THE LOCAL AREA AUGMENTATION SYSTEM: AN AIRPORT SURFACE GUIDANCE APPLICATION SUPPORTING THE NASA RUNWAY INCURSION PREVENTION SYSTEM DEMONSTRATION AT THE DALLAS/FORT WORTH INTERNATIONAL AIRPORT

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Abstract

The Runway Incursion Prevention System (RIPS) program is an ongoing National Aeronautics and Space Administration (NASA) research effort intended to reduce the number of runway incursions at airports throughout the National Airspace System (NAS). The RIPS program flight tests and demonstration of technologies activities at the Dallas/Fort Worth (DFW) International Airport were completed in October 2000. The demonstration involved the application of both airborne and ground based technologies, as well as the integration of these technologies to form a complete runway incursion prevention system.

This paper presents information on the research activities conducted at DFW related to the Ohio University Avionics Engineering Center (AEC) installed Global Positioning System (GPS) Local Area Augmentation System (LAAS) ground facility (LGF), it's use, the preliminary results obtained, and observations or conclusions when appropriate. A description of the RTCA DO-247 Surveillance and Guidance Sensor requirements is provided. Details of the DFW LAAS upgrade for NASA RIPS testing, AEC GPS LAAS test van equipage, and the Rockwell Collins Multimode LAAS receiver integration activities are presented. Data analysis activities have just been initiated.

Runway Incursion Prevention System – An Introduction

The RIPS program is a NASA research effort intended to "prevent runway incursion accidents through technologies that enhance surface situational awareness, navigation, and alerting for the pilot"[1]. The RIPS program flight tests and demonstration of technologies at DFW were performed in October 2000. The RIPS demonstration involved the application of both airborne and ground based technologies, as well as the integration of these technologies to form a complete runway incursion prevention system. One of the technologies employed is the use of LAAS to provide enhanced precision GPS position information.

NASA tasked the Ohio University Avionics Engineering Center (AEC) to upgrade and operate the current LGF at DFW. The upgrade supports the more stringent accuracy requirements for precision approach, landing and airport surface guidance operations as compared to surface surveillance requirements. The existing LGF was installed as part of the Federal Aviation Administration (FAA) Runway Incursion Reduction Program (RIRP) to provide differential corrections for GPS data used in airport surface surveillance applications.

GPS - Local Area Augmentation System (LAAS) Overview

LAAS is a differential GPS-based (DGPS) precision approach and landing system; it may also be used to support airport surface operations. LAAS is capable of providing GPS corrections for sub meter positional accuracy and consists of satellite, ground-based and airborne (or user) sub-systems (Figure 1).

The ground subsystem includes multiple reference antennas, receiving equipment, processing software/hardware, and VHF Data Broadcast (VDB) equipment.

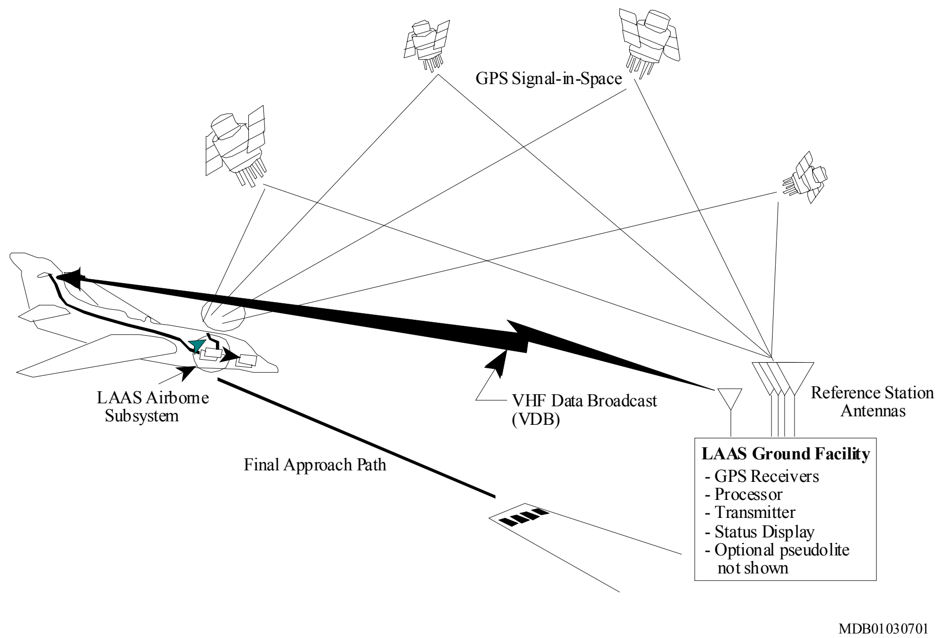

Figure 1. LAAS Satellite, Ground-Based, and Airborne Components.

The GPS signals received by multiple reference antennas are processed by separate GPS receivers to obtain differential-correction and integrity information. The VDB equipment transmits the correction and integrity information to the airborne (or user) subsystem. The airborne subsystem uses the information obtained from the GPS satellite constellation and the ground subsystems to calculate differentially corrected position estimates.

For the RIPS system at DFW, LAAS was used to provide differential corrections that enable the generation of very accurate DGPS position/velocity estimates. These position/velocity estimates, along with the user identifier, are broadcast by the data link equipment, thus supporting both airborne and/or surface guidance and surveillance operations. AEC was responsible for the upgrade of the LGF installed for the FAA's RIRP effort, operation, and evaluation of the LGF at DFW.

In conjunction with RIPS activities, AEC personnel performed additional evaluation of the LGF using a specially equipped AEC test van. This test was performed to ensure that the LGF was operating properly and to collect data for subsequent performance analysis. The results of the performance analysis are intended to verify the capability of LAAS to meet the surveillance-and-guidance function sensor-performance requirements presented in RTCA DO-247, "The Role of the Global Satellite Navigation System (GNSS) in Supporting Airport Surface Operations." Performance analysis of LAAS data from NASA RIPS activities has been initiated at the time of preparation of this paper.

RTCA DO-247 Guidance and Surveillance Sensor Requirements

A viable advanced surface movement guidance and control system must support the primary functions of surveillance, routing, guidance, and control and it must provide for the timely exchange of operationally essential information between the various system elements and users[2].

The four functions: surveillance, routing, guidance, and control, are typically supported by the integration of subsystems that support one or more of these functions. RTCA DO-247 focuses on the application of satellite technology to support airport surface operations. DO-247 presents a system for surface surveillance and guidance based on the Global Navigation Satellite System (GNSS) for the guidance function and source of position information. Automatic Dependant Surveillance – Broadcast (ADS-B) technology is used to broadcast the associated position information with user identification to support the surveillance function. DO-247 presents both functional and sensor level performance requirements. The requirements guidance and surveillance sensors supporting airport surface operations are contained in RCTA DO-247, sections 5.2 and 5.3 respectively.

Current DO-247 surveillance and guidance function sensor requirements are specified in terms of 95 percent accuracy performance (Table 1). The selected guidance sensor requirements in Table 1 are taken from a large list of requirements that account for a number of variables such as visibility conditions, airport type/size, aircraft type/size, etc. A description of the visibility conditions is given in Table 2. For visibility conditions one and two, the guidance sensor requirements are significantly less stringent (10m vs 2.2/1.5m) because the system is intended to be used by pilots for situational awareness of the airport surface environment as visibility levels are adequate for "normal" surface movement. Visibility conditions three and four are degraded conditions which require the pilot to rely on the electronic guidance from the GNSS sensors to keep the aircraft centered in the rapid exit, normal, and apron taxiways along with the taxilanes and gate region and away from other aircraft on the airport surface. The taxilanes and gate region guidance sensor requirements have not been defined to date.

Sensor availability is defined as the probability of the sensor being available at the beginning of the intended operation. Guidance sensor availability requirements are 0.95 for visibility conditions one and two and 0.999 for visibility conditions three and four. The surveillance sensor availability requirement is 0.999 for all visibility conditions.

To achieve performance in accuracy and availability requirements areas, GNSS needs to be augmented by one of several optional technologies. LAAS is one of the augmentation technologies that can be used for both the surveillance and guidance sensor functions. Table 1 contains the relevant accuracy requirements from DO-247 for the RIRP (surveillance) and RIPS (guidance) testing and demonstrations.

It is noted that the requirements given in DO-247 are provisional as no test activities had been performed that could be used to support validation of these numbers. Validation activities can begin using data collected during the FAA and NASA demonstrations at DFW using LAAS.

Table 1. RTCA DO-247 Sensor Requirements for Surveillance and Guidance Functions

Surveillance Sensor Requirements (95%)	**Guidance Sensor Requirements (95%)**
a) Longitudinal position accuracy Minimum: 8 meters b) Lateral position accuracy 1) Runways and taxiways Minimum: 8 meters 2) Stand (gate) region Minimum: 2 meters c) Vertical position accuracy Minimum: 16 meters	The requirements listed below are for longitudinal and lateral performance for rapid exit, normal and apron taxiways. a) Visibility Condition *1*: 10 meters b) Visibility Condition *2*: 10 meters c) Visibility Condition *3*: 2.2 meters d) Visibility Condition *4*: 1.5 meters Note: Requirements for taxilanes and the gate region are still being developed.

Table 2. Visibility Conditions Definitions from RTCA DO-247[2]

Visibility Condition 1	Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference, and for personnel of control units to exercise control over all traffic on the basis of visual surveillance
Visibility Condition 2	Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference, but insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance;
Visibility Condition 3	Visibility sufficient for the pilot to taxi but insufficient for the pilot to avoid collision with other traffic on taxiways and at intersections by visual reference with other traffic, and insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance. For taxiing this is normally taken as visibility equivalent to a RVR less than 400 m but more than 75 m.
Visibility Condition 4	Visibility insufficient for the pilot to taxi by visual guidance only. This is normally taken as a RVR of 75 m or less.

The preparation and execution of flight tests to provide the data needed to support validation activities involved personnel and equipment from Ohio University (LAAS ground facility), NASA (aircraft and test planning), and Rockwell Collins (LAAS receiver). The next sections will discuss the upgrades to the Ohio University LGF performed in Athens, Ohio and at the Dallas/Fort Worth airport, followed by a summary of the Ohio University test van configuration, and finally a brief description of the Rockwell Collins LAAS receiver deployment.

FAA RIRP LGF Architecture and Related Validation Activities

A two-reference station LGF configuration was installed at DFW to support the FAA RIRP test and demonstration activities. This two-reference station configuration was a based on the prototype system developed and tested by AEC at the Ohio University Airport. The two-reference station configuration was chosen to minimize schedule impact and cost to the FAA RIRP program because it can provide the accuracy and availability needed for supporting the RIRP demonstration activities. The data collection missions support verification of the surveillance sensor requirements. The focus of demonstrations during RIRP activities was the detection of runway incursions by ground based equipment and timely notification of air traffic and ground controllers to potential and actual runway incursions [3].

NASA RIPS LGF Architecture and Related Validation Activities

The scenarios considered during the NASA RIPS demonstrations provided an opportunity to perform data collection and analysis to aid validation of the guidance sensor requirements given in DO-247. These demonstrations highlight surface guidance and display technologies as a means of improving pilot situational awareness; a key element in reducing runway incursions. Accuracies for the aircraft positioning system need to be on the order of those required for visibility conditions 3-4 (~2 m) to fully demonstrate the benefit of such technology. This accuracy requirement is more rigorous than the surveillance sensor requirements, thus the two-reference station configuration could not provide the required level of service.

However, a four-reference station LGF, when combined with other existing aircraft sensors, could provide the levels of accuracy, continuity, integrity, and availability of service required to provide the guidance sensor function required by NASA. Thus, the two-reference station LGF hardware and software installed at DFW during the FAA RIRP program would need to be upgraded to a four-reference station configuration.

DFW LAAS Upgrade for NASA RIPS Testing

Accordingly, AEC was tasked by NASA to upgrade the existing LGF to a four-reference station configuration for use throughout the NASA RIPS testing. Figure 3 is a block diagram of the four-reference station configuration as installed at DFW. The physical layout of the DFW test site is given in Figure 4. The proximity to the east control tower is shown in the figure. Although this site was not ideal in terms of LGF siting, it provided an opportunity to study the effects of various sources of multipath on the LGF installation [3,4].

Software and hardware upgrades to the LGF, preliminary testing, and interoperability testing took place between late June and early September 2000 at the Ohio University Airport test site. The upgraded LGF was delivered and installed at DFW during the last week of September.

The existing Ohio University LGF software was written to support up to four reference stations although it was not exercised heavily in that configuration before the NASA RIPS work. During the upgrade process it was determined that the display interfaces had to be modified to provide the capability to display all LGF data for each of the four reference stations. Prior to the NASA RIPS effort the Ohio University LGF had broadcast a data message intended only for research and development LAAS equipment. During FAA RIRP testing, AEC provided a computer at the user end that converted the Ohio University message to the Special Category I (SCAT-I) ARINC-429 data message required by the early Collins GPS receivers [3].

NASA RIPS testing required that the LAAS VDB message format be compliant with RTCA DO-246 because the NASA 757 was equipped with a Rockwell Collins multimode receiver [5]. This receiver is discussed in a later section.

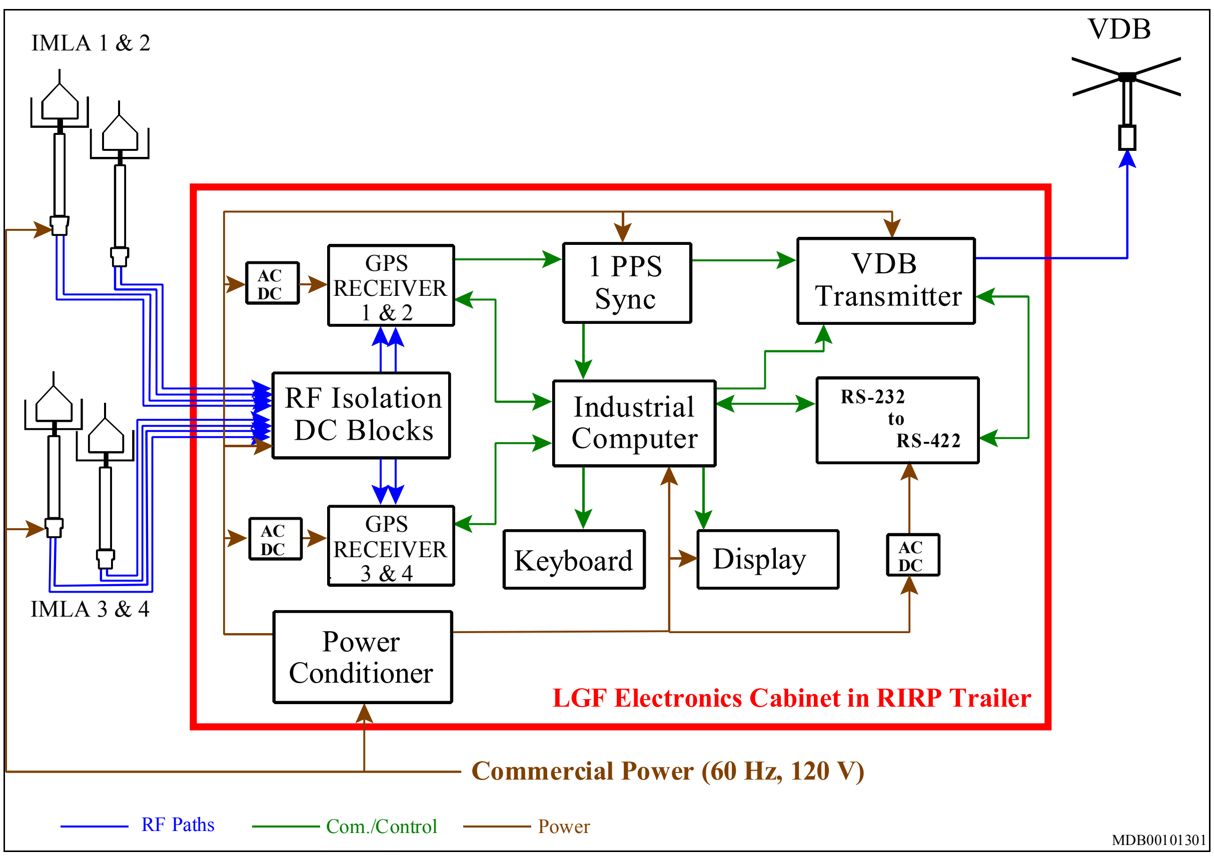

Figure 3. DFW RIPS LAAS Block Diagram

FAA personnel at the William J. Hughes Technical Center (WJHTC) had worked previously on developing this message for the Collins GNLU-930 and sent this software to AEC for use in the RIPS software upgrade. The focus of LAAS research at WJHTC differed from that conducted at Ohio University resulting in additional effort being expended to integrate the FAA developed LAAS VDB messages and control software with the RIPS LAAS software.

The hardware upgrade process resulting in the system shown in Figure 3, and included the integration of two additional Novatel Beeline GPS receivers, two Integrated Multipath Limiting Antennas (IMLA) (Figure 5), two antenna mounts, and cabling. Additional hardware was procured to replace the original IMLA power distribution box. Arrangements were made with the local DFW area contractor who installed the RIRP antenna mounts and cabling to provide the services required for installation of the additional two antenna mounts and cable runs.

A new Harris VDB prototype transmitter was installed in the LGF to increase the available broadcast power. The original Harris VDB prototype transmitter was capable of transmitting 20 watts while the new model provided up to 150 watts. The VDB transmitter was configured to broadcast with 75 watts (transmitter output) for the duration of NASA's RIPS demonstration activities. Effective radiated power was significantly less (approximately 3 dB) due to the long cable run from the transmitter to the antenna. Use of the new VDB transmitter required modification and upgrades of the driver software in the LGF.

An elliptically polarized antenna (Figure 6) was installed at DFW for RIPS testing replacing the horizontally polarized antenna used for the RIRP

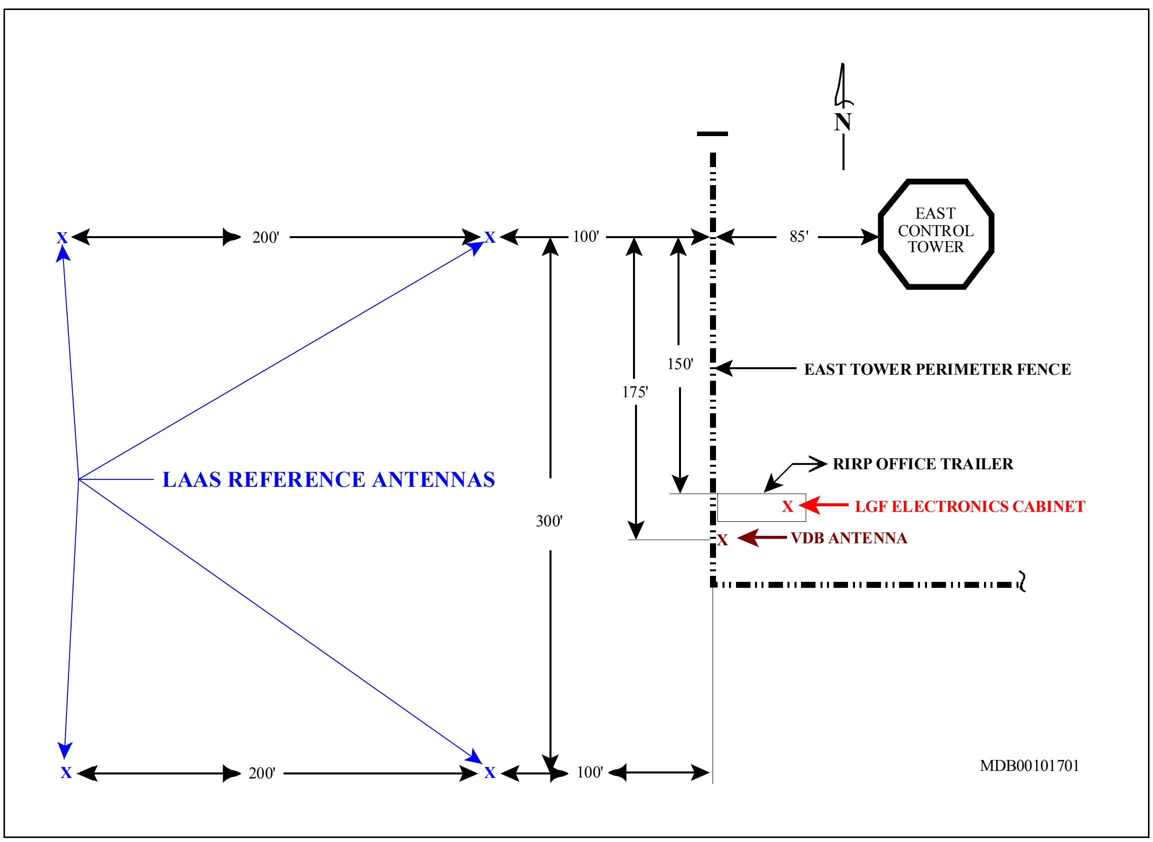

Figure 4. DFW RIPS LAAS Layout

testing. It was anticipated that this would improve the airport surface coverage. While the FAA's RIRP testing was conducted on the east side of the airport, NASA test scenarios required coverage to the American Airlines maintenance hanger located on the west side.

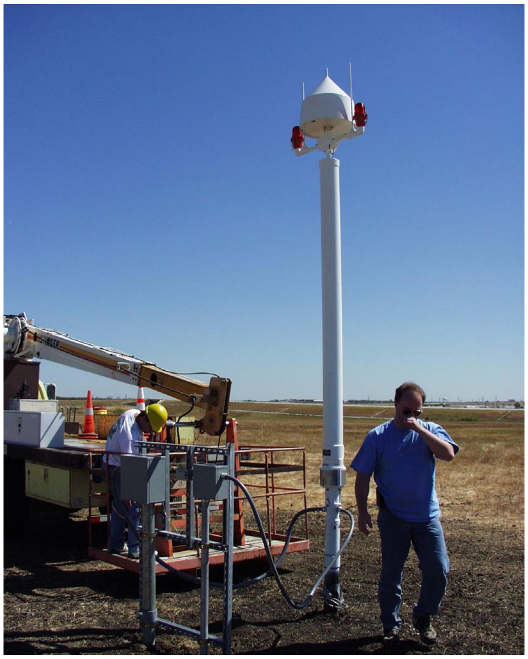

Figure 5. New LAAS IMLA Installation at DFW

Initial testing with the Ohio University test van in late September showed acceptable surface coverage as a result of the new transmitter/antenna combination on the west side of the Dallas/Fort Worth airport.

The IMLAs installed at DFW were developed through a joint effort between industrial partner dB Systems, Inc. and Ohio University. The antennas serve to effectively mitigate GPS multipath errors due to ground reflections.

Ohio University GPS LAAS Test Van

The Ohio University test van instrumentation included two NovAtel narrow-correlater GPS receivers, a Harris Digital Multimode VDB receiver (VDR-2205), and PC-104 based Pentium^{TM} class computer (Figure 7). In addition to recording the raw data, the computer combined the raw measurements from the NovAtel receivers with the differential corrections from the VDB receiver to

Figure 6. E-Pol Antenna at DFW

compute differentially-corrected position and velocity information. This information was generated at a 1 Hz rate for this test activity. Position, velocity, and status information were displayed in real-time during the tests on a flat-panel display situated between the driver and front passenger seats. A dual channel VHF communications transceiver, located beneath the display panel, was used to monitor airport activities and directives during engineering tests.

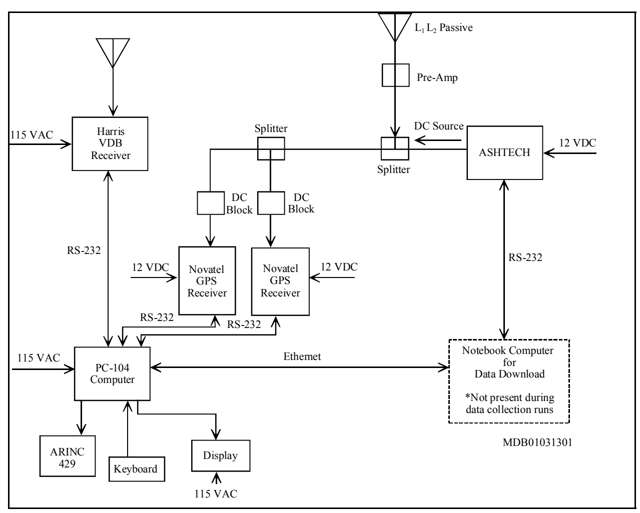

Figure 7. Ohio University Test Van Diagram

In addition to the aforementioned instrumentation, a high precision (i.e., centimeter-level accuracy) GPS-based kinematic survey system was used as a truth reference. The truth-reference system consisted of two Ashtech Z-12 survey receivers. One receiver, the base unit, was located at a precisely surveyed control point near the LGF. The other, rover unit, was installed in the test van (Figure 8). The GPS antenna installed on the van was shared by the NovAtel and Ashtech GPS receivers.

Figure 8. Ohio University Test Van

During the some of the demonstration runs, the truth-reference data (Ashtech) and the LAAS data were collected simultaneously. For each of these runs, position data, as well as raw data, were recorded with GPS-based time tags. The truth reference data were collected directly by the Ashtech receivers. The PC-104 computer was used to record the NovAtel receiver data, the VDB link data message, the VDB signal strength/status message output by the VDB receiver, and the LAAS generated differentially corrected position.

The data from the Ashtech base unit and corresponding rover unit will be processed using Ashtech PNAV software to compute the "true location" of the van, or aircraft, as a function of time. LAAS accuracy data will be generated by subtracting the truth-reference position (true location) from the LAAS position generated at the same instant in time. The resulting composite, time-synchronized data records allowed for data plots to be generated as a function of geographical location on the airport surface (Figure 9)

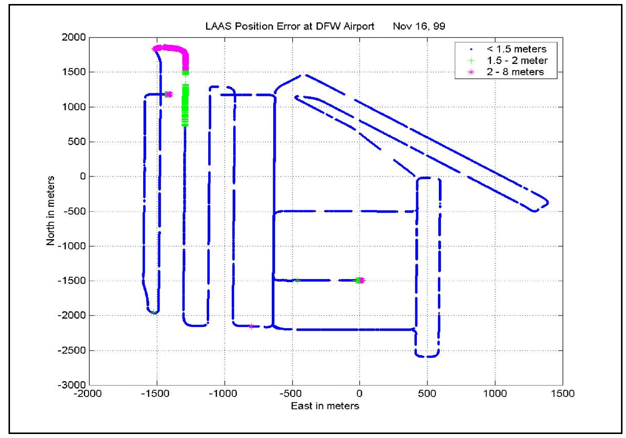

Figure 9. Sample Performance Data Versus Geographical Position

or as a function of run time (Figure 10). The existing data reduction software is capable of producing plots for position accuracy, VDB signal strength, and VDB message rate/interval.

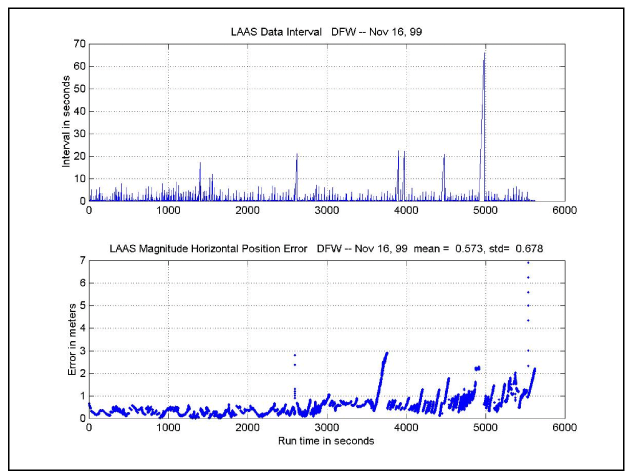

Figure 10. Sample Performance Data Versus Run Time

While not used extensively during the NASA RIPS effort the Ohio University test van provided a stable platform with which to verify proper operation of the LGF. Validation activities of DO-247 requirements will be accomplished with data recorded aboard the NASA 757 by the NASA Ashtech GPS receiver and the Rockwell Collins multimode receiver.

Multimode LAAS Receiver

A Collins Global Navigation and Landing Unit (GNLU) Model 930 was installed on the NASA

Boeing 757 aircraft as part of the RIPS electronics suite. The GNLU-930 was connected to the aircraft's GPS antenna and an aircraft VHF antenna. The VHF antenna is necessary for the GNLU to receive the LAAS data corrections broadcast from the LGF. Output data of the GNLU is fed to the main mission computer aboard the NASA aircraft where all data is recorded and processed. An engineering data collection computer located in the electronics bay collected additional engineering data from the GNLU. The Collins GNLU-930 is, with a few exceptions, compliant with RTCA DO-246 [5].

Rockwell Collins personnel worked with Ohio University personnel in the integration efforts during the months leading up to the NASA RIPS demonstrations. Rockwell Collins provided a list of exceptions and requirements for the GNLU-930 LAAS VDB message format before sending an engineering unit to Ohio University for engineering integration support in late August 2000. Rockwell personnel provided technical support by telephone and email during the integration period.

In late-September Ohio University delivered and installed the upgraded LGF and began site-specific LGF and LAAS airborne receiver integration tests. Once the upgrade to the DFW LGF was completed a team effort resulted in the operational LAAS solution (LGF, MMR, and datalinks) during NASA RIPS demonstration activities.

Initial Approach to Data Analysis

The LGF was online and recording data from October 15 to Oct 27, 2000 in the configuration shown in Figures 3 and 4 with the exception that data was not recorded on the evening of the 18th due to a hardware failure in the VDB transmitter. During this time period the LGF experienced a window of GPS satellite activity, a variety of weather events, and multiple traffic patterns at DFW all of which should provide insightful information for future LAAS users. Throughout testing and demonstration activities events were noted that will be reviewed during data analysis in the coming months.

Ohio University has six full CDs with LGF and test van data and two CDs from the NASA 757 that are to be analyzed. The raw data from the LGF will be analyzed to provide b-value trends for satellite-receiver pairs and estimates of daily Ground Accuracy Designator curves. During this analysis, data records for times that match identified event items will be reviewed to determine the health and status of the LGF at those exact times.

Accuracy, availability and continuity of service will be the metrics used when analyzing the LAAS positional data collected by NASA onboard the NASA 757. Integrity will be analyzed in terms of the correct and timely generation of alarms when system parameters warranted. VDB messages will be analyzed if detailed VDB data message parameters were recorded aboard the 757.

Data collected by the Ohio University test van will also be analyzed and assessed with the same metrics given for the NASA 757 data. All performance data will be compared to the provisional performance requirements contained in DO-247 (GNSS for Airport Surface Operations) and DO-246 (VDB).

LGF and test van data collected during the late September installation and verification period may also be used if needed in specific areas of interest.

Closing Comments

The successful demonstration of the NASA Runway Incursion Prevention System at Dallas/Fort Worth is the result of a team effort by government, industry, and research organizations. Ohio University successfully upgraded and integrated the LGF to support surface movement guidance activities for the duration of the NASA RIPS demonstration.

Data has been acquired and archived at Ohio University for the LGF and the Ohio University test van. Data analysis activities will begin this summer and is expected to be completed during the fourth quarter of 2001. The results of this data analysis can provide additional substantiation of the benefits of LAAS as a part of the National Airspace System through its use as a guidance sensor for supporting airport surface operations.

References

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