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Original article

Determination of reliability parameters of HPL and VPL technical safety in the procedure of a non-precision landing approach NPA GNSS with using GPS and GLONASS navigation systems in air transport

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ABSTRACT

The paper presents the results of determining the HPL and VPL safety parameters used to evaluate the reliability of aircraft positioning in air transport. The HPL and VPL security level parameters were determined using GPS and GLONASS systems for the NPA GNSS non-precision landing approach. The work also compares the HPL and VPL values with the technical standards published by ICAO.

KEYWORDS

GPS, GLONASS, HPL, VPL, NPA

1. Introduction

One of the fundamental tasks and requirements for the implementation of the GNSS satellite air transport technology is to increase the safety of air operations. The level of technical safety is particularly critical within the aircraft approach in the final phase of the flight. Within the implementation of GNSS satellite technology in air transport, there are 3 basic aircraft positioning systems that determine the type of landing aircraft approach [Jafernik et al. 2016]:

- Non-Precision Approach (NPA), used primarily in the Aircraft Based Augmentation System (ABAS),
- Approach with Vertical Guidance (APV-I, APV-II), mainly used in the Space Based Augmentation System (SBAS),
- Precision Approach (PA, Cat. I), primarily used in the Ground Based Augmentation System (GBAS).

The NPA approach is quite commonly used in the RNAV area navigation concept, and is also implemented for GPS, GLONASS or GALILEO navigation systems. The position of the aircraft in the NPA GNSS (GPS or GLONASS or GALILEO) approach is defined only and solely in the horizontal plane, but there are no recommendations for navigation in the vertical plane [Fellner et al. 2016]. It should be emphasized that the position of the aircraft is determined by means of the navigation device and the Flight Management System (FMS) integrated with the GNSS receiver. The GNSS on-board receiver must have the Receiver Autonomous Integrity Monitoring (RAIM) function, which enables continuous monitoring and the autonomy of indications of navigation parameters. The technical safety factors in the NPA GNSS approach are determined by the positioning reliability coefficients: HPL (*Horizontal Protection Level*) and VPL (*Vertical Protection Level*) [Kazmierczak et al. 2014]. It must be noted that certification of HPL and VPL parameters is defined and implemented by the International Civil Aviation Organization (ICAO) [Krzykowska et al. 2014].

The HPL and VPL technical security parameters allow determining the area of the actual and reliable position of the aircraft in the airspace. This information is of paramount importance for 'Search and Rescue' service in aviation rescue using satellite and navigation systems (e.g. COSPAS-SARSAT) [Wetoszka 2016]. It should be emphasized that the installation of verification system of the HPL and VPL safety parameters for onboard equipment on rescue aircrafts allows, among others, for:

- development of a unified security, interoperability and cooperation system for rescue and search operations carried out by aircraft crews,
- implementation of the flight crew teaching and training system with new instrumentation and onboard software equipped with the GNSS satellite technology elements,
- safe access to the crash site by the rescue team,
- avoiding collisions with other aircrafts heading for the disaster region,
- determining the cruising altitude for the aircraft rescue column,
- defining a safety zone for horizontal navigation conducted by rescue aircrafts,
- narrowing the potential area of search for catastrophe victims,
- logistical support of the crash site,
- enabling air navigation at the hard-to-reach crash site.

The primary purpose of this research paper is to determine the numerical values for the HPL and VPL safety parameters using the GNSS sensor in the air transport area. The HPL and VPL parameters were determined using the GPS and GLONASS observation as part of the NPA GNSS non-precision landing approach. The research experiment was carried out using the Topcon HiperPro mobile receiver mounted on the Cessna 172 board, which performed a test flight over the military airport in Dęblin on 1st June 2010. The satellite data from a geodetic receiver that was not coupled to the FMS onboard computer and did not have any official boarding certification were used for the experiment purposes. Such a use of the geographic receiver aimed to check its suitability for determining the HPL and VPL reliability parameters in air navigation. The article compares the values of HPL and VPL parameters with technical standards published by ICAO (Chicago Convention of 1944, Annex 10 'Aeronautical Telecommunications' Volume I 'Radio Navigation Aids'). The whole work is divided into: introduction, 3 theoretical chapters, conclusions and research literature (bibliography).

2. The mathematical model of HPL and VPL parameters determination for the NPA GNSS approach

The HPL and VPL parameters allow for the determination of technical safety levels using the GNSS sensor in flight operations. The HPL parameter is referred to as a permissible error of the aircraft position in the horizontal plane for the safety needs of the flight operation being performed. In turn, the VPL safety parameter defines the maximum permissible vertical position error of the aircraft for the purpose of the safety of the air operation [Ciecko et al. 2015]. The HPL and VPL values are determined with a probability of 95%. The values of HPL and VPL parameters can be specified using mathematical formulas as below [Jokinen et al. 2011]:

$$\begin{cases} HPL = k_H \cdot \sqrt{mB^2 + mL^2} \\ VPL = k_V \cdot mh \end{cases} \tag{1}$$

where:

- k_H – coefficient determining navigation in the horizontal plane,
- k_H = 6.18 for 'en-route' navigation,
- k_H = 6.0 for the precision approach (PA),
- k_V – coefficient determining navigation in the vertical plane,
- k_V = 5.33 for the precision approach (PA),
- mB – standard deviation of geodetic latitude B,
- mL – standard deviation of geodetic longitude L,
- mh – standard deviation of ellipsoidal height h.

The accuracy parameters (*mB*, *mL*, *mh*) of the aircraft position in the BLh geodetic system are determined in a stochastic process by the GNSS observation, recorded by a mobile receiver mounted on an aircraft. Parameter values (*mB*, *mL*, *mh*) are determined using GPS or GLONASS observations in accordance with ICAO standards within the framework of the NPA GNSS non-precision approach. In the GPS system, the permissible values for satellite positioning accuracy in the horizontal plane are 17 m and 37 m respectively in the vertical plane. In the GLONASS system, the maximum satellite positioning accuracy in civil aviation is 12 m in the horizontal plane and 25 m in the vertical plane. It should be emphasized that the accuracy parameters specified by ICAO are given with a probability of 95% [International Civil Aviation… 2006].

3. The research experiment and research results

The HPL and VPL technical security parameters for the NPA GNSS non-precision landing approach were determined using GPS and GLONASS observations for aircraft positioning under the method of Single Point Positioning (SPP).

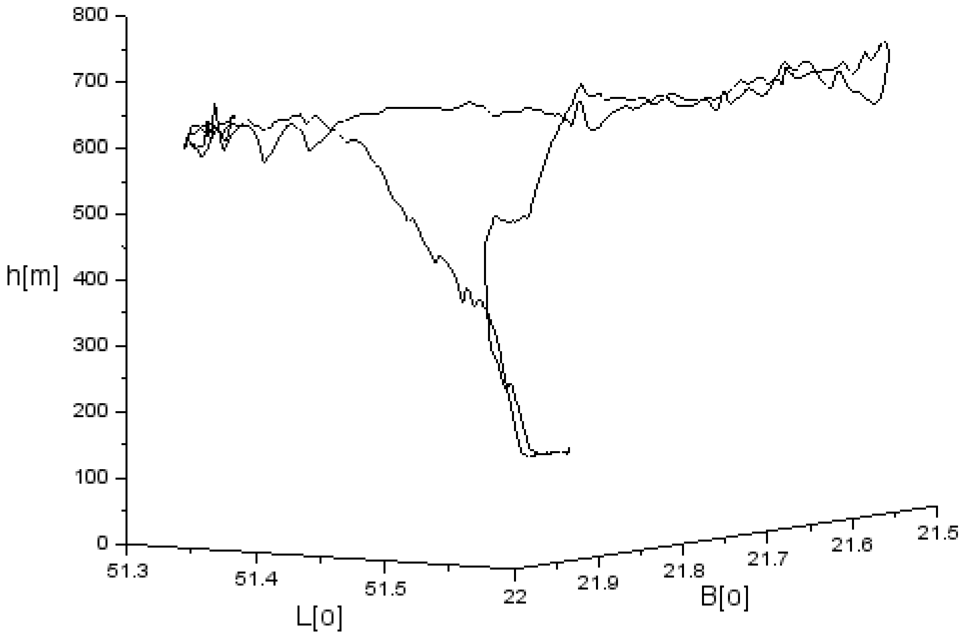

Fig. 1. The trajectory of flying Cessna 172 aircraft in 3D geometry
Source: own elaboration based on RTKLIB Program.

The research experiment was conducted for C/A code observations on L1 frequencies in GPS and GLONASS system. The GPS / GLONASS code observations were used in the research test, recorded and stored in the internal memory of the Topcon HiperPro receiver. The Topcon HiperPro dual-frequency receiver was mounted on-board on the Cessna 172 during the airplane test at the Dęblin Airport (see Fig. 1). The test flight was conducted on 1 June 2010 as part of a research project carried out by a team of experts from the Polish Air Force Academy (WSOSP) in Dęblin. The basic aim of the air test was to implement landing approaches using the GNSS satellite technology for the airport in Dęblin and to verify the operation of the experimental GNSS-based on-board system [Cwiklak and Jafernik 2010].

GPS / GLONASS observations in the RINEX 2.11 format were used in the calculations to determine the coordinates of the aircraft (see Fig. 1) and the positioning accuracy in the BLh geodetic system. Numerical calculations were made in the RTKLIB program in the RTKPOST module. In order to obtain a solution for the position of the aircraft, the following initial RTKPOST configuration parameters were set up in the RTKLIB program [Takasu 2013]:

– the positioning type: Single Point Positioning,
– the facade mask: 50,

– the ionospheric correction: the Klobuchar model,
– the tropospheric correction: the Saastamoinen model,
– the ephemeris data: onboard ephemeris,
– the satellite's clock correction data: onboard ephemeris,
– the GNSS system: GPS and GLONASS,
– the reference system: the WGS-84 global system.

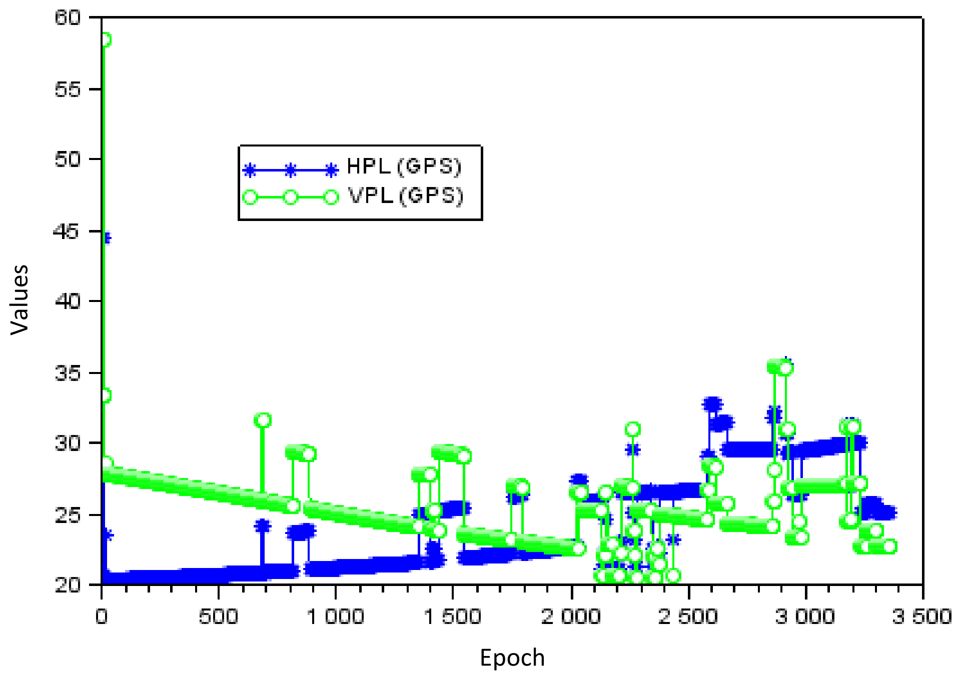

Fig. 2. Values of HPL and VPL parameters from the GPS solution
Source: own elaboration.

The obtained accuracy values (*mB*, *mL*, *mh*) of the aircraft positioning were used to determine the HPL and VPL parameters from Equation (1) for the GPS and GLONASS solution. When determining the HPL and VPL values, the following figures were used for the parameters: k_H = 6.18 and k_V = 5.33. Figure 2 shows the HPL and VPL values for the GPS solution. The average HPL value is 24,237 m, with the spread of results ranging from 20,410 m to 44,574 m. The median for the HPL results set is 22,538 m. It should be emphasized that approximately 94% of all HPL results from the GPS solution are less than 30 m. The average value for the VPL parameter is 25,691 m, with the spread of results from 20,480 m to 58,462 m. In turn, the median parameter for the VPL result set is 25,302 m. It is worth noting that about 97% of all results for the VPL parameter from the GPS solution is less than 30 m.

Figure 3 shows the HPL and VPL values for the GLONASS navigation solution. The average value of the HPL parameter is 41,831 m, with the spread of results from 36,893 m to 70,159 m. The median value for the HPL result set is 39,211 m. It is worth noting that about 90% of all HPL results from the GLONASS solution are less than 50 m. The average value for the VPL parameter from the GLONASS solution is 46,760 m, with the dispersion of results changing from 36,354 m to 88,213 m. The median value for the VPL parameter set is 46,673 m. It should be stressed that about 78% of all the VPL parameter results is less than 50 m, and 96% of the VPL parameter results is less than 60 m respectively.

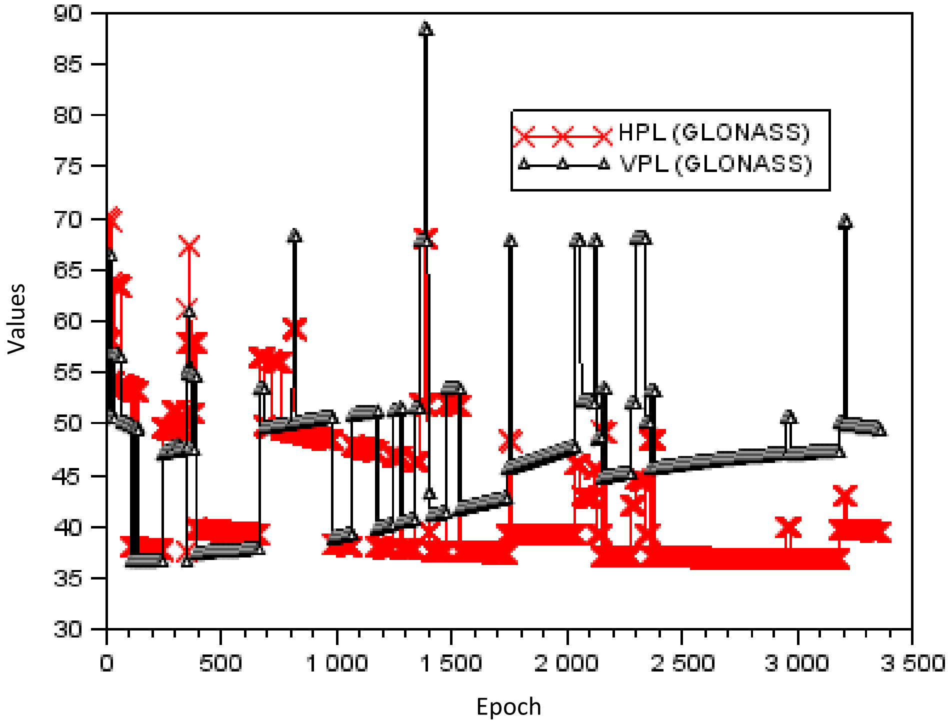

Fig. 3. The values of HPL and VPL parameters from the GLONASS solution
Source: own elaboration.

Figure 4 shows the difference of HPL and VPL values between GPS and GLONASS solutions. The value of the difference was determined according to the relation:

$$\begin{cases} dHPL = HPL_{GPS} - HPL_{GLO} \\ dVPL = VPL_{GPS} - VPL_{GLO} \end{cases} \tag{2}$$

where:

HPL_{GPS} – the HPL value from the GPS solution,
HPL_{GLO} – the HPL value from the GLONASS solution,
VPL_{GPS} – the VPL value from the GPS solution,
VPL_{GLO} – the VPL value from the GLONASS solution.

The average value of the difference for the HPL parameter results is -17.601 with the Root Mean Square (RMS) error of 8.5 m, and for the VPL parameter results, respectively, -21,078 m with the RMS error of 7.1 m. The spread of results for the dHPL difference is from -49.463 to -1.337 m, and for the dVPL difference from -60.379 to 7.868 m respectively. The median parameter for the dHPL result set is -16.623 m, while for the dVPL result set -21.016 m, respectively. It should be emphasized that the HPL and VPL reliability results from the GLONASS solution are definitely greater than from the GPS solution.

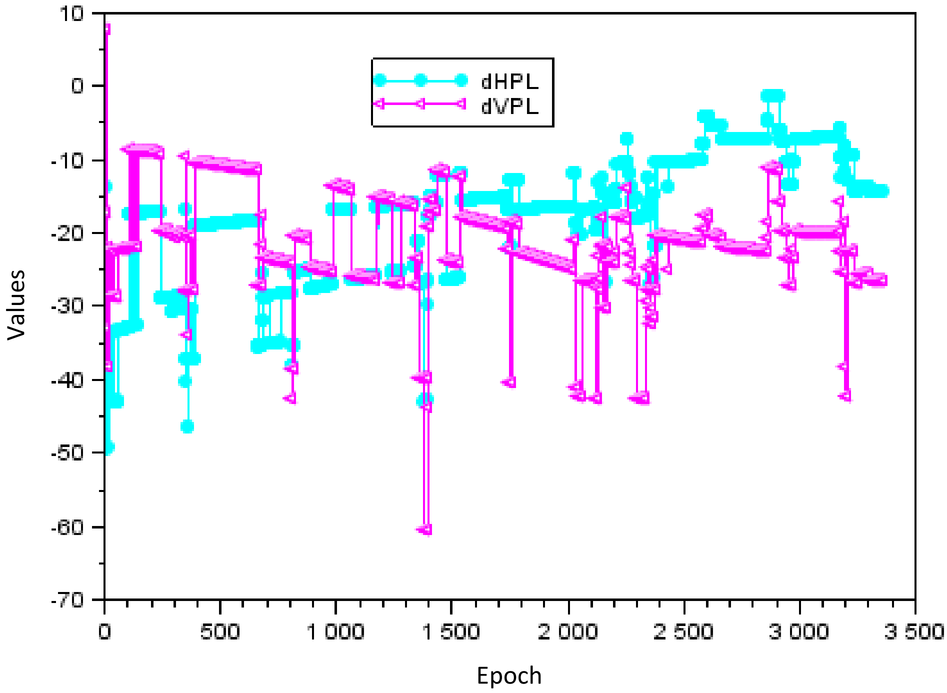

Fig. 4. The difference of values of HPL and VPL parameters between the GPS and GLONASS solutions
Source: own elaboration

4. Discussion

The International Civil Aviation Organization ICAO has introduced a metric framework related to the value of HPL and VPL security levels for landing approach procedures with the use of the GNSS sensor. For the NPA GNSS non-precision approach, the values for HPL and VPL are respectively [Grunwald et al. 2014]:

– 556 m for horizontal navigation,

– the VPL parameter is not determined for vertical navigation.

Table 1 summarizes the results obtained for the HPL and VPL parameters from the GPS and GLONASS solutions compared to the ICAO technical standards. The technical standards for horizontal and vertical navigation are included in Annex 10 'Aeronautical telcommunications' Volume I 'Radio Navigation Aids' issued by ICAO in 2006 and are constantly updated. The Polish version of the document 'Radio Navigation Aids' is available from the website of the Civil Aviation Office (ULC) [International Civil Aviation… 2006]. The HPL and VPL values determined for the purpose of this paper on the basis of the GPSLOG and GLONASS solutions do not exceed the critical limits for horizontal navigation. In the case of vertical navigation in the NPA GNSS landing approach procedure, VPL values should not be applied to evaluate the reliability of aircraft positioning. Thus, the VPL parameters for the NPA GNSS approach procedure described herein are purely informative and illustrative.

Table 1. The comparison of HPL and VPL reliability parameters with technical standards published by ICAO

<table>
<tr><th>Solution</th><th>The value of the HPL and VPL parameters obtained from the calculations</th><th>The theoretical value of HPL and VPL based on ICAO recommendations</th><th>Conclusion</th></tr>
<tr><td>GPS</td><td>* HPL is from 20.410 to 44.574 m.
** VPL is from 20.480 to 58.462 m.</td><td rowspan="2">* The theoretical value of the HPL parameter should not exceed 556 m for horizontal navigation.
** The critical value of the VPL parameter for the NPA non-precision approach was not specified in the ICAO technical standards.</td><td rowspan="2">* The aircraft's horizontal positioning accuracy values do not exceed the critical limits published by ICAO.
** In the NPA procedure, the VPL parameter does not have ICAO certification and should not be used to evaluate the positioning of the aircraft in the vertical plane.</td></tr>
<tr><td>GLONASS</td><td>* HPL is from 36.893 to 70.159 m.
** VPL is from 36.354 to 88.213 m.</td></tr>
</table>

Source: own elaboration.

Conclusion

This article discusses the results of determining the HPL and VPL security levels for the NPA GNSS non-precision landing approach procedure. The HPL and VPL values based on the GPS and GLONASS solutions were identified during the studies. The navigational data of the geodetic mobile receiver installed on board of the Cessna 172 aircraft was used in the research experiment. Furthermore, the HPL and VPL differences between the GPS and GLONASS solutions were determined. The obtained results of the HPL parameters from the GPS and GLONASS solutions do not exceed the critical limits for horizontal air navigation. For vertical navigation, VPL values are not certified by ICAO and constitute only information material for potential readers.

The obtained results of the satellite positioning reliability parameters were aimed at checking the suitability of the Topcon HiperPro geodetic receiver to determine the HPL and VPL parameters for air transport purposes. The results of the verification of HPL and VPL technical safety parameters presented in this work are also important in search and rescue operations. A uniform safety system based on the GNSS navigation system procedure can be very helpful in air rescue. Assimilation of safety procedures to the HPL and VPL parameters can accelerate the decision-making process in rescue operations and facilitate communication and logistics between rescue teams.

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Conflict of interests

The author declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

ORCID

Kamil Krasuski – The author declared that he has no ORCID ID's

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