWG) meeting in December 2016, Honeywell International (HI) announced their decision to pause GAST-D ground system development work at the end of CY 2017 as they wait for clear indication of industry commitment to GBAS deployment. At this time HI will continue moving forward with submittals of safety documentation related to their potential future GAST-D capable GBAS ground system, the SLS-5000. These submittals are expected to continue thru 2017 and will include GAST-D Integrity Risk Compliance Arguments (IRCAs), Algorithm Description Documents (ADDs) and Hazardously Misleading Information (HMI) analyses as well as the Functional Hazard Assessment (FHA), Preliminary System Safety Assessment (PSSA) and updates to existing GAST-C monitors as required. All software development work for the SLS-5000 has been postponed.

The FAA will continue review work of SLS-5000 safety documentation through 2017 as planned. Weekly technical teleconferences between the FAA and Key Technical Advisors (KTAs) and Honeywell will continue through the year. The FAA's SLS-5000 approval panel will also move forward with addressing high level questions on required design assurance level, hazard classifications and other issues that could impact final SDA.

4.3 VDB Message Failure Rate Lab Testing

The Technical Center (ANG-C32) is in the process of developing the capability to conduct VDB Message Failure Rate (MFR) Lab Testing (**Figure 29**). This capability will enable the testing of a simulated VDB radio link by measuring the number of VDB messages that are lost. VOR or ILS

Localizer signals will be radiated on adjacent channels, at different signal levels, during these tests and the impact to the desired VDB signal will be determined by the number of lost messages. Lost messages are either messages that were not received or failed the CRC test. The MOPS (DO-253D, Sec. 2.2.5) specifies a 1/1000 maximum message loss rate for the VDB link so if the number of lost messages exceeds this amount the test will have failed. New software is being developed to support this enhancement to the current lab test capability.

The upcoming lab tests are in support of RTCA SC-159 WG4 and ICAO NSP/SWG. The ultimate goal is to determine the maximum acceptable Desired to Undesired (D/U) signal difference that can be tolerated by a commercial GBAS receiver in the presence of other Navigation aids. The results of this testing will be presented to the RTCA SC-159 WG4 VDB Ad Hoc Working Group and ICAO as appropriate.

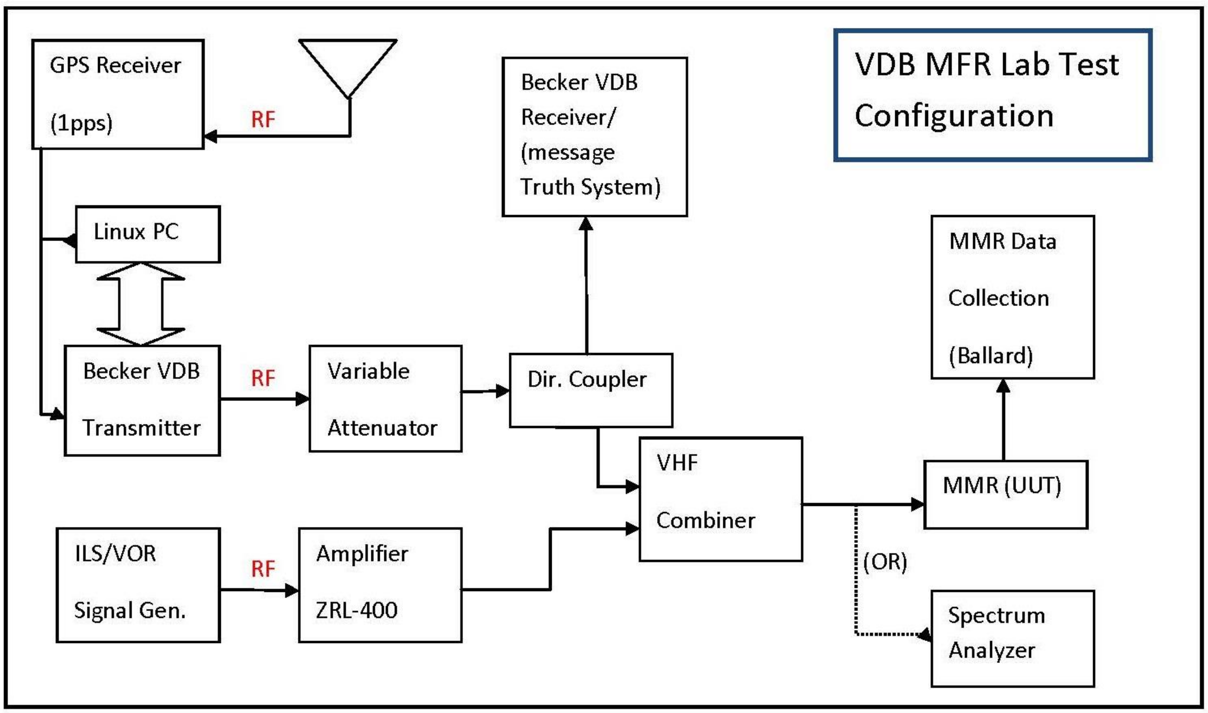

Figure 29 - VDB MFR Lab Test Equipment Configuration

4.4 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 4 – NANU Types and Definitions

NANU	TYPE	PRN	Start Date	Start Time (Zulu)	End Date	End Time (Zulu)
2017064	FCSTMX	23	07/11/2017	2300	07/12/2017	0700
2017065	FCSTMX	05	07/13/2017	2100	07/14/2017	0500
2017066	FCSTSUMM	02	07/06/2017	1841	07/07/2017	0009
2017067	FCSTSUMM	23	07/11/2017	2345	07/12/2017	0220
2017068	FCSTMX	07	07/18/2017	2030	07/19/2017	0430
2017069	FCSTSUMM	05	07/13/2017	2136	07/14/2017	0020
2017070	GENERAL	N/A	07/20/2017	N/A	N/A	N/A
2017071	FCSTSUMM	07	07/18/2017	2127	07/19/2017	0327
2017072	FCSTDV	25	08/03/2017	1605	08/04/2017	0405
2017073	FCSTMX	17	08/08/2017	2300	08/09/2017	0700
2017074	FCSTMX	15	08/10/2017	1400	08/10/2017	2200
2017075	FCSTSUMM	25	08/03/2017	1614	08/03/2017	2128
2017076	FCSTSUMM	17	08/08/2017	2345	08/09/2017	0335
2017077	FCSTMX	31	08/15/2017	1300	08/15/2017	2100
2017078	FCSTMX	02	08/18/2017	0230	08/18/2017	1030
2017079	FCSTSUMM	15	08/10/2017	1439	08/10/2017	1752
2017080	UNUSUFN	09	08/11/2017	1059	N/A	N/A
2017081	UNUSABLE	09	08/11/2017	1058	08/11/2017	1341
2017082	FCSTDV	09	08/18/2017	0800	08/18/2017	2000
2017083	FCSTCANC	09	08/18/2017	0800	N/A	N/A
2017084	FCSTSUMM	31	08/15/2017	1502	08/15/2017	1720

2017085	FCSTMX	29	08/22/2017	1930	08/23/2017	0330
2017086	FCSTMX	12	08/24/2017	0530	08/24/2017	1330
2017087	FCSTDV	09	08/25/2017	0815	08/25/2017	2015
2017088	FCSTSUMM	02	08/18/2017	0312	08/18/2017	0536
2017089	FCSTMX	21	08/29/2017	1700	08/30/2017	0100
2017090	FCSTDV	05	08/31/2017	1915	09/01/2017	0715
2017091	FCSTSUMM	29	08/22/2017	2008	08/22/2017	2221
2017092	FCSTSUMM	12	08/24/2017	0613	08/24/2017	0835
2017093	FCSTSUMM	09	08/25/2017	0847	08/25/2017	1358
2017094	FCSTSUMM	21	08/29/2017	1738	08/29/2017	2007
2017095	FCSTDV	13	09/07/2017	1030	09/07/2017	2230
2017096	FCSTSUMM	05	08/31/2017	1956	09/01/2017	0113
2017097	FCSTSUMM	13	09/07/2017	1050	09/07/2017	1757
2017098	FCSTDV	26	09/19/2017	1120	09/19/2017	2320
2017099	UNUSUFN	07	09/12/2017	0626	N/A	N/A
2017100	UNUSABLE	07	09/12/2017	0625	09/12/2017	1007
2017101	UNUSUFN	07	09/12/2017	1342	N/A	N/A
2017102	UNUSUFN	01	09/14/2017	0021	N/A	N/A
2017103	UNUSABLE	01	09/14/2017	0021	09/14/2017	0926
2017104	UNUSABLE	07	09/12/2017	1342	09/15/2017	2009
2017105	UNUSUFN	25	09/17/2017	1500	N/A	N/A
2017106	UNUSABLE	25	09/17/2017	1500	09/17/2017	1813
2017107	FCSTCANC	26	09/19/2017	1120	N/A	N/A
2017108	FCSTDV	32	10/04/2017	1000	10/05/2017	1000
2017109	UNUSUFN	01	10/04/2017	0937	N/A	N/A
2017110	UNUSABLE	01	10/04/2017	0937	10/04/2017	1256
2017111	FCSTSUMM	32	10/04/2017	1123	10/04/2017	1611
2017112	FCSTDV	29	10/12/2017	1359	10/13/2017	0159
2017113	FCSTSUMM	29	10/12/2017	1421	10/12/2017	1728
2017114	FCSTDV	26	10/19/2017	1630	10/20/2017	0430
2017115	FCSTSUMM	26	10/19/2017	1646	10/20/2017	0039
2017116	FCSTDV	31	10/27/2017	0045	10/27/2017	1245
2017117	FCSTDV	29	11/02/2017	0307	11/03/2017	0100
2017118	FCSTSUMM	31	10/27/2017	0101	10/27/2017	0647

Table 5 – NANU List

5. Meetings and Conferences

5.1 FAA LAAS Integrity Panel (LIP)

The FAA LAAS Integrity Panel (LIP) met at Honeywell International in Coon Rapids, MN, September 18-21, 2017. The purpose of the LIP was to review the progress of the design for System Design Approval (SDA) of the Honeywell SLS-5000 GAST D (Category III) GBAS. The FAA LIP is comprised of the GBAS Key Technical Advisors, represented by various FAA organizations, FAA consultants and subject matter experts in academia. The discussions at the LIP addressed several of the key technical aspects of the SLS-5000 design, including the ionospheric gradient mitigation (IGM) simulation modeling, code-carrier divergence (CCD) monitoring, ephemeris monitor, and signal deformation monitor (SDM). The discussions included a review of the IGM simulation model developed by the Korea Advanced Institute of Science and Technology (KAIST), which is being used for independent validation of the IGM design.

5.2 Port Authority of New York New Jersey GBAS Installation Meeting

On September 26, 2017, ANG-C32 personnel participated in two meetings with the PANYNJ, Honeywell International and additional GBAS Stakeholders within the FAA. The first meeting was a Kick-Off focused on logistics for an FAA approved performance upgrade to the existing Newark (EWR) GBAS. The second meeting focused on preparations for three new GBAS systems to be installed at airports under the PANYNJ's control. The meetings were headed by the airports "Delay Reduction" office of the PANYNJ.

The Newark GBAS is to be upgraded in December 2017 to Honeywell's latest FAA-approved configuration: SLS-4000 Block-IIs. This upgrade incorporates availability improvements and updated ionospheric condition monitoring. The Port Authority is also pursuing Block-IIs GBAS systems for LaGuardia Airport, Teterboro Airport, and John F. Kennedy International Airport. Siting alternatives for the three airports were discussed as well as civil works and infrastructure requirements. The 7460 forms required for GBAS installation work to proceed have already been submitted for JFK and LGA.

5.3 DECEA / FAA Program Management Review

Representatives from the FAA Office of Advanced Concepts & Technology Development, Engineering Development Services Division, Navigation Branch (ANG-C32), Boston College, Mirus, and Honeywell met at Santos Dumont Airport (SDU) in Rio de Janeiro Brazil October 23 – 27, 2017. The purpose of this trip was to support the US/Brazil Aviation Partnership Agreement, Article V (Safety), the DECEA/FAA Bi-lateral Agreement, Annex I (Ionospheric Research), and the US Trade Development Agency (TDA)/SDTP Grant Agreement in efforts assist DECEA in the validation of the SLS-4000 in Brazil. Regular teleconferences will continue every other Wednesday with two more follow up meetings in March 2018 at São Paulo and September 2018 in Rio de Janeiro.

In conjunction with the meetings at SDU, repairs were made to the existing Ground Based Performance Monitor located at Galeão International Airport (GIG), and an inventory check was taken for the equipment sent down to support various GBAS efforts since 2002.

The goal of the work being conducted under the GBAS Annex to the FAA/DECEA MOU is to support Brazil granting approval for CAT-I operations during limited hours to the Honeywell SLS-4000 Block II GBAS. The goal date for this achievement is in mid-2019. ANG is waiving reimbursement for federal labor hours under this agreement, while DECEA is covering federal employee travel costs, and labor hours and travel costs for contract support.

5.4 ICAO Navigation Systems Panel (NSP) Meeting – October 2017

The GBAS Working Group met in Montreal, Canada October 10-13, 2017. Progress was made on technical issues associated with GBAS VDB compatibility with ILS and VOR. Related papers were presented by Germany, France, and Japan. The VDB ad-hoc group developed a framework of new requirements to address the issue. This included proposed SARPs changes defining conditions where the ILS localizer should not transmit and potentially interfere with GBAS. This also included a framework for new adjacent channel rejection requirements for VDB receivers.

Progress was reported on the use of GBAS in low-latitude regions. This included the development of ionospheric threat models in Singapore and India. Status was reported on several of the operational GAST C (Category I) GBAS installations. The GBAS in Melbourne, Australia was commissioned June 2017. The Melbourne GBAS is now being used for more approach operations than the ILS systems. The Frankfurt, Germany GBAS will be assessed for use with DMAX set to 35 NM, with an expanded approach service volume of 25 NM.

The GWG initiated discussions about the development of standards for dual-frequency multi-constellation (DFMC) GBAS. It was generally agreed that a concept paper should be developed for DFMC GBAS.

5.5 RTCA SC-159 Meeting – October 2017

SC-159 Working Group 4 (GBAS) met in Washington, DC October 24-26, 2017. The first two days were a joint meeting with Working Group 2 (SBAS). The joint meeting discussed the development of Minimum Operational Performance Standards (MOPS) for dual-frequency multi-constellation (DFMC). The plan is to include requirements for GPS L5 and Galileo E1 and E5a signals, in addition to the current GPS L1.

The Working Group 4 meeting concentrated on VDB compatibility with ILS and VOR. The group developed a framework for new adjacent channel rejection requirements for VDB in the GBAS MOPS. This includes strawman values for adjacent channel rejection. The proposed new requirements will be reviewed by airborne equipment manufacturers.

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

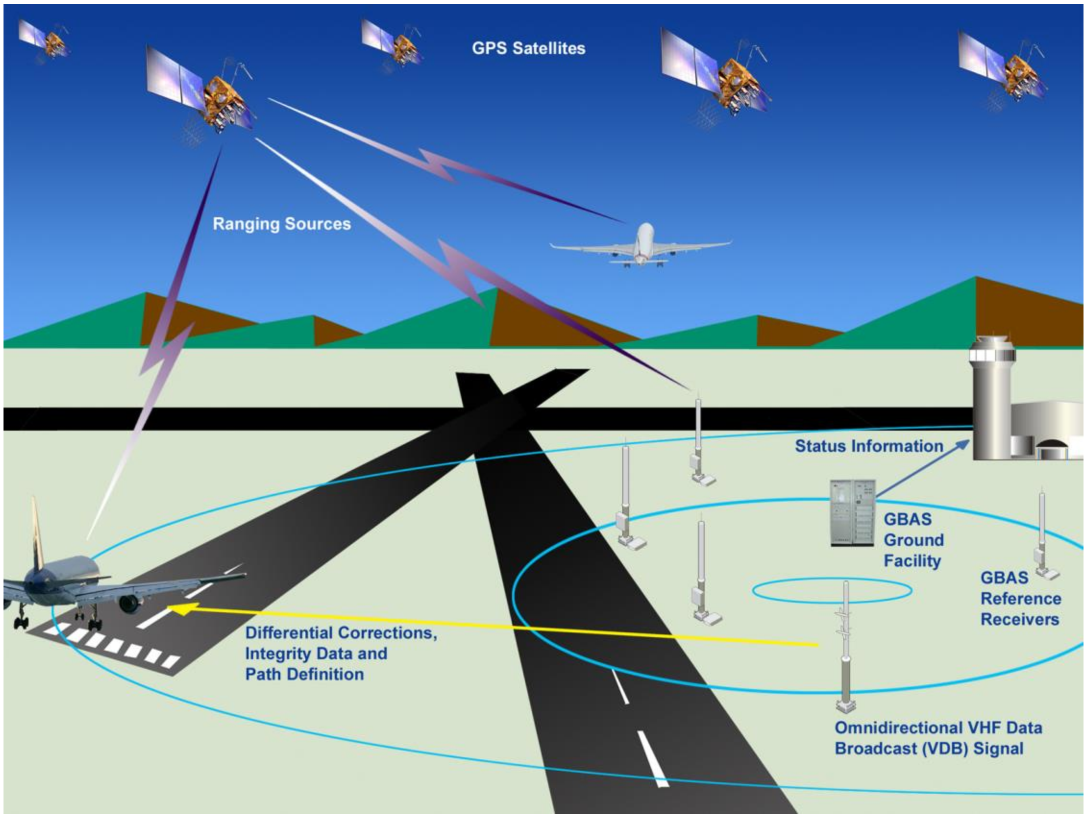

Figure 30 – GBAS Architecture Diagram

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.

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 (LT) sites; there were originally five LT sites (LT1 through LT5), excluding LT4. LT4 was originally used for the L1/L2 site (**Figure 31**).

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 31 - 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 32 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.

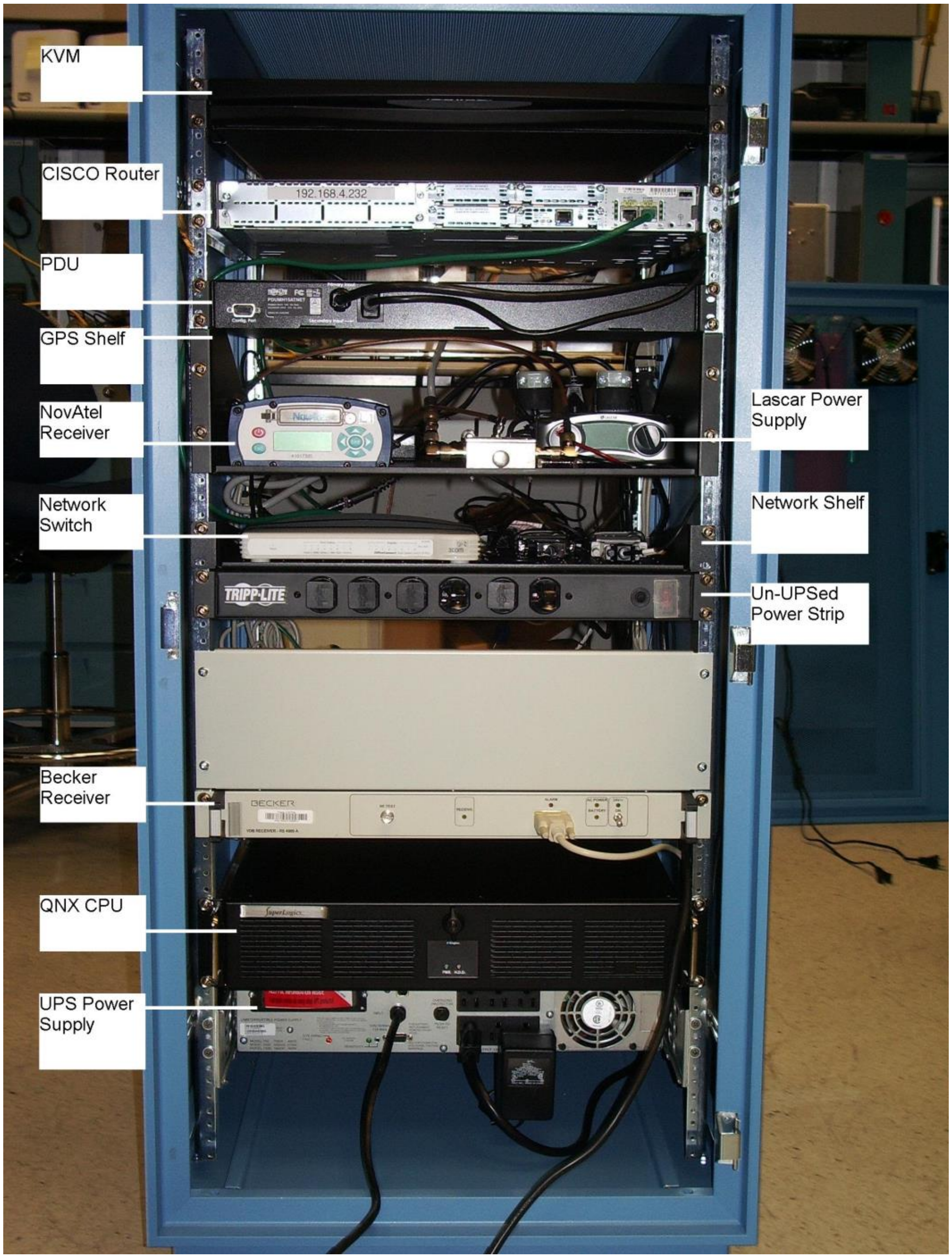

Figure 32 - Ground Based Performance Monitor (GBPM)

Glossary of Terms

—A—
ACY
Atlantic City International Airport 3, 5
—C—
CPU
Central Processing Unit 33
—E—
EWR
Newark Liberty International Airport 5, 6
—F—
FAA
Federal Aviation Administration.... 3
—G—
GBAS
Ground Based Augmentation System 3
GBPM
Ground Based Performance Monitor 3
GIG
Galeão International Airport 5
GNSS
Global Navigation Satellite System 34
GPAR
GBAS Performance Analysis Report.... 3
GSL
GBAS Service Level....32
—H—
HI
Honeywell International.... 3
HPL
Horizontal Protection Level 32
—I—
IAH
George Bush Intercontinental Airport 5, 10
—L—
LHCP
Left Hand Circular Polarized 35
LT
LAAS Test....34
—M—
MASPS
Minimum Aviation System Performance Standards....31
MI
Misleading Information 31
MLA
Multipath Limiting Antenna....34
MWH
Grant County International Airport.... 5

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