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ANALYSIS OF THE ACCURACY OF EGNOS+SDCM POSITIONING IN AERIAL NAVIGATION

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Abstract:

The article presents a modified scheme of determining the accuracy parameter of SBAS (Satellite Based Augmentation System) positioning with use of two supporting systems: EGNOS (European Geostationary Navigation Overlay Service) and SDCM (System of Differential Correction and Monitoring). The proposed scheme is based on the weighted mean model, which combines single solutions of EGNOS and SDCM positions in order to calculate the accuracy of positioning of the aerial vehicle. The applied algorithm has been tested in a flight experiment conducted in 2020 in north-eastern Poland. The phase of approach to landing of a Diamond DA 20-C1 aircraft at the EPOD airport (European Poland Olsztyn Dajtki) was subjected to numerical analysis. The Septentrio AsterRx2i geodesic receiver was installed on board of the aircraft to collect and record GPS (Global Positioning System) observations to calculate the navigation position of the aircraft. In addition, the EGNOS and SDCM corrections in the ".ems" format were downloaded from the real time server data. The computations were realized in RTKPOST library of the RTKLIB v.2.4.3 software and also in Scilab application. Based on the conducted research, it was found that the accuracy of aircraft positioning from the EGNOS+SDCM solution ranged from -1.63 m to +3.35 m for the ellipsoidal coordinates BLh. Additionally, the accuracy of determination of the ellipsoidal height h was 1÷28% higher in the weighted mean model than in the arithmetic mean model. On the other hand, the accuracy of determination of the ellipsoidal height h was 1÷28% higher in the weighted mean model than for the single EGNOS solution. Additionally, the weighted mean model reduced the resultant error of the position RMS-3D by 1÷13% in comparison to the arithmetic mean model. The mathematical model used in this study proved to be effective in the analysis of the accuracy of SBAS positioning in aerial navigation.*

Keywords: *accuracy, SBAS, EGNOS, SDCM, RMS-3D*

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1. Introduction

The SBAS supporting systems enable the identification of 4 main parameters that determine both the effectiveness and quality of GNSS positioning in aviation (Tabti et al., 2021). These parameters are accuracy, continuity, availability, and integrity (Krasuski and Wierzbicki, 2020). Such GNSS systems as GPS and GLONASS are certified by the ICAO and they ensure the determination of the accuracy, continuity, and availability parameters (ICAO, 2006). On the other hand, SBAS supporting systems additionally guarantee the determination and calculation of the integrity parameter (Krasuski and Wierzbicki, 2020; ICAO, 2006; Januszewski, 2010), which is essential for air transport and, in particular, for the procedures of landing approach and landing of an aerial vehicle based on GNSS sensors. On the other hand, when we consider the application of the SBAS supporting system in aerial navigation, this is understood, first of all, as determining the accuracy of GNSS positioning (Popielarczyk, 2011). The accuracy parameter should be defined and calculated as the difference between the coordinates of an aerial vehicle determined from the SBAS solution and the reference position of the flight (Krasuski, 2019). In this specific case, the reference position of the flight should be determined with use of the GNSS phase observations for the RTK-OTF differential technique (Krasuski et al., 2020). The accuracy of the autonomous positioning for the GPS system ranges from 9 to 17 m for the horizontal plane and from 15 to 37 m for the vertical component, and for the GLONASS system, respectively, from 5 to 12 m in the horizontal plane and from 9 to 25 m for the vertical component (ICAO, 2006; Krasuski and Ćwiklak, 2017; Krasuski, 2017). SBAS supporting systems significantly improve this accuracy, currently to the level of 1-3 m for all the components of the determined position of an aerial vehicle (Grunwald et al., 2016). This makes the application of SBAS supporting systems in aerial navigation even more effective and, at the same time, interesting navigation solution to determine the position of an aircraft (Hvezda, 2021).

2. Analysis of the current state of knowledge in the analysed subject

Examples of the application of the SBAS system in aerial navigation can be found in numerous research papers. However, the examples presented below refer only to those flight experiments that were conducted in Poland, and where the SBAS positioning accuracy was calculated. Firstly, it should be emphasized that until now, flight experiments conducted in Poland generally used the EGNOS supporting system (Ciećko, 2019; Grunwald et al., 2021). This system, similarly as other SBAS supporting systems, such as: the Chinese BDSBAS, Indian GAGAN, Australian GATBP, Japanese MSAS, Nigerian NSAS, Russian SDCM, and the American WAAS are fully operational and are used in GNSS satellite navigation (MGEX Website, 2021).

The beginnings of using the EGNOS system in flight tests date back to the year 2003, when the quality of the ESTB (EGNOS System Test Bed) signal was tested in actual measurement conditions. These experiments were conducted as part of the "BRDA" and “ODRA” research projects, in co-operation with the University of Warmia and Mazury in Olsztyn and the Polish Air Force Academy in Dęblin. The research project involved a total of 3 experimental flights of the TS-11 Iskra aircraft, equipped with two geodesic receivers: Ashtech Z-XII and Z-Surveyor, which enabled to determine the actual reference flight trajectory with use of the RTK-OTF technique. Additionally, for the purposes of determining the quality of EGNOS positioning, two navigation receivers with EGNOS tracking function were placed in the cockpit, i.e.: Garmin GPS Map 76S and Javad Legacy. During the test flights, the ESTB positioning proved to be better than code positioning in each of the cases. Apart from that, during each of the performed flights, epochs without EGNOS adjustments were observed, which proves that the transmitted ESTB test signal was unstable (Cydejko et al., 2004; Grzegorzewski, 2005).

Further flight experiments were conducted in 2007, immediately after the RIMS station of the EGNOS system in Warsaw had been put into use. The tests were conducted with a Cessna aircraft as part of the “LIWIEC” project. The aircraft was equipped with the following receivers: Thales Mobile Mapper, U-Blox and an Eten Glofiish integrated with palmtop on the SirfStar III chipset. EGNOS positioning for the U-Blox receiver was obtained only in the mid-flight phase. In spite of information about corrections throughout the whole flight, the Thales Mobile Mapper receiver obtained much higher accuracy values in the time range signalled by the U-Blox receiver. It is highly likely that the Thales receiver signals the receipt of adjustments even if they cannot be considered correct. The EGNOS positioning accuracy values were significantly better than those obtained at the same time with use of the SPP code method. This means that the accuracy of EGNOS was 1-5 m (Grzegorzewski et al., 2008).

Another experiment was conducted in 2010, immediately after launching the Open Service (OS) of the EGNOS system. The tests were conducted in south-eastern Poland with use of a Cessna aircraft. Two Thales Mobile Mapper receivers with SBAS/EGNOS positioning option were installed on board of the aircraft. During the test in Dęblin, the accuracy of EGNOS positioning fell into the range of 1-3 while in Chełm it was 1-10 m, which was a worse result than that for the SPP absolute method in the GPS system. The results of EGNOS positioning accuracy demonstrated only that east of the Vistula River the problem with EGNOS quality data was relatively serious and that it needed solving (Grzegorzewski et al., 2012).

Further tests were conducted in 2013, after launching the Safety of Life (SoL) system whose aim was to improve the aviation safety as part of EGNOS positioning. The experiment consisted of two test flights with a Cessna aircraft equipped with a Septentrio AsteRx2e receiver. During flight No. 1, the accuracy of EGNOS positioning ranged from 1 m to 6 m in the horizontal plane and from 1 m to 8 m in the vertical plane. On the other hand, during flight No. 2, the accuracy of EGNOS positioning ranged from 1 m to 2.5 m. The factor that improved the results was the application of ionospheric correction in form of a SBAS model of the ionosphere during flight No. 2 (Ciećko et al., 2013).

3. Research problem

The analysis of the state of knowledge leads to the following conclusions:

- The accuracy of positioning the aerial vehicle was determined from a single EGNOS solution for a single GNSS receiver;
- Previously obtained EGNOS positioning results pointed to a problem with the accuracy parameter in eastern Poland;
- Flight tests were conducted in the eastern part of Poland;
- Flight tests were conducted with use of various class receivers, which obviously influenced the accuracy of EGNOS positioning;
- Experiments were conducted at various times of day and various ionospheric conditions.

The analysis of the state of knowledge revealed that there was no research concerning:

- the combination or connection of the EGNOS navigation solutions with another SBAS supporting system;
- the verification of the position determined from the EGNOS solution in reference to another SBAS supporting system;
- developing the algorithms to improve the determination of the accuracy of SBAS positioning in eastern Poland;
- conducting a larger number of flight tests in eastern Poland.

Based on these findings, the authors of this article have proposed an innovative SBAS navigation solution to determine the position of an aerial vehicle, which will enable to improve the accuracy parameter. In order to achieve it, a resultant model was developed to determine the position of the aerial vehicle based on two independent solutions from different SBAS supporting systems.

Thus, two supporting systems: EGNOS and SDCM were used in the study in order to determine the position of the aerial vehicle from a single SBAS solution (Bakuła et al., 2022). Then, the authors proposed to create a linear combination to determine the resultant position of the aircraft. The linear combination combines single EGNOS and SDCM solutions and allows for the determination of the resultant coordinates of the aerial vehicle.

The proposed SBAS solution was based on the weighted mean model, where weight coefficients were applied for the purposes of creating the linear combination. The determined resultant coordinates of the aerial vehicles lead to an improvement in the positioning accuracy in comparison to the reference trajectory of the flight calculated with use of the RTK-OTF method.

The paper consists of seven sections: 1. Introduction, 2. Analysis of the current state of knowledge in the analysed subject, 3. Research problem, 4. Research methodology, 5. Research test, 6. Results and discussion, 7. Conclusions. Bibliography is placed at the end of the study.

4. Research methodology

The accuracy parameter of EGNOS+SDCM positioning was determined based on the following mathematical model (Krasuski, 2019):

$$\begin{bmatrix} dB \\ dL \\ dh \end{bmatrix} = \begin{bmatrix} B_m - B_{ref} \\ L_m - L_{ref} \\ h_m - h_{ref} \end{bmatrix} \tag{1}$$

where:
(dB, dL, dh) – accuracy of aircraft positioning in form of position errors (Specht et al., 2019),
(B_m, L_m, h_m) – the coordinates of the aerial vehicle determined from the EGNOS+SDCM resultant solution, $(B_{ref}, L_{ref}, h_{ref})$ – reference coordinates of the flight of the aerial vehicle calculated with the RTK-OTF differential technique (Krasuski et al., 2020).

On the other hand, the values of the resultant coordinates of the aircraft (B_m, L_m, h_m) were calculated from the formula:

$$\begin{cases} B_m = \dfrac{\alpha_E \cdot B_{EGNOS} + \alpha_S \cdot B_{SDCM}}{\alpha_E + \alpha_S} \\ L_m = \dfrac{\alpha_E \cdot L_{EGNOS} + \alpha_S \cdot L_{SDCM}}{\alpha_E + \alpha_S} \\ h_m = \dfrac{\alpha_E \cdot h_{EGNOS} + \alpha_S \cdot h_{SDCM}}{\alpha_E + \alpha_S} \end{cases} \tag{2}$$

where:
B_{EGNOS} – geodesic latitude from the EGNOS solution, B_{SDCM} – geodesic latitude from the SDCM solution, L_{EGNOS} – geodesic longitude from the EGNOS solution, L_{SDCM} – geodesic longitude from the SDCM solution, h_{EGNOS} – ellipsoidal height from the EGNOS solution, h_{SDCM} – ellipsoidal height from the SDCM solution, α_E – measurement weight from the EGNOS solution, α_S – measurement weight from the SDCM solution.

Equation (2) describes the weighted mean model for the purposes of describing the resultant position of the aerial vehicle.

The measurement weight was defined as a function of the number of tracked satellites, for which SBAS corrections were determined, as below:

$$\alpha_E = \frac{1}{ns_{EGNOS}^2} \text{ and } \alpha_s = \frac{1}{ns_{SDCM}^2} \tag{3}$$

where:
ns_{EGNOS} – is the number of satellites in a single SBAS solution, for which EGNOS corrections were developed, ns_{SDCM} - is the number of satellites in a single SBAS solution, for which SDCM corrections were developed.

Additionally, equation (1) was the basis for the determination of the resultant position error in 3D space, in the form of (Krasuski and Savchuk, 2020):

$$RMS - 3D = \sqrt{dB^2 + dL^2 + dh^2} \tag{4}$$

where:
$RMS - 3D$ – resultant position error of the aerial vehicle in 3D space.

5. Research test

The course of the experiment was divided into three stages:

1) performing a test flight with use of the Diamond DA 20-C1 aircraft that is owned by the Aero Club of Warmia-Mazury in Olsztyn. A double-frequency Septentrio AsterRx2i geodesic receiver was installed on board of the aircraft to collect and record GPS observations to calculate the navigation position of the aircraft. The time of recording GPS observations was 1 second. Figure 1 shows the horizontal trajectory of the flight of the Diamond aircraft. The flight lasted from 07:57:07 hours to 11:55:59 hours according to system GPS Time. Figure 2 shows the ellipsoidal height of the flight. It varied from 159 m to 604 m. The starting and ending point of the flight route was the EPOD airport (Olsztyn Dajtki).
2) The pre-processing phase. At this stage, all satellite data from the Septentrio receiver and from other on-board devices were downloaded to mobile carriers and portable computers. Data were converted from the binary format to the RINEX format. As a result, a RINEX observation file and a RINEX navigation file were obtained in the GPS satellite system. The EGNOS and SDCM corrections in the "*.ems" format were downloaded from the real time server ftp://serenade-public.cnes.fr/ (SERENAD Service, 2021). It should be added that all potential users may access these corrections free of charge.

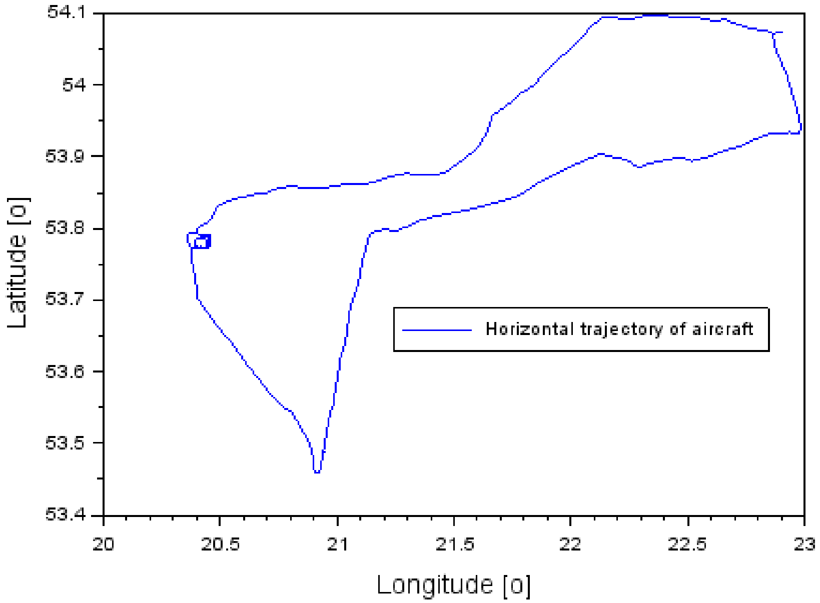

Fig. 1. Horizontal trajectory of aircraft [own study]

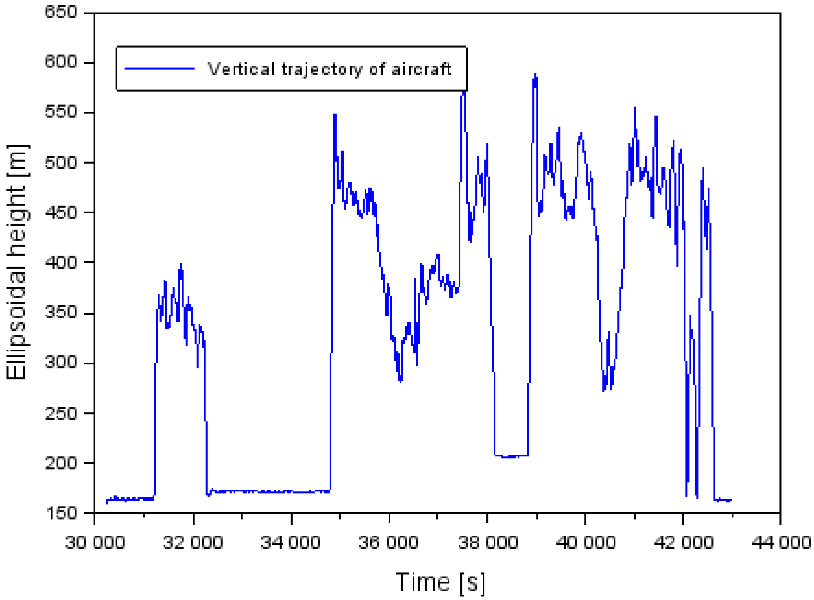

Fig. 2. Vertical trajectory of aircraft [own study]

3) Final elaboration of the GNSS observations This phase consisted in determining the position of the Diamond aircraft with use of the RTKPOST library of the RTKLIB v.2.4.3 software (RTKLIB Website, 2021). The RINEX observation file with GPS measurements was imported to the RTKPOST application together with the GPS navigation message and the EGNOS and SDCM corrections in the "*.ems" format. Subsequently, the configuration of calculations of the aircraft position for a single SBAS solution was set in the RTKPOST library. The configuration of the input parameters and models was as follows (Krasuski et al., 2020):
   - positioning with the SPP code method,
   - the source of GNSS observation data are kinematic GPS observations in the RINEX 2.12 format,
   - the elevation mask was set at 5 degrees,
   - the source of GNSS navigation data is the GPS navigation message,
   - the sources of SBAS corrections are the EGNOS and SCDM systems,
   - the applied model of the ionosphere is the SBAS (EGNOS and SCDM) model,
   - the troposphere model is the SBAS model,
   - the model of the orbit and clocks was set as the on-board ephemeris and SBAS (EGNOS and SCDM),
   - the interval for calculating the measurement epoch is 1 second,
   - the determined coordinates of the airplane are the BLh ellipsoidal coordinates (B – geodesic latitude, L – geodesic longitude, and h – ellipsoidal height),
   - navigation system GPS+SBAS (EGNOS and SCDM).

Then, the position of the Diamond aircraft was calculated in the RTKPOST library. The final position parameters, the values of mean errors of the determined coordinates, the recording time, and the configuration of calculations were recorded in the calculations report in the "*.pos" format. The next stage of the experiment consisted in determining the accuracy of the EGNOS+SDCM positioning in the Scilab v.6.0.0 software (SCILAB Website, 2021), according to formulas (1-4).The resulting "*.pos" report was imported to Scilab from the RTKPOST application. Based on the collected data from the "*.pos" report, the values of accuracy of EGNOS+SDCM positioning were determined in a language script in the Scilab software. The analysis of the obtained results of the quality parameters of EGNOS+SDCM positioning is presented in Section 6.It should be added that the analysis of the accuracy results focused on the final stage of flight, i.e. the approach of the Diamond aircraft to landing.

6. Test results and discussion

Figure 3 shows the results of the EGNOS+SDCM positioning accuracy in form of position errors (dB, dL, dh), determined for the weighted mean model (see equations (1-3)).The values of the dB parameter range from -1.58 m to +0.33 m. Additionally, the average dB value for the landing approach phase was -0.65 m. The values of the dL parameter range from -1.63 m to +0.42 m, while the average dL value for the landing approach phase was -0.50 m. The values of the dh parameter range from +0.38 m to +3.35 m. Additionally, the average dh value for the landing approach phase was +2.14 m. The obtained accuracy values were compared with the ICAO standards for the SBAS APV-I procedure. The critical value of positioning accuracy in the horizontal plane was 16 m, and, respectively, 20 m for the vertical component (International Civil Aviation Organization, 2006). The accuracy requirements were met in compliance with ICAO standards for all measurement epochs during the approach to landing. Therefore, it may be stated that the proposed mathematical model for equations (1-3) is correct and may be applied in the SBAS APV-I landing approach procedure.

The key parameter in the landing approach is the ellipsoidal height h. Conducting numerical analyses to calculate the accuracy of the determination of the vertical component is essential for improving the safety of flight. Thus, the search for solutions that would allow to improve the value of the vertical component seems essential here. Figure 4 presents a comparison of the accuracy of the determination of the vertical component h from the weighted mean and arithmetic mean models. For the weighted mean model, algorithm (1-3) was applied, which is also shown in Figure 3. On the other hand, in the arithmetic mean model, the values of the measurement weights are: α_E=α_S=0.5. This was the basis for comparing the accuracy of the determination of the ellipsoidal height h. The results obtained from the weighted mean model are presented and described in Fig. 3.On the other hand, the positioning accuracy results for the h component for the weighted mean model ranged from +0.52 m to +3.41 m with an average value of 2.23 m. The comparison between the dh parameter obtained from the weighted mean model and the arithmetic mean model allow us to state that the accuracy achieved by the weighted mean model is from 1% to 28% higher than that of the arithmetic mean model. This means that the proposed algorithm (1-3) is correct for the applied SBAS navigation solution.

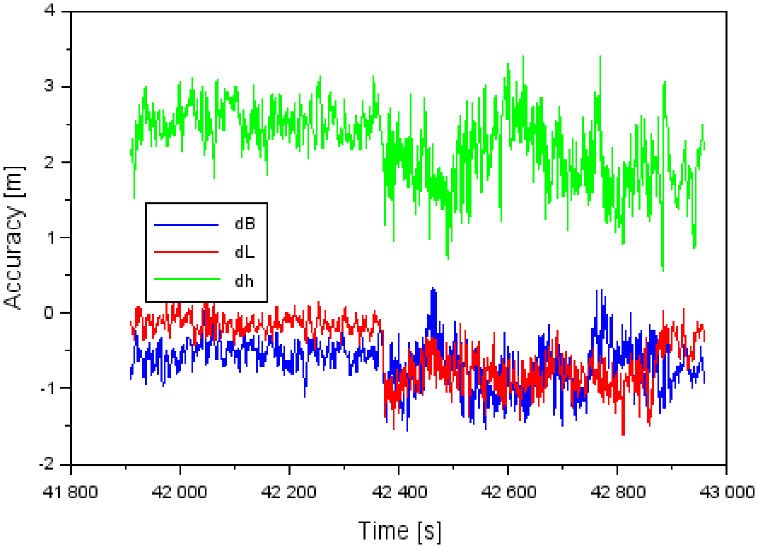

Fig. 3. Accuracy of aircraft position based on EGNOS+SDCM solution [own study]

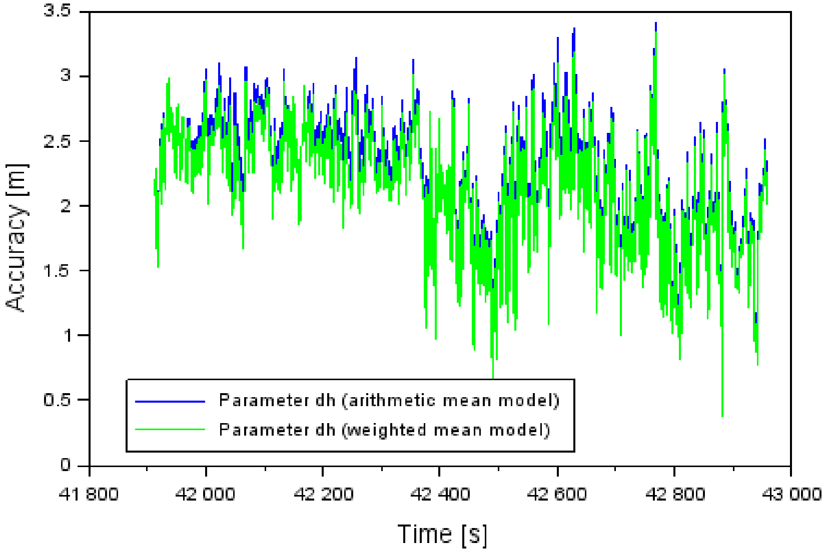

Fig. 4. Accuracy of vertical component based on the comparison of the arithmetic mean and weighted mean solution [own study]

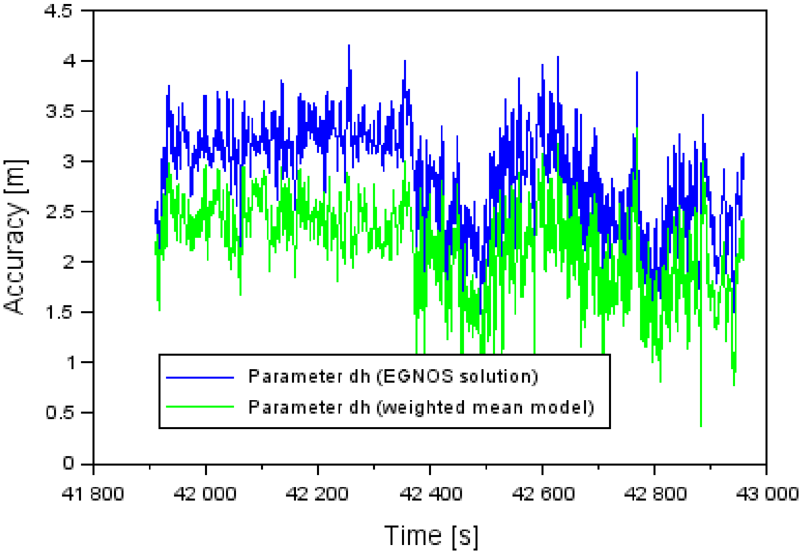

Fig. 5. Accuracy of vertical component based on the comparison of EGNOS and the weighted mean solution [own study]

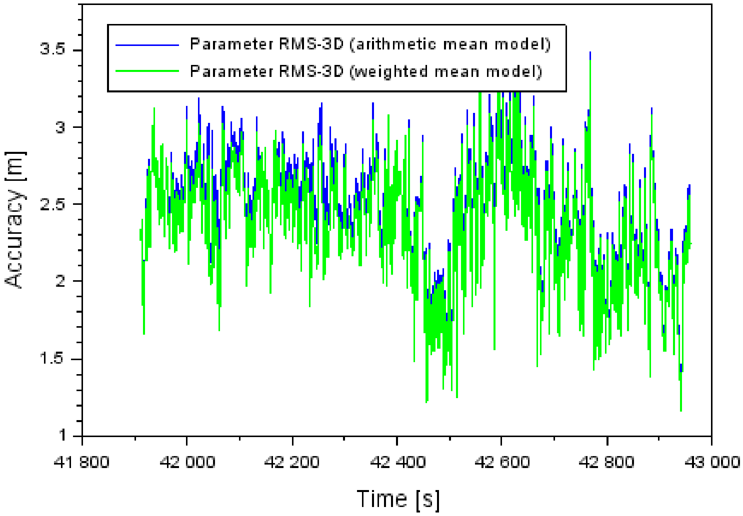

Fig. 6. Accuracy of RMS-3D term based on the comparison between the arithmetic mean and weighted mean solutions [own study]

7. Conclusions

The paper presents the preliminary results of tests on the determination of EGNOS+SDCM positioning accuracy in aerial navigation. The authors used the weighted mean model to determine the resultant position of the aircraft from the EGNOS and SDCM solutions, and then the accuracy of positioning was calculated. The accuracy parameters were defined in reference to the RTK-OTF solution. The algorithm was tested for GNSS data recorded by the Septentrio AsterRx2i receiver during a flight test conducted with a Diamond DA 20-C1 airplane in north-eastern

Poland. Calculations were performed in the RTKLIB and Scilab software. They were based on the observation and navigation GPS data and the corrections from the EGNOS and SDCM systems. The performed calculations referred to the phases of approach to landing and landing. Based on the conducted research, it was found that the accuracy of aircraft positioning from the EGNOS+SDCM solution ranged from -1.63 m to +3.35 m for the ellipsoidal coordinates BLh. Additionally, the accuracy of determination of the ellipsoidal height h was 1÷28% higher in the weighted mean model than in the arithmetic mean model. On the other hand, the accuracy of determination of the ellipsoidal height h was 1÷28% higher in the weighted mean model than for the single EGNOS solution. Additionally, the weighted mean model reduced the resultant error of the position RMS-3D by 1÷13% in comparison to the arithmetic mean model. In the future, the proposed algorithm may become a very interesting solution for Multi-SBAS positioning in aerial navigation.

References

[1] Bakuła, M., Krasuski, K., Dawidowicz, K., (2022). Dual Receiver EGNOS+SDCM Positioning with C1C and C1W Pseudo-Range Measurements. *Remote Sens.*, *14,* 3152. DOI: 10.3390/rs14133152.

[2] Ciećko, A., Grzegorzewski, M., Ćwiklak, J., Oszczak, S., Jafernik, H., (2013). Air navigation in eastern Poland based on EGNOS. In *Proceeding of the Aviation Technology, Integration, and Operations Conference* (ATIO 2013), Los Angeles, CA, USA, 12–14 August 2013; Red Hook: Curran, NY, USA, 1, 603–613. ISBN 978-1-62993-206-4.

[3] Ciećko A., (2019). Analysis of the EGNOS quality parameters during high ionosphere activity. *IET Radar, Sonar & Navigation*, 13(7): 1131-1139. DOI: 10.1049/iet-rsn.2018.5571.

[4] Cydejko, J., Grzegorzewski, M., Oszczak, S., Ciećko, A., (2004). ESTB in Marine, Air and Land Applications; Paper Presented at EGNOS Workshop, 24.08.2004; Number of Slides: 38; Faculty of Mining Surveying and Environmental Engineering of AGH University of Science and Technology: Kraków, Poland.

[5] Grunwald, G., Bakuła, M., Ciećko, A., (2016). Study of EGNOS accuracy and integrity in eastern Poland. *Aeronautical Journal*, 1230, 1275–1290.

[6] Grunwald, G., Ciećko, A., Krasuski, K., Kaźmierczak, R., (2021). The GPS / EGNOS Positioning Quality in APV-1 and LPV-200 flight procedures. *Communications - Scientific Letters of the University of Zilina*, 23(2), E23-E34. DOI: 10.26552/com.C.2021.2.E23-E34.

[7] Grzegorzewski, M., (2005). Navigating an aircraft by means of a position potential in three dimensional space. *Annual of Navigation,* 9, 1–111.

[8] Grzegorzewski, M., Ciećko, A., Oszczak, S., Popielarczyk, D., (2008). Autonomous and EGNOS Positioning Accuracy Determination of Cessna Aircraft on the Edge of EGNOS Coverage, *Proceedings of the 2008 National Technical Meeting of The Institute of Navigation*, San Diego, CA, January 2008, 407-410.

[9] Grzegorzewski, M., Światek, A., Ciećko, A., Oszczak, S., Ćwiklak, J., (2012). Study of EGNOS safety of life service during the period of solar maximum activity. *Artificial Satellites*, 47, 137–145.

[10] Hvezda, M., (2021). Simulation of EGNOS satellite navigation signal usage for aircraft LPV precision instrument approach. *Aviation*, 25: 171–181.

[11] ICAO, (2006). International Civil Aviation Organization., (2006). ICAO Standards and Recommended Practices (SARPS), Annex 10 Volume I (Radio Navigation Aids). Available online: www.ulc.gov.pl/pl/prawo/prawomi%C4 %99dzynarodowe/206-konwencje, [Accessed: 10 February 2021].

[12] Januszewski, J., (2010). Satellite Navigation Systems in the Transport, Today and in the Future. *Archives of Transport*, 22 (2): 175-187. DOI: 10.2478/v10174-010-0011-4.

[13] Krasuski, K., Ćwiklak, J., (2017). Application of the GLONASS code observations for the designation of coordinates of an aircraft in flight test mode: a case study. *Scientific Journal of Silesian University of Technology. Series Transport*, 97, 69-80. ISSN: 0209-3324. DOI: 10.20858/sjsutst.2017.97.7.

[14] Krasuski, K., (2017). Application the GPS Observations in SPP Method for Aircraft Positioning in Flight Experiment in Dęblin, Poland

(01.06.2010), *Journal of Automation, Mobile Robotics and Intelligent Systems*, 11(1), 42-47. DOI: 10.14313/JAMRIS_12017/5.

[15] Krasuski, K., (2019). The research of accuracy of aircraft position using SPP code method. PhD Thesis, Warsaw University of Technology, Warsaw, Poland, 1–106. (In Polish).

[16] Krasuski, K., Wierzbicki, D., (2020). Monitoring Aircraft Position Using EGNOS Data for the SBAS APV Approach to the Landing Procedure. *Sensors, 20,* 1945. DOI: 10.3390 /s20071945.

[17] Krasuski, K., Ciećko, A., Bakuła, M., Wierzbicki, D., (2020). New Strategy for Improving the Accuracy of Aircraft Positioning Based on GPS SPP Solution. *Sensors*, *20*, 4921. DOI: 10.3390/s2017492.

[18] Krasuski, K., Savchuk, S., (2020). Accuracy Assessment of Aircraft Positioning Using the Dual-Frequency GPS Code Observations in Aviation. *Communications - Scientific Letters of the University of Zilina*, *22*(2), 23-30. DOI: 10.26552/com.C.2020.2.23-30.

[19] MGEX Website. 2021. [Online]. Available: https://www.igs.org/mgex/constellations/ #sbas, [Accessed: 10 February 2021].

[20] Popielarczyk, D., (2011). Application of Global Navigation Satellite System and Hydroacoustic Techniques to Safety of Inland Water Navigation. *Archives of Transport,* 23 (2): 191-207. DOI: 10.2478/v10174-011-0013-x.

[21] RTKLIB Website., (2021). [Online]. Available: http://rtklib.com/, [Accessed: 10 February 2021].

[22] SCILAB Website., (2021). [Online]. Available: https://www.scilab.org, [Accessed: 10 February 2021].

[23] SERENAD Service., (2021). [Online]. Available: ftp://serenad-public.cnes.fr, [Accessed: 10 February 2021].

[24] Specht, C., Pawelski, J., Smolarek, L., Specht, M., Dabrowski, P., (2019). Assessment of the Positioning Accuracy of DGPS and EGNOS Systems in the Bay of Gdansk using Maritime Dynamic Measurements. *Journal Of Navigation*, *72*(3), 575-587. DOI: 10.1017/s037346 3318000838.

[25] Tabti, L., Kahlouche, S., Benadda, B., (2021). Performance of the EGNOS system in Algeria for single and dual frequency. *International Journal of Aviation, Aeronautics, and Aerospace*, 8(3): 1-19.