Comparative Study between GBAS and Conventional Aircraft Precision Approach Guidance System

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Since the ICAO decided to adopt the GNSS-based CNS/ATM as a future standard navigation system, there has been much research to guarantee the required navigation performance of CNS/ATM sub-systems (GBAS, SBAS, etc.), mainly in the integrity or continuity aspect. However, it is also important to study the interoperability and natural transition between the old and new nav-aids because of their very different features. Therefore, we focused on the verification of the performance of the new systems, especially GBAS, through comparison with conventional aircraft landing guidance systems such as ILS. For performance verification, we developed the GBAS system and conducted three types of ground tests and several flight tests. In the analysis of the test data, we compared the GBAS navigation solutions with the data collected from the ILS inspection device — Theodolite. From the analysis, we concluded that the developed GBAS system satisfied the Precision Approach Category I requirements in the aspect of accuracy, and was consistent with the conventional aircraft precision approach guidance system.

Key Words: GBAS, GNSS, Flight Test

1. Introduction

In 1995, the ICAO (International Civil Aviation Organization) decided to use a 21st-century standard navigation system; CNS/ATM (Communication, Navigation, Surveillance, Air Traffic Management), instead of the navigation aids that had been used up to that time. This new system was based on the GNSS (Global Navigation Satellite System) that includes GPS, GLONASS, and Galileo. For standardization of the system, the ICAO provided the technical standards for GPS, GLONASS, SBAS (Satellite Based Augmentation System) and GBAS (Ground Based Augmentation System) systems, and advised each country to develop and utilize the new system.\(^1,2\) These policies of the ICAO were prompted by the efficiency of GNSS.

The GBAS has several merits that are derived from the efficiency of GNSS and other factors. The following aspects are for the LAAS (Local Area Augmentation System) as defined by the FAA of the United States, conceptually identical to GBAS.

1) CAT-I or II/III : precision approach capability
2) Remote Coverage : available to areas not covered by the WAAS
3) Tailored Approaches : to avoid obstacles, noise sensitive areas, or congested airspace
4) Multiple Runway Coverage : one LAAS will serve the entire airport
5) Aircraft Surface Navigation : can use LAAS as a guide when taxing

To prepare for the era of the new navigation system, our research team developed an aircraft landing guidance system based on Differential GPS in 1998, and has conducted flight tests for 3 years. Since 2000, we have been joined in related projects ordered in 1997 by the Korean Civil Aviation Bureau (KCAB) and Korean Airport Company (KAC). This paper provides the hardware and software configuration of the developed GBAS that is installed at Ulsan Airport, located in the south-east part of Korea, and the ground and flight test results. The paper also contains the comparison analysis between GBAS and Theodolite data; a nav-aid inspection device for the ILS (Instrument Landing System).

2. System Configuration

This section describes the configuration of the GBAS ground system and the airborne system used in the performance evaluation of the ground system.

2.1. Ground system

The ground system includes a GPS receiver, a wireless modem for data link with the airborne system, and a PC. The PC controls the hardware, processes the GPS measurements, and displays the status of the entire ground system. This configuration is shown in Fig. 1.

This is similar to a general DGPS reference station, but meets the international standards of the ICAO. This system uses the GBAS standard data transmission protocol, SARPs\(^1\) suggested by the ICAO. Compared with the basic DGPS correction transmission protocol (RTCM), SARPs can provide higher-resolution correction data, a more precise statistical confidence level of correction, and a more tightened integrity monitoring parameter. Four message types are defined currently.
2.2. Airborne system

Like the ground system, the airborne system also includes a GPS receiver, a wireless modem, and a PC. The PC controls the hardware, processes the GPS measurements, and shows cockpit display. The configuration of the airborne system is shown in Fig. 2.

3. Performance Evaluation

We implemented the ground and airborne system, and conducted three types of ground tests, and several flight tests.

Fig. 1. Configuration of ground system.

To obtain the true trajectory of the vehicle, we utilized an Ashtech Z-12 receiver, which shared the GPS antenna with the GBAS airborne system. If the data collected by the Ashtech receiver is post-processed, we can get the vehicle’s trajectory which has the accuracy of cm-level. It is sufficient to analyze the GBAS accuracy performance at meter-level.

3.1. Ground test

Before flight tests, we conducted three types of ground tests at Ulsan airport; static zero-baseline and non-zero-baseline test for 24 hours respectively, and a dynamic test using a mini-van.

The results of the static tests are shown in Table 1. Both
horizontal and vertical positioning errors of the non-zero-baseline test are bigger than those of the zero-baseline test because of non-common error sources.

We installed the airborne system in a mini-van and drove the road around the runway ten times. Figure 3 shows the differences between the real-time navigation solution and the true trajectory of the vehicle determined by the Ashtech Z-12 in East/North/Up directions. Table 2 summarizes the statistical values that resulted from the accuracy analysis using the positioning errors in Fig. 3.

These results of the ground tests show potential that the developed GBAS system may satisfy the Precision Approach Category I requirements.

### 3.2. Flight test

Flight tests were performed at Ulsan airport with an inspection aircraft (Challenger 601/3R) owned by the KCAB (Fig. 4).

**Flight scenario:** The GBAS coverage volume presented in Ref. 4) consists of two sub-volumes. One is the approach coverage volume, the other is the VHF data broadcast coverage volume. These volumes may be sketched roughly as a cylinder, as presented in Fig. 5. We designed a flight test scenario for the approach coverage volume: 1) approaching the origin of Ulsan airport with level flight at an altitude of 10,000 ft, 2) bypassing the origin and flying out along a line of positive 35° up to the radius of 23 nm in level flight, and 3) flying down to a point that is on a negative 35° direction, at a 23 nm radius with an altitude of 1,300 ft. 4) After the flight test for approach coverage volume, the aircraft repeats the precision approach procedure.

**Accuracy analysis:** We conducted several flight tests using the scenario, and collected data for 11 precision ap-
proaches. We analyzed the real-time navigation results to get the statistics of positioning accuracies in a similar way to the dynamic ground tests. We only considered the epochs at which the aircraft were within the GBAS coverage volume and the real-time positions were computed without failure of data link resulting from the local terrain.

However, in the case of the flight test, the aircraft was maneuvering from right above the ground to an altitude of more than 10,000 ft. It resulted in a varying accuracy level according to the height of the aircraft, because the correlation of the GPS error sources, especially tropospheric delay, is gradually lowered in proportion to the difference between the GPS antennas of ground and airborne systems.

In the documents that describe the GBAS, document 5 suggests the horizontal and vertical accuracy level, e.g. NSE (Navigation Sensor Error) with a 95% error limit value as a function of the distance and height from the touchdown point. Tables 3 and 4 show the horizontal and vertical NSE limits for the 3 types of precision approaches.

Considering the suggested requirements, we can find that the vertical error limit is more threatening to the GPS-based sensors than the horizontal one. Generally, the GPS positioning error is less accurate in a vertical direction because of satellite positions. Due to limited paper space, only the vertical NSE value of the developed GBAS system is presented in Fig. 6. This figure shows that the GBAS system can sufficiently meet the Category I precision approach requirement, and there is potential to meet the Category II/IIIa in the accuracy aspect within the parameters of RNP (Required Navigation Performance). It will be proven to be the actual performance of the system through more flight tests scheduled this year.

### 4. Comparison with Theodolite

Until now, we have examined the GBAS system by comparing it to known system of the Ashtech Z-12 receiver. But, the known system is also based on GPS. Therefore, we have to follow a different method to verify the consistency between the developed GBAS and conventional nav-aids. The GBAS is devised to replace the systems that serve as a guide for precision approach of aircraft, such as ILS, MLS, etc., therefore, we can verify the previously analyzed GBAS performance by comparing with those systems.

A Theodolite is a measuring or surveying device that gathers data by reading the elevation and azimuth angle of the target object from a reference, also used in the inspection of ILS. Our objective is to compare the Theodolite measurement with our GBAS navigation solution and confirm the consistency between them.

### Tables

#### Table 3. Horizontal NSE limit

<table>
<thead>
<tr>
<th>Performance type</th>
<th>95% Horizontal NSE limit (meter)</th>
<th>Distance (D, meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT-I</td>
<td>≤ 16.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤ 0.00176 × D + 14.46</td>
<td>291 &lt; H ≤ 873</td>
</tr>
<tr>
<td></td>
<td>≤ 27.2</td>
<td>H &gt; 7212</td>
</tr>
<tr>
<td>CAT-II/IIIa</td>
<td>≤ 6.9</td>
<td>0 &lt; H ≤ 291</td>
</tr>
<tr>
<td></td>
<td>≤ 0.000835 × H + 6.66</td>
<td>291 &lt; H ≤ 7212</td>
</tr>
<tr>
<td></td>
<td>≤ 12.7</td>
<td>H &gt; 7212</td>
</tr>
</tbody>
</table>

#### Table 4. Vertical NSE limit

<table>
<thead>
<tr>
<th>Performance type</th>
<th>95% Vertical NSE limit (meter)</th>
<th>Height (H, feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT-I</td>
<td>≤ 4.0</td>
<td>100 &lt; H ≤ 200</td>
</tr>
<tr>
<td></td>
<td>≤ 0.0117 × H + 1.66</td>
<td>200 &lt; H ≤ 1290</td>
</tr>
<tr>
<td></td>
<td>≤ 16.7</td>
<td>H &gt; 1290</td>
</tr>
<tr>
<td>CAT-II/IIIa</td>
<td>≤ 2.0</td>
<td>50 &lt; H ≤ 100</td>
</tr>
<tr>
<td></td>
<td>≤ 0.0117 × H + 0.83</td>
<td>100 &lt; H ≤ 1290</td>
</tr>
<tr>
<td></td>
<td>≤ 15.9</td>
<td>H &gt; 1290</td>
</tr>
</tbody>
</table>

![Fig. 6. Vertical error vs. height (flight test).](image)
The most unique feature of the GPS against the conventional systems is the coordinate system. GPS is based on the WGS-84 ellipsoid, but the others are based on the locally defined ellipsoid (ex. Bessel ellipsoid) or other coordinate systems such as TM (Transverse Mercator) projected coordinates. The differences are not successfully rectified with only a few simple transformations.

According to the documents related to the GBAS or GNSS, such as Refs. 2, 4, 5), the FAS (Final Approach Segment) parameter will be defined with the WGS-84 ellipsoid and its coordinate system. Therefore, it is necessary to transform the conventional coordinate values of the reference points in each airport after minute investigations, or totally re-survey them.

Figure 7 shows that, with a Theodolite, inspectors measure the true trajectory — described by GP (Glide Path) and LLZ (Localizer) angle — of the aircraft that tries to land on the runway.

The Theodolite measurements are transmitted to the inspection aircraft via wireless modem, compared with received ILS measurements, and recorded for post-processing. We compared the recorded Theodolite data with the GP and LLZ angles computed from the GBAS navigation solution. These are presented in Fig. 8 (GP) and Fig. 9 (LLZ).

In calculation of the GP and LLZ angle from the GBAS

![Theodolite and Wireless Modem](image_url)

Fig. 7. Inspector operating Theodolite.

![GP angle](image_url)

Fig. 8. GP angle.

![LLZ angle](image_url)

Fig. 9. LLZ angle.
nav-solution, we considered the distortion of the reference plane (WGS-84 ellipsoid or Mean Sea Level), and solve the inherent problem to a sufficient extent. So, there is no serious problem caused by the reference plane. But, the comparison results still contain error sources as follows.

1) Theodolite-operational error caused by the inspector, generally 0.02 deg.

2) Lever arm between ILS antenna and GPS antenna installed on the aircraft varying according to the attitude of aircraft.

3) 0.01 deg resolution of the Theodolite measurement.

The errors of GBAS nav-solutions with respect to the Theodolite measurements are less than 0.04 deg, excluding the region where the measurements are not confident (around the GP antenna), and the error values applied to length unit are still below the requirements of Category I. Although there are the above-mentioned limitations, we can find that the GBAS system is consistent with the conventional systems.

5. Conclusion

In this paper, we presented the performance of the GBAS ground system and airborne system developed by our team. The systems are based on the Differential GPS method and satisfy the Standards/Recommended practices as published by the ICAO. We conducted ground tests before flight tests. The ground tests showed solid evidence to anticipate that the system will meet the Category I accuracy requirements. This turned out to be supported after the flight tests, including GBAS coverage volume test and precision approach tests. However, more flight tests have to be conducted to increase the confidence level of the GBAS positioning performance and to confirm potential to the CAT-II/IIIa.

Additionally, we compared the GBAS nav-solutions with the measurements of the ILS inspection device, and found consistency between them. However, there are some unavoidable limitations of the device and error sources added in its operation. More systematic tests and analysis will be scheduled for the next flight.

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References

1) Homepage of Korean Airport Company, http://www.cnsatm.co.kr