Assessment and Modelling of Avionics EGNOS Protection Levels

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Abstract—Performance-based applications imply a reliable GNSS navigation guidance corresponding to the PBN navigation specification requirements. While fixed-wing applications usually still have sufficient alternative means of navigation, helicopter operations often count on high availability and integrity considering only GNSS navigation sources due to particular operations close to the terrain. This holds true especially by implementing helicopter routes under instrument flight rules using the advanced RNP 0.3 helicopter navigation specification.

In the frame of the Swiss-wide implementation program to promote GNSS procedures and applications in Switzerland, several projects have been launched allowing for a smooth integration of the new technologies. One of these, the project Helicopter Recording Random Flights (HRRF), aims at recording randomly collected data from helicopters of the Swiss Air Force and the Swiss HEMS operator REGA on their daily missions. Helicopter are operating under visual and instrument meteorological conditions, on different flight levels and in different topographies. All helicopters are equipped with a TSO-certified GPS/EGNOS receiver. In the meantime, data of more than 10'000 flight hours has been recorded.

The horizontal and vertical protection levels are statistically analyzed. Differences between the helicopter types and GPS/EGNOS receivers are taken into account. The correlation of the protection levels with the flight altitude and the flight region is assessed. The tails of the protection level distribution are specifically analyzed to get a characteristics of the highest expectable protection levels under nominal conditions.

The analyses show that the protection level histograms of the three different helicopter types are in the same order of magnitude. Small variations are mainly assumed due to the different type of missions of the helicopters, some close to the terrain, and others more on higher flight altitude. Some operations are carried out with shorter, others with longer flights. At visual level, a correlation of the horizontal protection level with the helicopter altitude and the number of satellites used for positioning has not been found. Also, no correlation was observed with respect to the geographic area flown. Only the flight height above terrain was seen to be correlated with the protection level in the sense that high protection levels mainly appear on low flight height above terrain. Overall, a homogeneously high protection level performance was observed in the whole Swiss airspace.

Keywords—EGNOS; SBAS; HIL; Protection Level; Avionics

I. INTRODUCTION

Helicopters usually carry out flight operations in remote areas and close to the terrain. As sufficient navigation sensors for aviation are often not available at such locations, the flight operations must be carried out under visual flight rules. Nowadays, with the emerged GNSS for navigation purposes, enormous new possibilities are leveraged.

The ICAO implemented the PBN concept with a dedicated navigation specification – RNP 0.3 – for advanced helicopter operations [1]. While most of the navigation specifications in use today for fixed wing operations may be flown with GNSS or conventional ground navigation aids, the RNP 0.3 navigation specification relies on GNSS. Inertial navigation may remain as the only backup, if at all installed in the helicopter. In addition, as helicopter operations are often performed close to the terrain, a high availability and integrity is crucial for such applications.

In the frame of the Swiss-wide implementation program to promote GNSS procedures and applications in Switzerland (CHIPS), several flight procedures have also been implemented for the benefit of helicopter operations. Amongst them are approach procedures to helipads and hospitals as well as a low-level route network for helicopter operations only. Various investigations show that the availability of GPS augmented by RAIM (Receiver Autonomous Integrity Monitoring) is somewhat limited, especially in mountainous areas, where terrain masking can obstruct the reception of GPS satellite signals. Therefore, it is recommended to fly such operations only with GPS augmented by SBAS.

In the past, several investigations on flight trajectory accuracy have been carried out. For part of them, a true reference has been used. As a conclusion, the investigations showed that the RNP 0.3 requirements are fulfilled with a large margin, containing a potential for a more stringent RNP performance. The design of the Swiss low-flight helicopter network and accuracy investigations are described in [2]. Although the investigations are covering several flight operations, the amount of trajectory data investigated is limited. In the present paper, a more comprehensive analysis is carried out using EGNOS protection level data of avionics GPS/EGNOS receivers.
II. PROJECT HELICOPTER RECORDING RANDOM FLIGHTS

In the frame of the CHIPS program, several technical projects have been launched to allow a smooth implementation of the new GNSS technologies. One of the project is called Helicopter Recording Random Flights (HRRF) aiming to collect helicopter data during normal daily helicopter missions, i.e. on random flights. For this project, helicopters of the Swiss Air Rescue REGA and the Swiss Air Force have been equipped with avionica mQAR access recorders to collect GPS, flight management system (FMS) and attitude data (Fig. 1). This includes 11 Agusta DaVinci AW109 and 6 Eurocopter EC145 helicopters of the Swiss Air Rescue REGA and 18 EC635 helicopters of the Swiss Air Force (Fig. 2). The helicopters are equipped with three different FMS and two different avionics GPS receivers. The CMC CMA-5024 is installed in the EC145 and EC635 helicopters and the Genesys Aerosystems GPS-WAAS receiver is installed in the AW109. Both GPS receivers are SBAS enabled, meaning that - if available - they automatically use EGNOS information within the EGNOS service area. The EGNOS geostationary satellites are at an elevation angle of approximately 30°-35° in Switzerland and have limited visibility with severe terrain masking only.

The project started in the year 2012, and the helicopters have been gradually equipped with the mQAR access recorders. Data logging started in April 2013 with the first equipped helicopter and in November 2014, finally, all helicopters have been equipped. The data investigated in the present paper includes the years 2015 and 2016.

III. GNSS MONITORING

As Switzerland is located close to the center of the EGNOS service area, an excellent performance can usually be achieved. Skyguide is running a GNSS monitoring system assessing the GNSS performance at its premises close to Zürich using several static geodetic and avionics receivers. This includes a Rockwell Collins GPS-4000S receiver as well as a CMC CMA-5024 receiver. The latter receiver is also installed in the EC145 and EC635 helicopters.

Tab. I is giving a summary on the performance parameters achieved in the years 2015 and 2016 for the two avionics GPS/EGNOS receivers. The present paper is focusing on the

<table>
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<th></th>
<th>CMC CMA-5024</th>
<th>Rockwell Collins GPS-4000S</th>
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<tbody>
<tr>
<td>Accuracy horizontal (95%)</td>
<td>1.20</td>
<td>1.16</td>
</tr>
<tr>
<td>Accuracy vertical (95%)</td>
<td>2.08</td>
<td>2.15</td>
</tr>
<tr>
<td>HPL (99%)</td>
<td>12.97</td>
<td>11.83</td>
</tr>
<tr>
<td>VPL (99%)</td>
<td>19.50</td>
<td>18.28</td>
</tr>
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</table>
HPL and VPL. Its 99% percentile is in the range of 11-14 m for the HPL, and 18-20 m for the VPL. For comparison reasons, also the 95% horizontal and vertical position accuracies are given in Tab. I. It is clearly visible that the performance is improving from 2015 to 2016.

IV. DATA ANALYSIS

A. Selected Data Set

The investigations include the data recorded on 13 EC635, 5 EC145 and 11 AW109. It sums up to 2'555 flight hours for the AW109, 2'280 flight hours for the EC145 and 7'350 flight hours for the EC635. The analysis includes only data with a minimum helicopter ground speed of 10 knots and where EGNOS derived protection levels were available.

B. Horizontal and Vertical Protection Level

The distribution of the horizontal and vertical protection levels (HPL and VPL) are analyzed in detail. Fig. 3 shows a representative histogram example of the HPL for a single EC145, EC635 and AW109 helicopter. Furthermore, the number of used satellites for positioning is investigated as well (Fig. 4). Fig. 5 shows the summary for HPL, VPL and number of satellites used for all individual helicopters and Tab. II gives an overview of the consolidated results obtained for the different types of helicopters.

The evaluation shows that the results achieved do not significantly vary within the helicopters of one type. Some variations are observed for the three different type of helicopters. The EC635 has a slightly better performance than the other two helicopter types. As the same GPS receiver is installed in the EC635 and EC145 helicopters, the performance differences should be negligible. Here, it is assumed that the different types of operations are the main reason for the differences of the performance levels. Other possible causes are the location of the GPS antenna and fuselage effects as described in [3]. While the EC635 helicopters of the Swiss Air Force often have longer flights and higher flight altitude, missions of the Swiss Air Rescue REGA are often shorter with a significant part of the flight close to the terrain. The comparison of the EC145 and AW109 shows similar results. While the 95% percentile is slightly smaller in case of the EC145, the contrary appears for the 99% percentile. As the EC145 is mainly used in flat areas and the AW109 in the mountains, a slightly better performance of the EC145 would not be surprising.

Finally, a comparison is made between the static receivers and the ones installed in the helicopters. It is especially of interest, that data of the CMA-5024 receiver is available from the GNSS monitoring on the ground as well as from the helicopters EC145 and EC635. The HPL as well as the VPL of the ground receivers are significantly lower than the results obtained from the on-board receivers. The differences are in the order of magnitude factor 2 – 5.

C. Correlation of Data

The HPL data is further analyzed to investigate correlations with other information. This includes the correlation with the number of satellites used, correlation with the helicopter
attitude as well as the flight altitude and the geographical distribution of the flights.

D. Comparison with the Number of Satellites Used

The comparison of the number of satellites used for positioning with the HPL did not show a solid correlation. An example is given in Fig. 6. Admittedly, the HPL is usually lower if many satellites are used for positioning. However, there exist still many occurrences with high HPL and many satellites used for positioning as well as the contrary with a small HPL but also only few satellites used for positioning.

E. Comparison with the Helicopter Attitude

Significant roll and pitch angles lead to satellite signal loss and consequently may increase the HPL. Therefore, a correlation between the HPL and the flight attitude has been investigated. Fig. 7 shows an example for an EC635 helicopter which is representative for all investigated helicopters. It is clearly visible that significant roll and pitch angles do not necessarily increase the HPL. In fact, in most cases the HPL is independent on roll and pitch angles. No correlation between the flight attitude and the HPL is found. A similar conclusion has been found in [3] analyzing satellite loss based on interference events. Nevertheless, a weak correlation may still be possible, if significant roll and pitch angles have a delayed influence on the HPL.

F. Comparison with the Flight Altitude

It seems obvious that the HPL may be higher if flying closer to the terrain. This correlation seems to be even more comprehensible in mountainous terrain. Fig. 8 depicts a representative example with an EC145 helicopter. Considering the flight altitude above mean sea level (MSL), no correlation is

<table>
<thead>
<tr>
<th>HPL [m]</th>
<th>50%</th>
<th>95%</th>
<th>99%</th>
<th>Flight Hours</th>
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<tbody>
<tr>
<td>EC635</td>
<td>8.4</td>
<td>12.0</td>
<td>24.9</td>
<td>7353 h</td>
</tr>
<tr>
<td>EC145</td>
<td>8.3</td>
<td>11.1</td>
<td>18.4</td>
<td>2276 h</td>
</tr>
<tr>
<td>AW109</td>
<td>20.3</td>
<td>34.4</td>
<td>52.1</td>
<td>2555 h</td>
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<table>
<thead>
<tr>
<th>VPL [m]</th>
<th>50%</th>
<th>95%</th>
<th>99%</th>
<th>Flight Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC635</td>
<td>12.7</td>
<td>18.4</td>
<td>28.4</td>
<td>7353 h</td>
</tr>
<tr>
<td>EC145</td>
<td>12.6</td>
<td>16.9</td>
<td>19.7</td>
<td>2276 h</td>
</tr>
<tr>
<td>AW109</td>
<td>32.3</td>
<td>54.6</td>
<td>82.0</td>
<td>2555 h</td>
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</table>

<table>
<thead>
<tr>
<th>No. Sat. Used</th>
<th>50%</th>
<th>95%</th>
<th>99%</th>
<th>Flight Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC635</td>
<td>9.6</td>
<td>9.9</td>
<td>5.6</td>
<td>7353 h</td>
</tr>
<tr>
<td>EC145</td>
<td>10.0</td>
<td>7.9</td>
<td>6.6</td>
<td>2276 h</td>
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visible. Considering the flight height above terrain, the correlation is clearly visible. The 99% HPL percentile for the data shown in Fig. 8 is at 94 m. For the remaining 1% tail of the HPL distribution, the flight height is always close to the terrain (Fig. 8, top).

G. Geographical Distribution of the Flights

In addition, a correlation of the HPL with the geographic region is analyzed. The intention is to see, whether flights in the mountainous areas generally have higher HPL than in flat areas. Fig. 9 shows the HPL for the year 2015-2016 for the EC145, EC635 and AW109 helicopters, displayed as a mean value of squares of 1x1 km². It is obvious that the HPL is uniformly distributed over the whole geographic area. Some small peaks are present, which corresponds in most cases to helipads and aerodromes.
V. CONCLUSIONS

In the frame of the project HRRF, a huge set of data from GPS, FMS and attitude information is recorded, allowing for various investigations on GNSS performance in the Swiss airspace. The HPL is the main parameter defining the GNSS performance availability of the low-route helicopter network. While the GNSS ground monitoring network shows a 99% percentile for the HPL of around 11-14 m, flight data from the various helicopters result in 25-70 m. This deviation clearly shows the effect of real flights, e.g. with visibility limitation based on terrain, just to name one of these effects.

The HPL and VPL of the different helicopters from the same type are quite homogeneous. Between the different helicopter types, some slight differences are possible. The reason for these differences is assumed in the different kind of helicopter missions. While missions of the Swiss Air Rescue REGA are usually relatively short with a significant amount of flight time close to the terrain, Swiss Air Force missions are often longer and on a higher flight level.

Correlations of the HPL with different other parameters have been visually investigated. However, no correlations of the HPL with the number of satellites used and the helicopter attitude has been found. Also analyzing flights over flat and mountainous terrain, the mean HPL is homogeneously distributed. Slightly higher mean HPL are only visible at some discrete locations, which often represent helipads and aerodromes. The only correlation found is between the HPL and the flight height above terrain. High HPL mainly appear on flights close to the terrain.

The investigations show an overall high protection level performance in the whole Swiss airspace. The values slightly vary for different helicopter types but to the full extent comply with the PBN requirements of advanced helicopter operations to carry out flights on the low-flight route network as well as EGNOS-based approach operations to hospitals and heliports.

ACKNOWLEDGMENT

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REFERENCES


Fig. 9: Geographic distribution of flights carried out with EC635 (top), EC145 (middle) and AW109 (bottom). The colors indicate the mean HPL of squares of 1x1 km^2 for the years 2015-2016.