[EN-A-78] Development of a CAT-III GBAS (GAST-D) ground subsystem prototype and its performance evaluation with a long term-data set

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Abstract: GBAS (Ground-based Augmentation System) is a GNSS-based navigation system for aircraft precision approach and landing. In May 2010, ICAO (International Civil Aviation Organization) NSP (Navigation Systems Panel) working group completed to develop a baseline SARPs (Standards and Recommended Practices) of GBAS ground subsystem to support category-III precision approach using single frequency of L1-C/A signal, which is called as GAST-D (GBAS Approach Service Type D). Electric Navigation Research Institute (ENRI) developed a prototype of GAST-D ground subsystem to operationally validate the baseline SARPs. Because a large spatial gradient of ionospheric delay is one of the most important integrity risks to GAST-D operation, it was installed in the low magnetic latitude region, where plasma bubble was a famous phenomenon to cause steep spatial gradients in ionospheric delay. The early results were reported in NSP working group before the baseline SARPs was approved in December 2016 with an expectation of its effectiveness in 2018. This paper reports initial results of performance evaluation using ENRI's GAST-D subsystem prototype and describes its perspective toward future implementation using long term-data set, which are continuously collected from the installation in February 2014.

Keywords: GNSS, Landing system, Safety system design, Ionospheric delay, Precision approach

1. INTRODUCTION

GBAS (Ground-based Augmentation System) is a GNSS-based navigation system to support aircraft precision approach and landing. In GBAS operations, there are categories depending on its support phases of precision approach and landing. Namely, category-I (CAT-I) GBAS can provide guidance for precision approach with a decision height of 200 feet, and CAT-III is one for landing (below 200 feet) including rollout from the runway. Because GBAS supports one of the most critical flight phases, a high-level safety is required. Its ground system requirements are defined in ICAO (International Civil Aviation Organization) SARPs (Standards and Recommended Practices). GBAS Approach Service Type D (GAST-D) is proposed as a service type of GBAS to support CAT-III precision approach with single frequency of L1-C/A signal. Because GBAS is based on differential GNSS positioning technique, spatial changes in ionospheric delay of GNSS signal is one of significant error sources. Moreover, a large spatial gradient in ionospheric delay is the most important threat to GBAS safety. Therefore, GAST-D is designed to mitigate ionospheric threat with integrity monitors of the both ground and airborne in order to realize extremely high safety operations. ICAO NSP (Navigation Systems Panel) WG1 (Working Group 1) CSG (Category II/III Subgroup) had developed a baseline SARPs of GAST-D with completion of its technical validation in May 2010 [1]. After its operational validation in the NSP working group with a period of about six and a half years, the baseline SARPs has been approved by the NSP in December 2016 with an expectation to be effective in 2018.

ENRI participated in the above operational validation activities of NSP working group. There, four projects to develop a prototype of GAST-D ground subsystem were carried out in the world including ENRI's validation program, which was conducted under the low magnetic latitude region in different from the other projects. Namely, the other projects were conducted in the middle magnetic latitude region. This paper reports initial results of system performance evaluation using ENRI's GAST-D subsystem prototype and describes its perspective toward future implementation of GAST-D using long term-data set, which are continuously collected after its installation in February 2014.

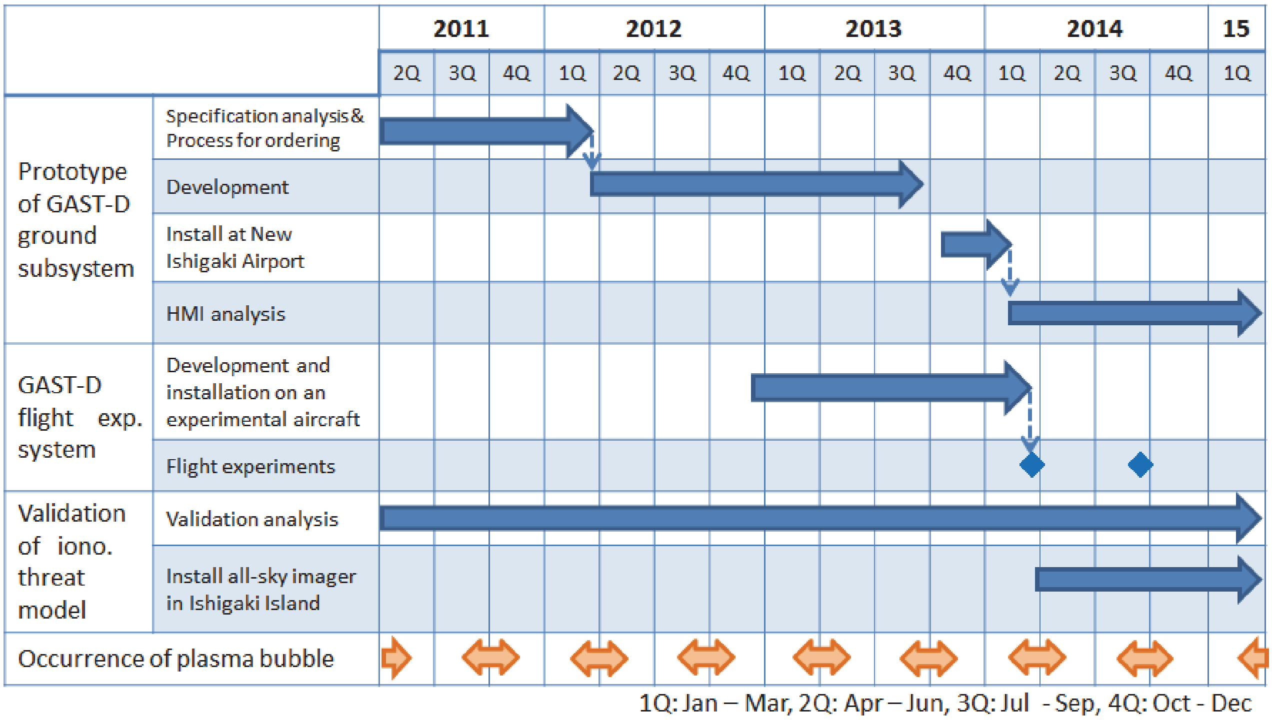

Figure 1. Actual schedule of ENRI's GAST-D validation program.

2. ENRI's PROTOTYPE SYSTEM FOR GAST-D GROUND SUBSYSTEM

Purpose of ENRI's GAST-D program included operational validation of the baseline GAST-D SARPs, identification of major technical subjects and fundamental solutions to them for future GAST-D implementation in Japan. The project consisted of three major parts, which were development of a research prototype of GAST-D ground subsystem, development of a GAST-D experimental onboard equipment including major airborne integrity monitors for GAST-D, and validation of the GAST-D ionospheric threat model for the low magnetic latitude region. Figure 1 shows actual schedule of ENRI's GAST-D program.

To develop the prototype of GAST-D ground subsystem, ENRI contracted with NEC corp. in March 2012. The prototype of ground subsystem is designed in compliance with the GAST-D requirements of the ICAO baseline SARPs, RTCA Do-246D [2] and Do-253C [3]. Safety design and validation processes were done according to a guidance of SAE ARP4754 [4] and ARP4761 [5]. Totally, 23 meetings for safety design review were held between ENRI and the manufacture almost every three weeks during a period of one and a half year until its delivery in September 2013.

For reference receivers of the prototype, dual frequency (L1/L2) GNSS receivers (Novatel Euro-3) are employed because of ionospheric observation to validate the system performance including integrity monitors. The prototype can also broadcast GBAS messages for usage of SBAS ranging sources. The following GAST-D integrity monitors are implemented to the prototype as major monitors, which are ionospheric spatial gradient monitor (ISGM), Signal Deformation monitor (SDM), Code-Carrier-Divergence (CCD) monitor, Excessive acceleration monitor, Ephemeris monitor, and RFI monitor. Including IFM (Ionosphere Field Monitor), the prototype has all integrity monitors for CAT-I which are based on ENRI's another CAT-I prototype [6]. The prototype also has some novel functions for advanced researches, which are an option to use reference signal with CSAC (Chip Scale Atomic Clock) [7] and implementation of an integrity monitor to detect multiple receiver faults.

3. INSTALLATION AND CONTINUROUS DATA COLLECTION AT NEW ISHIGAKI AIRPORT

ENRI installed the prototype in New Ishigaki airport (24.4N, 124.2E; See Figure 2) especially with aspects of evaluation and validation of ionospheric issues including performance evaluation for integrity monitors to detect ionospheric anomaly at the both sides of ground and

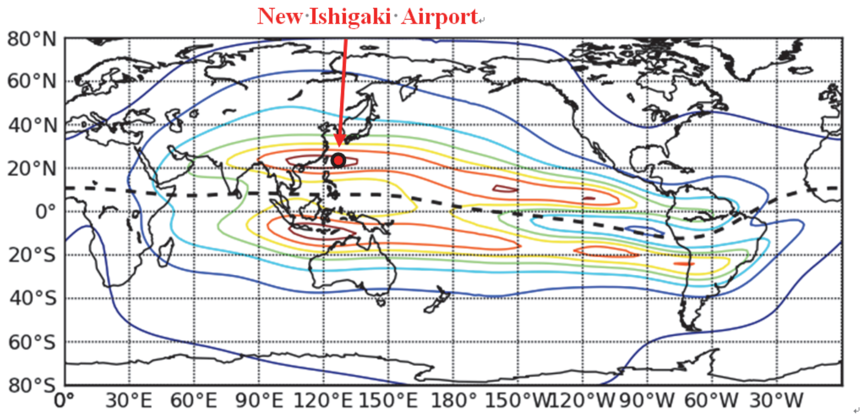

Figure 2. Location of New Ishigaki Airport and an example of ionospheric electron density distribution (12JST; Japan Standard Time).

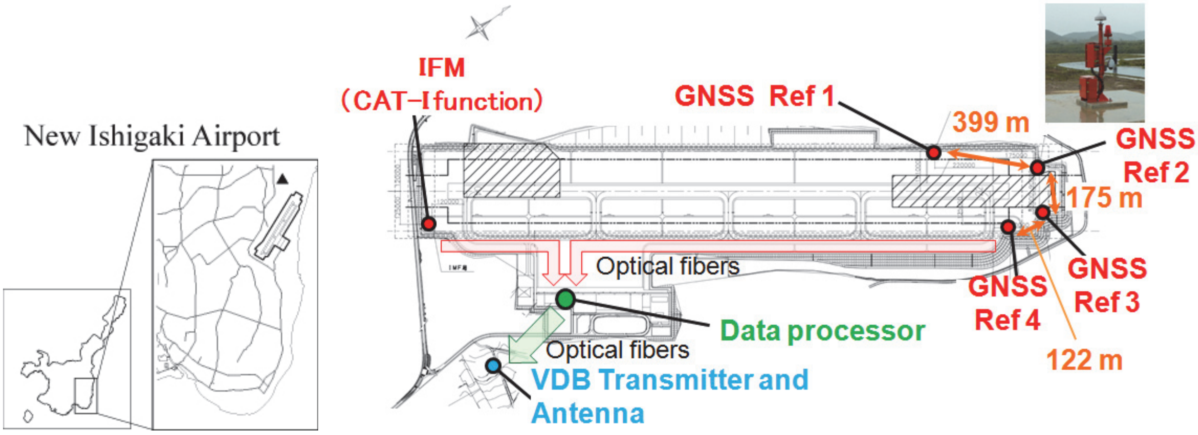

Figure 3. Location for each component of the prototype in the New Ishigaki airport.

airborne subsystems. Figure 3 shows location for each component of the prototype in the New Ishigaki airport. The prototype has four GNSS reference stations to generate differential corrections and an IFM station, which is a component for CAT-I function of the ENRI's prototype to monitor ionospheric delay difference from GBAS reference stations and reduce potential range error due to ionospheric spatial gradients in geometry screening process. Each reference station and IFM has a set of GNSS antenna (NovAtel ANT-C2GA-TW-N) and receiver (Novatel Euro-3). GNSS observational data is transmitted to a data processor by optical fibers. GBAS messages are generated in the data processor and sent to VDB transmitter also by optical fibers. The prototype system was used for flight experiments to demonstrate a fundamental concept of GAST-D, which is mitigation of ionospheric threat in cooperation with both ground and airborne subsystems, under ionospheric disturbances of plasma bubble [8].

4. PERFORMANCE EVALUATION USING A LONG TERM-DATA SET

Purpose of continuous operation of the prototype in real airport includes process to determine a set of appropriate values for thresholds of integrity monitors. For an example, a set of parameters for the SDM were calculated from observational data on the roof of building and used in its initial variation before the delivery. Therefore, we have to reanalyze its performance and validate the requirement using actual data collected in real airport. Hazardous misleading information (HMI) analysis is another important issue of long-term data collections.

After its installation in February 2014, the prototype has been continuously operated. Concerning positioning accuracy (95%), Table 1 shows initial results of the prototype for GAST-C and GAST-D solution using GNSS observational data at the IFM station as a pseudo user. The results are enough to meet with requirements and there are not significant differences between two seasons. It is also

Table 1. Positioning accuracy (95%) of the prototype.

2014	GAST-C		GAST-D	
	Horizontal (m)	Vertical (m)	Horizontal (m)	Vertical (m)
March 21 - 27	0.1455	0.3848	0.2010	0.5212
August 07 - 13	0.1541	0.3705	0.2060	0.4938

confirmed that positioning errors for GAST-D solutions are lager because of a shorter time smoothing constant. Regarding the integrity monitors, fundamental performance evaluation of the ISGM is reported [9].

For further analysis, we are going to evaluate the following perspectives with a long-term data set including HMI analysis:

- Validation of the current parameter set in the integrity monitors, which is determined from the initial analysis with a short data set at the airport,
- Performance validation of each integrity monitor including missed detection and false alarm rates,
- System performance with integrity and availability indexes in addition to accuracy.

5. SUMMARY AND FUTURE WORK

ENRI developed a prototype of GAST-D ground subsystem and installed it in the low magnetic latitude region to operationally validate the baseline GAST-D SARPs. The system has been continuously operated to collect a long-term data set to analyze total system performance and HMI events to solve further detailed subjects for future GAST-D implementation in Japan. The initial and fundamental performance evaluation has been done for system accuracy and the integrity monitor of ISGM with a short-term data set. Using a long-term data set, we are going to validate the current parameter set, performance of integrity monitors, and total system performance including integrity and availability.

From another viewpoint of usage of the long-term data set, it is important to solve subjects that became clear during the operational validation of the baseline SARPs in the NSP working group. Although the validation was completed with conclusions that the baseline SARPs covered ionospheric conditions in the middle magnetic latitude region at least, it was also recognized that further work may be needed to enhance availability of GAST-D in the low magnetic latitude region, where steep spatial gradient in ionospheric delay and scintillations frequently occur associated with plasma bubbles. Therefore, we are also going to use the data set for investigating impacts of the ionospheric disturbances on GAST-D ground subsystem.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] ICAO/NSP WGW May 2010 Report - Attachment G, MSP May 10 / Flimsy 29, Navigation Systems Panel (NSP) Working Group of the Whole Meeting, Montreal, 17-28 May 2010, Agenda Item 3: SARPs for GNSS Elements and Signals (GBAS), Development Baseline SARPs Proposal, Presented by Tim Murphy and Stefan Naerlich

[2] GNSS-Based Precision Approach Local Area Augmentation System (LAAS) Signal-in-Space Interface Control Document (ICD), RTCA/ DO-246D, December 16, 2008

[3] Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment, RTCA/DO-253C, December 16, 2008

[4] Certification Considerations for Highly-Integrated or Complex Aircraft Systems, SAE ARP4754, 1996-11

[5] Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment, SAE ARP4761, 1996-12

[6] S. Fukushima, et al., "Development and Safety Assurance of Satellite-Based Precision Approach and Landing System", IEICE Vol. J94–B, No. 7, pp.802–811, June 2011 (in Japanese).

[7] T. Yoshihara, F. Murashi, S. Saito and K. Hoshinoo, "A Study on Integrity Improvement of GBAS Ground Subsystem Using CSAC (Chip Scale Atomic Clock)", Proc. of ION ITM 2015, pp.593-599, Dana point, CA, January 2015.

[8] S. Saito et al., "GAST-D flight experiment results with disturbed and quiet ionospheric conditions", Proc. of ION GNSS+ 2015, pp. 1494-1499, Tampa, FL, September 2015.

[9] Saito, S., Yoshihara, T., Nakahara, H., "Performance of GAST-D Ionospheric Gradient Monitor Studied with Low Latitude Ionospheric Disturbance Data Obtained in a Real Airport Environment," Proc. of

ION Pacific PNT, pp. 815-820, Honolulu, Hawaii, April 2015.

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