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OPERATION AND RELIABILITY OF AN ONBOARD GNSS RECEIVER DURING AN IN-FLIGHT TEST

Summary. This article presents and describes the operational capabilities of an onboard GNSS receiver to determine the reliability of the in-flight navigation parameters. An analysis was made of the operation reliability of an autonomous single-frequency Thales Mobile Mapper receiver in air navigation as compared to the technical operation of a dual-frequency Topcon HiperPro receiver. To this end, this work contains a comparison of the aircraft flight navigation parameters based on readings obtained from the Thales Mobile Mapper and Topcon HiperPro receivers. In particular, the comparison concerned the reliability of coordinate determination and flight speed parameters of an aircraft. The research experiment was conducted using a Cessna 172 aircraft, a property of the Military University of Aviation in Dęblin, Poland. Technical operation of the GNSS satellite receivers was tested in the flights of the Cessna 172 aircraft around the EPDE military airport in Dęblin. Based on the results obtained from the tests, it was found that the operational reliability of the Thales Mobile Mapper in the operational phase of the in-flight test ranged from -3.8 to +6.9 m in the XYZ geocentric frame and from -2.2 to +8.1 m in the BLh ellipsoidal frame, respectively. On the other hand, the accuracy of the Cessna 172 aircraft positioning when using the Thales Mobile Mapper receiver was higher than 1.7 m in the XYZ geocentric frame and higher

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than 2 m in the BLh ellipsoidal frame, respectively. Furthermore, the reliability of the Cessna 172 flight speed determination was from -3.4 to +2.4 m/s.
Keywords: GNSS, satellite receiver, flight test

1. INTRODUCTION

A GNSS navigation receiver is an indispensable component of every aircraft's onboard avionics. In particular, in the present reality of a globalised world, the knowledge of the actual position of the aircraft forces aviation engineers to build more advanced onboard instruments comprising built-in GNSS receivers. The process of determining the actual position of an aircraft appears to be a key navigation parameter in the operation of aircraft used in aviation. Similar needs exist in maritime traffic [2]. Moreover, the GNSS sensor implementation in air navigation must be consistent with the certification of GNSS satellite systems to be used in aviation, published and recommended by the International Civil Aviation Organisation (ICAO). Following the adopted ICAO terminology, global GNSS navigation systems can be used in aircraft operations within the framework of the following:
- GPS navigation system,
- GLONASS navigation system,
- ABAS support system,
- SBAS support system,
- GBAS support system [10].

Each of the aforementioned GNSS satellite systems used in aviation has its own technical parameters and specifications within the accuracy, reliability, availability, and continuity of aircraft positioning [1]. The GPS and GLONASS satellite systems may be used as support systems to provide source data to an FMS onboard computer. Furthermore, GPS and GLONASS navigation systems can be used in air operations such as en-route and terminal navigation, and in the non-precision GNSS approach to landing procedure (NPA) [6]. The ABAS support system is an extension of the GPS and GLONASS systems' operation in aviation, with a RAIM (Receiver Autonomous Integrity Monitoring) module function enabling continuous monitoring of GNSS signals, as well as the real-time detection of aircraft position errors and the loss of position solution [3]. The SBAS support system is used in such air operations as the NPA GNSS non-precision approach and SBAS APV-I and SBAS APV-II approach. The GBAS support system is alternatively used particularly in Cat I Precision Approach (PA) [6]. The implementation of a GNSS sensor in the operation of an aircraft during an air operation phase forces the appropriate selection, adaptation and assembly of a certain class GNSS satellite receiver. There are three classes of receivers used in air navigation: A – instruments comprising a GNSS receiver and blocks performing navigation functions, B – instruments in which the GNSS receiver is the data source for the integrated aircraft navigation system, C– devices in which a GNSS receiver is the data source for the integrated aircraft navigation system controlling the flight in the autopilot mode.

For the GNSS satellite navigation technology implementation, during the aircraft operation, it is very important to determine the operational reliability parameter of an onboard GNSS satellite receiver. Reliability parameter may be determined for one or more GNSS receivers installed onboard the aircraft. The reliability parameter in air navigation determines the number of independent elements, which control the obtained values of a specific technical parameter in the active phase of the aircraft operation [11]. In its literal sense, a given, obtained, technical parameter of the aircraft ought to be subjected to external validation and verification to determine its suitability, readiness for operation, and to maintain the operation range in which readings from the equipment are obtained. In the area of GNSS satellite technology application in air navigation, these will be the control elements in the following forms: application of another GNSS receiver onboard the aircraft, application of another test method (or measurement technique) to check the reliability of the results obtained, or application of another software to verify the calculations performed. Within the scope of the GNSS satellite technique application in air navigation, the following technical parameters of an aircraft can be controlled: BLh coordinates in 3D space, speed, HPR (Heading, Pitch, Roll) orientation angles, precise flight time of the aircraft, etc.

This article aims to assess the reliability of the onboard GNSS receiver operation in the operation phase of the Cessna 172 during a test flight around the EPDE military airport in Dęblin. In the research test, navigation data coming from two satellite receivers, Thales Mobile Mapper and Topcon HiperPro, placed in the cockpit of the Cessna 172 aircraft were used in the process of determining reliability. In particular, this article contains verification and validation of the readings of aircraft coordinates, in the BLh ellipsoid frame and the XYZ geocentric frame, based on navigation data obtained from both GNSS satellite receivers. A new approach to the assessment of a GNSS satellite receiver reliability of operation in air navigation is presented in this study. The research method presented in this work makes it possible and ensures the verification of the operation of an autonomous GNSS receiver with the navigation solution obtained from a GNSS receiver in the post-processing mode. This article has been divided into four sections: 1- introduction, 2- materials and method, 3- results and discussion, 4- conclusions. A list of reference literature has been added at the end of this article.

2. MATERIALS AND METHOD

For completing the research task, two navigation receivers were used, a single-frequency Thales Mobile Mapper code receiver and a dual-frequency Topcon HiperPro code-phase receiver. Both receivers were placed in the cockpit of a Cessna 172 aircraft (Figure 1). The GNSS receivers were mounted in the cockpit so that the gap between them was the smallest possible and did not exceed 10 cm [7]. The GNSS receivers were used to determine the precise trajectory of the Cessna 172 aircraft flight around the EPDE military airport, which belongs to the 41st Air Training Base of the Polish Air Force in Dęblin, Poland. The test flight of the Cessna 172 aircraft was conducted along the Dęblin – Kozienice – Kazimierz Dolny – Puławy – Dęblin route. The duration of the test flight was approximately 1 hour according to GPST time [5]. The ellipsoidal height of the Cessna 172 flight ranged from approximately 150 to almost 750 m. The flight speed of the Cessna 172 ranged from 0 to the maximum value of approximately 80 m/s. The Thales Mobile Mapper receiver recorded the position of the Cessna 172 in real-time, with a 1-second interval. The Topcon HiperPro receiver recorded raw GPS observations, upon which the reference position of the Cessna 172 could be determined. The recording frequency of the GPS observations in the Topcon HiperPro was also 1 second.

During the in-flight experiment, the Thales Mobile Mapper code receiver was monitoring and displaying the changes of BLh coordinates in real-time. The position parameters of the Cessna 172 were used by the pilots to assess the position reliability and determine the aircraft trajectory. In addition, the Thales Mobile Mapper receiver was working in the GPS constellation tracking mode, and the readings of the aircraft position were related to the WGS-84 global system. Basic technical and configuration parameters of the Thales Mobile Mapper receiver in the GPS tracking mode for navigation positioning can be characterised as follows: operating memory, typically up to 4 MB RAM (even 32 MB or 64 MB as an option); internal receiver software: Mobile Mapper Field and Mobile Mapper Office; data export format: SHP, MIF, and DXF, the capability of using GIS tools: yes; the capability of using base maps: yes; reference system: global, standard WGS-84; calculation modes: GPS, EGNOS, DGPS; maximum number of tracked GPS satellites: up to 12; GPS satellite tracking mode: sequential; calculation initialisation: "cold start" < 2 minutes, "warm start" <1 minute, "hot start" < 15 seconds; calculation interval and observation recording time: typically 1 second or 2 seconds; positioning accuracy: up to 3 m; receiving antenna: in-built within the receiver; receiver weight: less than 0.5 kg; battery life: typically up to 8 hours; number of batteries in the set: 2 in-built batteries as standard; weather conditions of using the receiver: air temperature from -10 to +60°C [9].

Fig. 1. Thales Mobile Mapper and Topcon HiperPro receivers onboard the Cessna 172
Source: scientific materials from the Institute of Navigation of MUA in Dęblin

Owing to the GPS code observations that were recorded, it was possible to retrieve the position of the Cessna 172 aircraft using the Topcon HiperPro receiver in the post-processing mode. The BLh ellipsoidal coordinates of the Cessna 172 aircraft was determined based on the GPS observations performed by the Topcon HiperPro receiver, were retrieved in the RTKLIB software (RTKPOST module). RTKLIB is an open source application development tool similarly used for GNSS satellite positioning in air navigation [19].
Both in the internal software of the Thales Mobile Mapper receiver and the RTKLIB application, Single Point Positioning (SPP) absolute method for GPS L1-C/A code observations was used in calculating the position of the Cessna 172 aircraft, given below [16]:

$$l = d + c \cdot (dtr - dts) + Ion + Trop + Rel + bs + M_{C/A} \tag{1}$$

where:
l - code measurement of the L1-C/A in the GPS system,
d - geometric satellite-receiver distance,
$d = \sqrt{(x - X_{GPS})^2 + (y - Y_{GPS})^2 + (z - Z_{GPS})^2}$,
(x, y, z) - aircraft coordinates in the XYZ geocentric frame,

$(X_{GPS}, Y_{GPS}, Z_{GPS})$ - coordinates of GPS satellites in the orbit,
c - speed of light,
dtr - receiver clock bias correction,
dts - satellite clock bias correction,
Ion - ionospheric correction,
$Trop$ - tropospheric correction,
$\mathrm{Re}l$ - relativistic effect,
bs - total value of hardware delays for the satellite and the receiver,
$M_{C/A}$ - multipath effect.

The coordinates of the aircraft related to the geocentric XYZ frame are determined using the least squares method in the stochastic process below [14]:

$$\begin{cases} \mathbf{A} \cdot \mathbf{Qx} - \mathbf{dl} = \mathbf{v} \\ \mathbf{N} = \mathbf{A}^{\mathbf{T}} \cdot \mathbf{p} \cdot \mathbf{A} \\ \mathbf{L} = \mathbf{A}^{\mathbf{T}} \cdot \mathbf{p} \cdot \mathbf{dl} \\ \mathbf{Qx} = \mathbf{N}^{\mathbf{-1}} \cdot \mathbf{L} \end{cases} \tag{2}$$

where:
$\mathbf{Qx}$ - vector of parameters searched for, $\mathbf{Qx} = [x; y; z; c \cdot dtr]^T$,
$\mathbf{N}$ - matrix of the standard equation frame,
$\mathbf{A}$ - design matrix,
$\mathbf{p}$ - matrix of weights,
$\mathbf{L}$ - vector of free terms,
$\mathbf{dl}$ - vector defining the difference between observed and approximate coordinates determined from the model,
$\mathbf{v}$ - vector of corrections.

The position of the Cessna 172 aircraft expressed in the geocentric XYZ coordinate frame is transformed into the BLh ellipsoidal coordinate frame as written below [14, 16]:

$$\begin{bmatrix} B \\ L \\ h \end{bmatrix} = \begin{bmatrix} arc\tan\left(\dfrac{z}{\rho} + \dfrac{\delta_1 \cdot tgB_{j-1}}{\sqrt{\delta_2 \cdot tg^2 B_{j-1}}} \right) \\ arc\tan\left(\dfrac{y}{x} \right) \\ \dfrac{\rho}{\cos B} - R \end{bmatrix} \tag{3}$$

where:
(a, b) - semi-major and semi-minor axis of the WGS-84 ellipsoid,

e - eccentricity, $e=\sqrt{\frac{a^2-b^2}{a^2}}$,

R - prime vertical circle curvature radius, $R=\frac{a}{\sqrt{1-e^2\cdot\sin^2 B}}$,

$\delta_1=\frac{a\cdot e}{\rho\cdot\sqrt{1-e^2}}$,

$\delta_2=\frac{1}{1-e^2}$,

j - step of iteration,

$\rho=\sqrt{x^2+y^2}$,

(B,L,h) - aircraft coordinates in the geodesic frame,

B - geodesic latitude,

L - geodesic longitude,

h - ellipsoidal height.

The coordinates of the Cessna 172 aircraft obtained from the Thales Mobile Mapper and Topcon HiperPro receivers, determined based on equations (2) and (3) will be compared to determine the accuracy of GPS satellite positioning and the reliability of the GPS navigation system operation in aviation. The results of the comparisons are presented in Section 3.

3. RESULTS AND DISCUSSION

In the research test, first, the reliability of the GNSS receivers in tracking GPS satellites was determined. Figure 2 presents the number of GPS satellites being tracked by the Thales Mobile Mapper and the Topcon HiperPro receivers, respectively. In the operation of the Thales Mobile Mapper receiver, the number of satellites tracked was from 6 to 9. Moreover, the average number of GPS satellites tracked by the Thales Mobile Mapper receiver was 8. As far as the Topcon HiperPro receiver is concerned, the number of satellites tracked was from 6 to 10. Moreover, the average number of GPS satellites tracked by the Topcon HiperPro receiver was approximately 9. The Topcon HiperPro receiver tracked approximately 8% more GPS satellites than the Thales Mobile Mapper. The key element in the reliability of tracking GPS satellites by both onboard GNSS receivers is maintaining and sustaining the continuity of navigation data recording during their activity in flight operations [12]. Moreover, the number of GPS satellites tracked by each GNSS onboard receiver was at least 6, which allowed the determination of the aircraft's navigation position and controlling navigation calculations by mechanisms and algorithms of the RAIM module. In the aspect of ICAO technical standards and recommendations, the availability of the GPS satellite constellations should be 99% of the in-flight test duration [10]. Consequently, the operation of the GNSS onboard receivers met the ICAO criteria for maintaining the availability and visibility of the GPS navigation system constellation during an in-flight experiment.

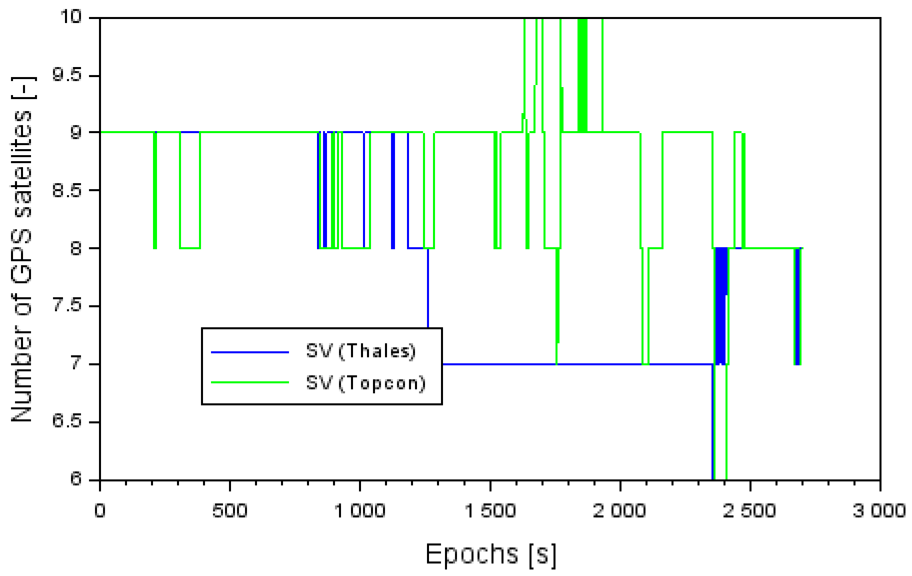

Fig. 2. The number of GPS satellites tracked by
the Thales Mobile Mapper and Topcon HiperPro receivers

The second phase of this study concerned the reliability of determining the aircraft coordinates in the XYZ geocentric system based on navigation data obtained from the Thales Mobile Mapper and Topcon HiperPro receivers. For this purpose, the difference of the aircraft coordinate values - in the geocentric XYZ frame - was determined based on the autonomous solution and post-processing shown below [13]:

$$\begin{cases} dx = x_{Thales} - x_{Topcon} \\ dy = y_{Thales} - y_{Topcon} \\ dz = z_{Thales} - z_{Topcon} \end{cases} \tag{4}$$

where:

x_{Thales} - aircraft coordinate along the X-axis of the geocentric system from the Thales Mobile Mapper solution,

y_{Thales} - aircraft coordinate along the Y-axis of the geocentric system from the Thales Mobile Mapper solution,

z_{Thales} - aircraft coordinate along the Z-axis of the geocentric system from the Thales Mobile Mapper solution,

x_{Topcon} - aircraft coordinate along the X-axis of the geocentric system from the Topcon HiperPro solution,

y_{Topcon} - aircraft coordinate along the Y-axis of the geocentric system from the Topcon HiperPro solution,

z_{Topcon} - aircraft coordinate along the Z-axis of the geocentric system from the Topcon HiperPro solution.

Figure 3 presents the results of the reliability parameter determination in the (dx, dy, dz) coordinate determination for the Cessna 172 aircraft.

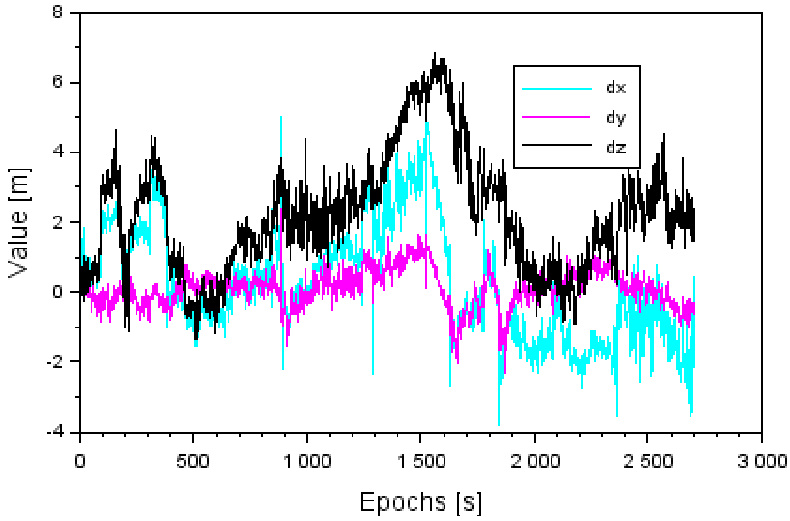

Fig. 3. Reliability of determining the Cessna 172 coordinates in the XYZ geocentric frame

The reliability values of determining the Cessna 172 coordinates along the X-axis are from -3.8 to +5.7 m, respectively. Moreover, the mean value of the $Vo\ dx$ parameter equals 0.3 m, with the statistical median being 0.2 m. It should be stressed that in the initial flight phase, the values of the dx parameter are positive, whereas in the final flight phase, during the landing approach, the values of the dx parameter are definitely negative. The reliability values of determining the Cessna 172 coordinates along the Y-axis are from -2.3 to +2.4 m, respectively. Moreover, the mean value of the dy parameter equals 0.1 m with the statistical median being also equal to 0.1 m. The character of the dy parameter changes has the lowest dispersion in comparison with the (dx, dz) parameters. Thus, the reliability of determining the aircraft coordinates along the Y-axis is the best in the presented research test. The reliability values of determining the Cessna 172 coordinates along the Z-axis are from -1.4 to +6.9 m, respectively. Moreover, the mean value of the dz parameter equals 2.2 m, with the median being 2.1 m. The character of the dz parameter dispersion is the highest in comparison with the (dx, dy) parameters. Subsequently, the reliability of determining the aircraft coordinates along the Z-axis is the worst in the presented research test. Within the scope of determining the aircraft coordinates in the XYZ geocentric frame, the accuracy of satellite positioning using the SPP method in air navigation was determined as below [17]:

$$\begin{cases} RMS_X = \sqrt{\dfrac{dx^2}{n}} \\ RMS_Y = \sqrt{\dfrac{dy^2}{n}} \\ RMS_Z = \sqrt{\dfrac{dz^2}{n}} \end{cases} \tag{5}$$

where:
n - number of the parameter set (dx, dy, dz).

Using the SPP method, the respective accuracy of the aircraft positioning is, 1.6 m along the X-axis, more than 0.5 m along the Y-axis, and approximately 1.7 m along the Z-axis. It should be noted that the highest RMS error value is along the Z-axis whereas the lowest along the Y-axis.

The third phase of this study concerned the position displacement vector of the Cessna 172 aircraft position in the XYZ geocentric frame. The position displacement vector, referred to as the $3D-error$ parameter was determined from the following relationship [15]:

$$3D-error = \sqrt{dx^2 + dy^2 + dz^2} \tag{6}$$

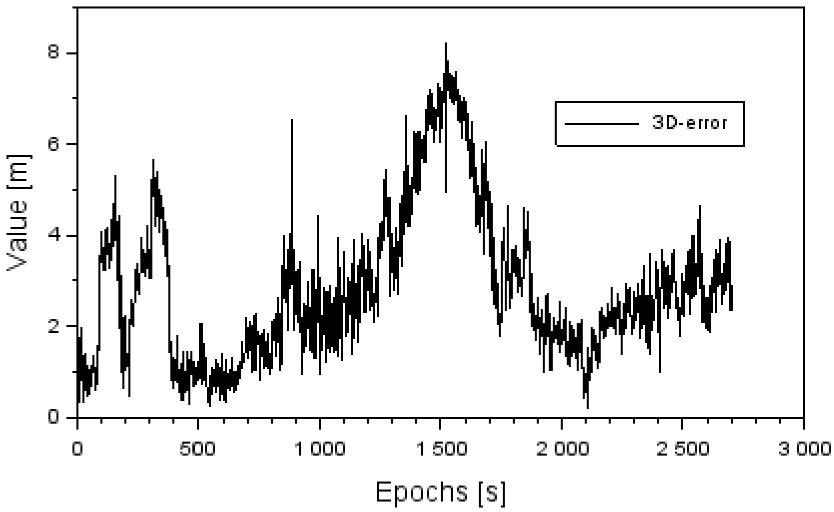

Fig. 4. The 3D-error parameter values in the XYZ geocentric frame

The values of the $3D-error$ parameter were determined and presented in Figure 4. The respective values of the $3D-error$ parameter equal from 0.2 to 8.2 m Moreover, the mean value of the $3D-error$ parameter equals 2.8 m, with its median being 2.5 m. More than 34% of all $3D-error$ parameter results is less than 2 m, whereas approximately 81% of $3D-error$ parameter results is less than 4 m. It is worth mentioning that in the middle phase of the experiment, the value of the $3D-error$ parameter rises to more than 8 m, and in the final flight phase, is less than 4 m.

The fourth phase of this study concerned the reliability of determining the aircraft coordinates in the BLh ellipsoidal frame based on the navigation data obtained from the Thales Mobile Mapper and Topcon HiperPro receivers. For this purpose, the difference of the aircraft coordinate values - in the ellipsoidal BLh frame - was determined as below [18]:

$$\begin{cases} dB = B_{Thales} - B_{Topcon} \\ dL = L_{Thales} - L_{Topcon} \\ dh = h_{Thales} - h_{Topcon} \end{cases} \tag{7}$$

where:

B_{Thales} - value of the aircraft B coordinate value from the Thales Mobile Mapper solution,

L_{Thales} - value of the aircraft L coordinate value from the Thales Mobile Mapper solution,

h_{Thales} - value of the aircraft h coordinate value from the Thales Mobile Mapper solution,

B_{Topcon} - value of the aircraft B coordinate value from the Topcon HiperPro solution,

L_{Topcon} - value of the aircraft L coordinate value from the Topcon HiperPro solution,

h_{Topcon} - value of the aircraft h coordinate value from the Topcon HiperPro solution.

Figure 5 presents the results of the reliability parameter determination in the (dB, dL, dh) coordinate determination for the Cessna 172 aircraft.

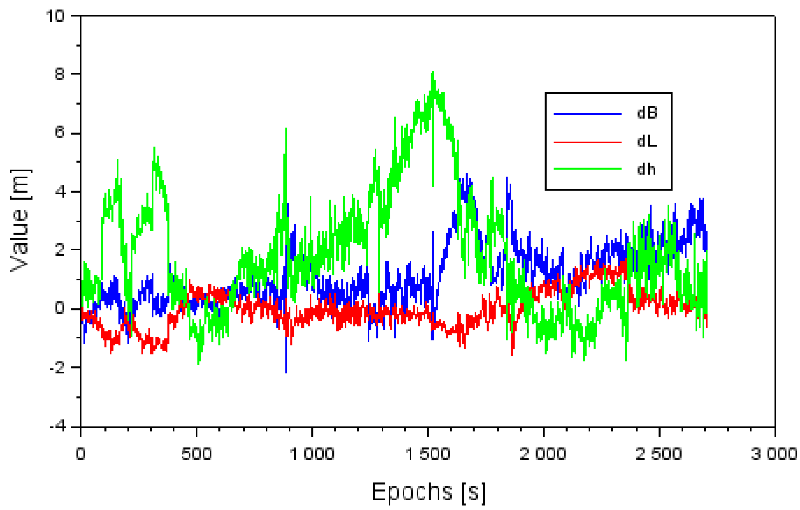

Fig. 5. The reliability of determining the Cessna 172 coordinates in the BLh ellipsoidal frame

The reliability values of determining the Cessna 172 coordinates for the B component are from -2.2 to +5.7 m, respectively. Moreover, the mean value of the dB parameter equals 1.2 m, with the median being 0.9 m. It should be noted that in the initial flight phase, the values of the dB parameter are close to zero, whereas in the final flight phase, during the landing approach, the values of the dB parameter are definitely positive. The reliability values of determining the Cessna 172 coordinates for the L component are from -1.6 to +1.7 m, respectively. Moreover, the mean value of the dL parameter equals 0.1 m, with the statistical median being also 0.1 m. The character of the dL parameter changes has the lowest dispersion in comparison with the (dB, dh) parameters. Thus, the reliability of determining the aircraft coordinates along the L-axis is the best in the presented research test. The reliability values of determining the Cessna 172 coordinates for the h coordinate are from -1.9 to +8.1 m, respectively. Moreover, the mean value of the dh parameter equals 1.9 m, with the median being 1.5 m. The character of the dh parameter changes has the highest dispersion in comparison with the (dB, dL) parameters. Subsequently, the reliability of determining the aircraft coordinates along the h-axis is the worst in the presented research test. Especially in the middle phase of the flight, the dispersion of the dh parameter results is quite large and exceeds 8 m.

Regarding the reliability of the aircraft coordinate determination in the BLh ellipsoidal frame, the accuracy of satellite positioning using the SPP method in air navigation was determined as below [4]:

$$\begin{cases} RMS_B = \sqrt{\dfrac{dB^2}{N}} \\ RMS_L = \sqrt{\dfrac{dL^2}{N}} \\ RMS_h = \sqrt{\dfrac{dh^2}{N}} \end{cases} \tag{8}$$

where:
N - number of the parameter set (dB, dL, dh), $N = n$.

Using the SPP method, the respective accuracy of the aircraft positioning, is approximately 1.1 m along the B-axis, more than 0.6 m along the L-axis, and more than 2 m along the h-axis. It would be observed that the highest RMS error value is along the h-axis, whereas the lowest along the L-axis.

In the last phase of the comparison and verification of the GNSS receiver operation during an air operation, the comparison was made between the reliability of the flight speed parameter determination using the autonomous solution and the post-processing mode. Namely, the flight speed parameter readings from the Thales Mobile Mapper and the Topcon HiperPro solutions were verified, as below [8]:

$$dV = V_{Thales} - V_{Topcon} \tag{9}$$

where:
dV - difference of flight speed readings,
V_{Thales} - aircraft velocity based on the Thales Mobile Mapper solution,
V_{Topcon} - aircraft velocity based on the Topcon HiperPro solution.

The values of the dV parameter were determined and presented in Figure 6. The reliability values of the Cessna 172 flight speed determination were from -3.4 to +2.4 m/s. Moreover, the mean value of the dV parameter equals -0.1 m/s, with the statistical median being -0.1 m/s too. In addition, approximately 99% of all dV parameter results belong to the -1 to +1 m/s range. Furthermore, the reliability of the dV parameter reading determined employing the RMS parameter equals approximately 0.3 m/s.

The process of aircraft operation in terms of determining navigation parameters using the GNSS satellite technology is crucial in the safety aspect of flight operations. The reliability of the GNSS onboard receiver operation and the credibility of navigational data readings are the basic technical elements that enable determining the quality of the navigation solution in aircraft positioning. Verification and validation tests of an onboard GNSS receiver should be performed periodically, using precision dual-frequency geodesic receivers that enable checking and monitoring the changes in aircraft navigation parameter readings from an autonomous solution in real-time. Such an approach is important as it allows the determination of gross errors in the aircraft coordinates determined or detection of systematic errors in the aircraft coordinate changes. In the analysed example, the catalogue accuracy of determining the aircraft position using the Thales Mobile Mapper is 3 m. Therefore, the boundary error of the coordinate determination reliability using the Thales Mobile Mapper may be up to 9 m. Considering the research results from Figures 3 and 5, we may conclude that the obtained reliability values of the Thales Mobile Mapper receiver to the Topcon HiperPro receiver do not exceed the 9 m limit. Additionally, the tests performed, meet the boundary criterion of operation and admission of the Thales Mobile Mapper onboard receiver to use. Moreover, this solution allows further testing of the Thales Mobile Mapper receiver in the operation of the Cessna 172 aircraft and enables planning subsequent flight operations using the GNSS satellite technology in aviation.

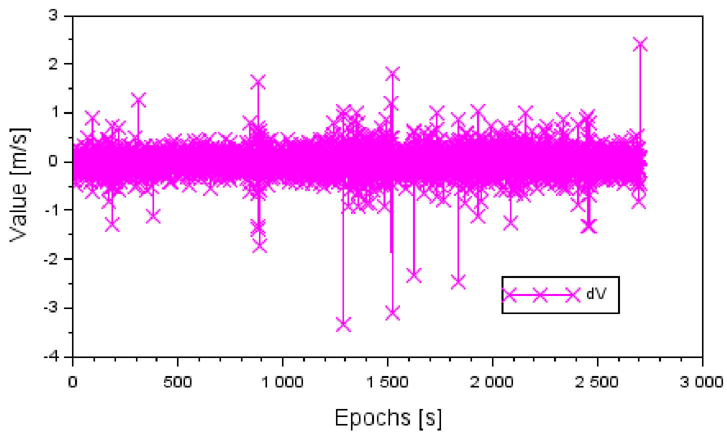

Fig. 6. The reliability of determining the flight speed of the Cessna 172 aircraft

4. CONCLUSION

In this article, the reliability parameters of the onboard GNSS receiver operation was described in the operation phase of the in-flight experiment. Particularly, the reliability of the following aircraft flight parameters was determined using the GPS satellite technology: the availability of traced satellite constellations, coordinates of the aircraft position in the XYZ geocentric and ellipsoid BLh frames, and flight speed. The research test was conducted for the Thales Mobile Mapper receiver installed onboard a Cessna 172 aircraft. Thales Mobile Mapper receiver is a single-frequency GPS satellite receiver, which records aircraft navigation data in real-time. The reliability of aircraft flight navigation parameters was verified and validated against the solution obtained using the Topcon HiperPro receiver in a post-processing mode. Both satellite receivers were used in the in-flight experiment at the EPDE military airport in Dęblin. The reliability of determining the position of the Cessna 172 aircraft in the geocentric XYZ frame ranged from -3.8 to +6.9 m, whereas in the ellipsoidal BLh frame, it ranged from -2.2 to +8.1 m. Furthermore, the reliability of the Cessna 172 flight speed determination was from -3.4 to +2.4 m/s. On the other hand, the positioning accuracy of the Cessna 172 aircraft was higher than 1.7 m in the geocentric XYZ frame and higher than 2 m in the BLh ellipsoidal frame, respectively. Moreover, the accuracy of the flight speed determination for the Cessna 172 aircraft was 0.3 m/s. The research tests conducted, confirm the usefulness of the Thales Mobile Mapper in air operations.

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