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Engineering Notes

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In-Flight GPS-Signal-Reception Anomalies of Helicopters

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Introduction

IT IS difficult to find appropriate installation points for global positioning system (GPS) antennas on helicopters, because structures such as rotors and engines that are located above the fuselage may degrade GPS positioning accuracy. Even for fixed-wing airplanes that have no such obstacles on the fuselage, an in-flight GPS antenna performance study has revealed that large bias errors can be caused by distortions in the GPS antenna pattern due to other antennas nearby [1]. The effects of such problems are not so great when GPS usage is limited to en-route navigation. However, they will be more significant in approach and landing with vertical guidance (APV) or precision approaches using a GPS satellite/ground-based augmentation system (SBAS/GBAS), such as the Federal Aviation Administration's GPS wide/local area augmentation system (WAAS/LAAS). Although the minimum operational performance standards (MOPS) for WAAS/LAAS airborne equipment [2,3] specify an airborne accuracy model that includes an airframe multipath based on flight test data from large commercial jet transports [4], there is little quantitative flight test data for helicopter GPS antenna performance, and it is thought to be difficult for helicopters to meet the MOPS specifications.

This paper presents in-flight GPS-signal-reception anomalies, such as GPS signal masking and multipath that degrade positioning accuracy, observed using the Japan Aerospace Exploration Agency's (JAXA) research helicopter.

GPS Antenna Installation

JAXA's Mitsubishi Heavy Industries MH2000A-based research helicopter [5] (Fig. 1) is equipped with two GPS receivers: a Thales Navigation Z-Eurocard dual-frequency GPS receiver and a Furuno Electric GW-10II GPS/SBAS receiver. The GW-10II has equivalent capabilities to a Class Beta-3 GPS/SBAS receiver defined in the WAAS MOPS. Both GPS receivers use the same GPS antenna installed on the roof of the cockpit on the right-hand side (Fig. 1), which may be representative of a typical helicopter GPS antenna location. The elevation angle from the GPS antenna surface to the top of the main rotor head is about 15 deg.

Airframe Multipath

The rotor and engine structures around the GPS antenna may cause multipath signals. Figure 2 shows the effects of multipath error during turns observed by the onboard Z-Eurocard GPS receiver. To isolate the error residuals on the code-phase measurements, the standard code-minus-carrier (CMC) technique was applied. The two upper graphs show aircraft bank and heading angles recorded during left- and right-turning flight, and the two lower graphs show the difference between the code-phase and carrier-phase signals (CMC residuals) received by onboard and ground-based receivers for two GPS satellites with different elevation angles.

The results for JAXA's Dornier-228-based fixed-wing research airplane (Fig. 3) are also shown for comparison. Its GPS antenna is installed on the top of the center fuselage section, with no significant obstructions around it. A Trimble 4000 SSI GPS receiver was used for data collection.

Large periodic variations appear only in the helicopter's CMC residuals. These variations are considered to be caused by airframe multipath effects, because they correlate with the aircraft heading angle and can be seen only in the onboard receiver signals. Their amplitudes become larger for lower-elevation satellites, reaching up to 1–1.5 m for satellite no. 17. In the WAAS/LAAS MOPS, the airframe multipath-error model is independent of aircraft type and is simply specified as a function of satellite elevation angle. The observed multipath errors are substantially greater than the MOPS specifications, in which the maximum value is about 0.5 m (1σ). Note that the observed periodic multipath errors will change to bias errors when the aircraft flies straight with constant heading, because their magnitudes are mainly determined by aircraft heading. This means that multipath errors cannot be eliminated by the carrier-smoothing technique specified in the WAAS/LAAS MOPS.

GPS Signal Masking

The probability of the rotor head masking the GPS signal increases when the helicopter banks to the right. Figure 4 exemplifies the GPS signal masking observed by the onboard GW-10II GPS/SBAS receiver during a 360-deg right turn at a bank angle of 10–20 deg. In this flight, the Japanese SBAS, MSAS [6], was used for GPS augmentation. The graphs on the left of the figure show the helicopter bank angle, protection levels, dilution of precision (DOP), and the number of available satellites. The plot on the right shows the

Fig. 1 JAXA's research helicopter and its GPS antenna installation.

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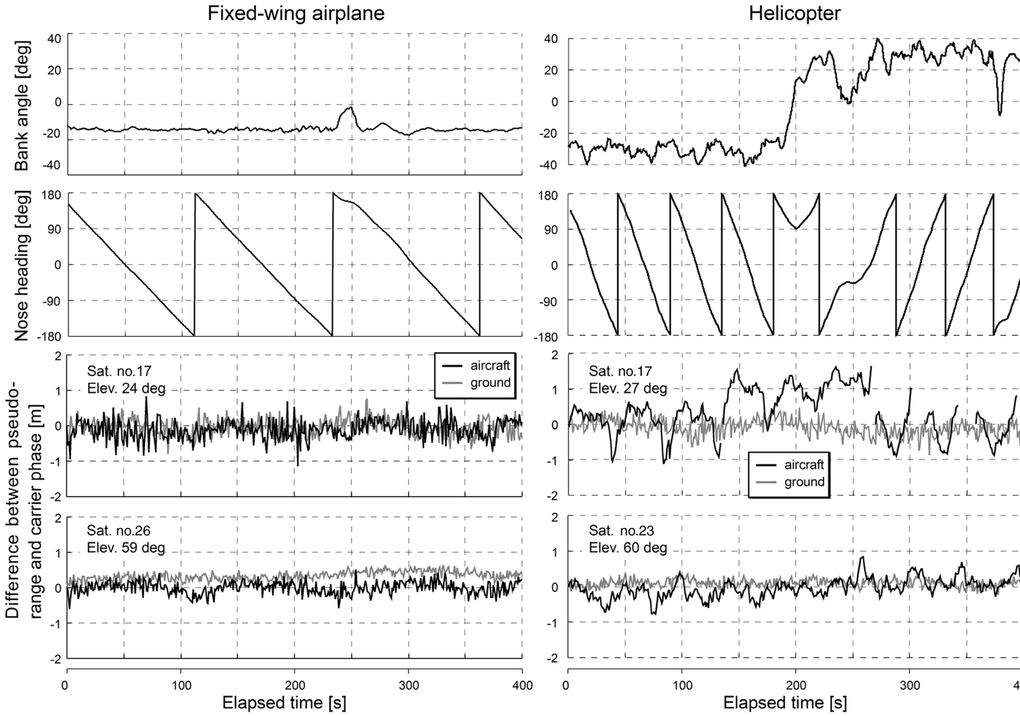

Fig. 2 Multipath error evaluation.

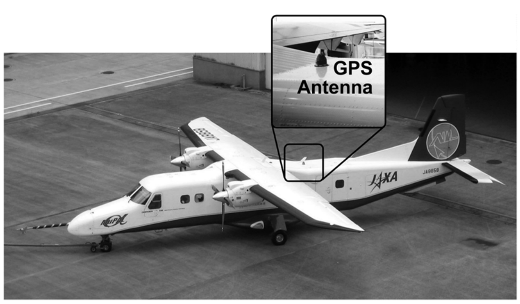

Fig. 3 JAXA's research airplane and its GPS antenna installation.

statuses of received GPS signals as a function of elevation and azimuth angles from the GPS antenna surface to each satellite. The solid lines indicate areas in which code-phase signals could be obtained, and dashed lines indicate areas in which no signal could be received. It can be seen that no signal could be received from satellites when they were behind the main rotor head. As a result, the number of available satellites was reduced and protection levels fluctuated greatly. Although the protection-level fluctuations of the SBAS augmented outputs are much smaller than those of standalone GPS, the vertical protection level (VPL) exceeded the APV-I alert limit (50 m) for around 26 s in Fig. 4. Such protection-level fluctuations would rarely occur in current APVs, because the final

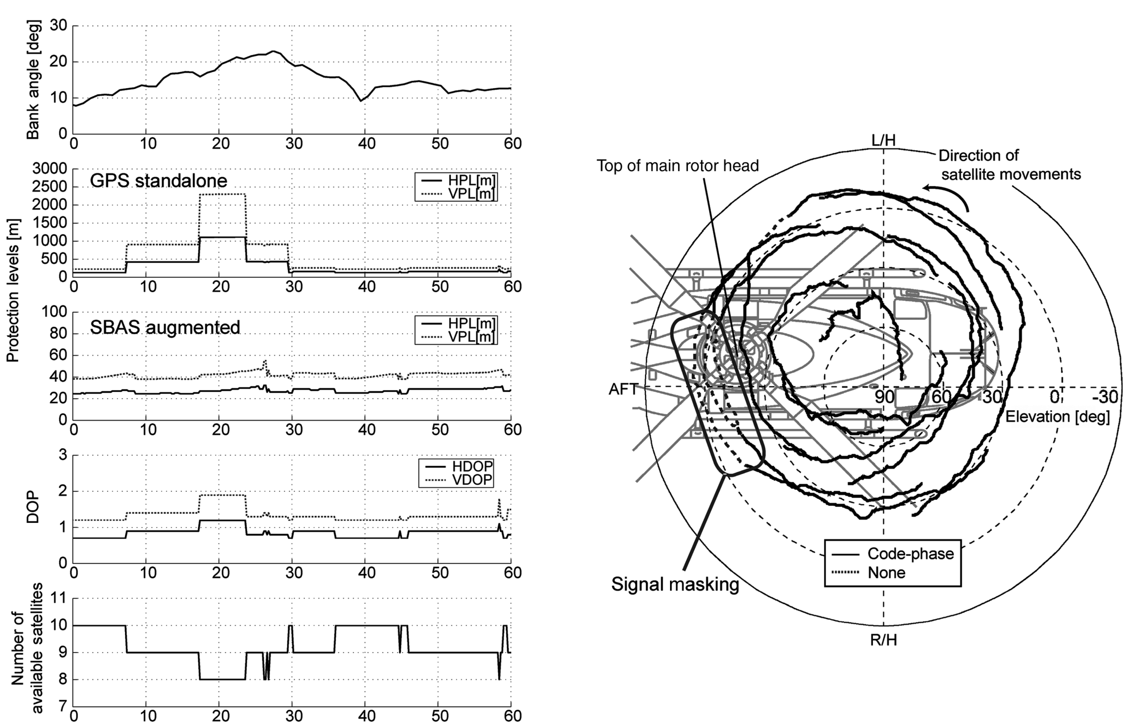

Fig. 4 GPS signal masking evaluation.

segments do not include turns. However, GPS-based curved approaches that have turns in the final segments are strongly desirable in helicopter operations, because many heliports cannot accept long, straight, final segments due to terrain or environmental (e.g., noise) constraints. The observed protection-level fluctuations may seriously degrade the availability of such curved approaches.

Conclusions

This paper presented in-flight GPS-signal-reception anomalies observed using JAXA's research helicopter. The following findings were obtained:

1) Multipath reception caused by obstructions around the GPS antenna, such as the main rotor and engines, can degrade code-phase signal accuracy by as much as 1–1.5 m, which is substantially greater than the WAAS/LAAS MOPS specifications.

2) Signals from low-elevation GPS satellites are blocked by the obstructions around the GPS antenna, especially during turning flight. This degrades protection levels during maneuvering.

The observed GPS-signal-reception anomalies could be a serious problem when GPS-based curved approaches or precision approaches that have strict accuracy/integrity requirements are introduced to helicopter operations. To overcome this, several solutions are being considered:

1) Establish new technical standards for GPS antenna installations to ensure good GPS signal reception, even during maneuvering.

2) Improve multipath mitigation techniques such as correlators.

3) Develop an airborne-based GPS augmentation system (ABAS), such as coupling the GPS receiver with an inertial navigation system (INS).

JAXA has been developing the low-cost GPS/INS hybrid navigation system for small aircraft to realize GPS-based precision approaches [7].

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