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RESULTS OF AIRCRAFT POSITIONING TESTS IN POST-PROCESSING USING THE GNSS

Summary. In this paper, the results of an aircraft's positioning in aviation during two flight tests are presented. The aircraft's position was established using GPS data with a sample rate of 1 s in both experiments. The raw GPS data were collected by a Topcon Hiper Pro receiver, which was installed in the pilot's cabin of a Cessna aircraft. The aircraft's coordinates in the BLh geodetic frame were determined using the single point positioning (SPP) method in gLAB software. The mathematical algorithm for the aircraft's coordinates are also described in the article. The typical standard deviations for the aircraft's coordinates were less than 10 m in test I and less than 30 m in test II.
Keywords: aircraft trajectory monitoring; GPS, SPP method; accuracy; ICAO.

1. INTRODUCTION

The exploitation of GNSS satellite technology in aviation offers new technological possibilities and development trends to the field of air transport. Purchasing and equipping

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an aircraft with a GNSS satellite receiver is becoming a common and obligatory technical standard. The GNSS satellite receiver makes it possible to determine an aircraft's position, improve the safety of air transport movements, facilitate the aircraft's operation and navigation, help the crew during take-off and landing, ensure the aircraft's orientation in airspace etc. Usually the GNSS receiver helps to determine an aircraft's position using C/A code observations at the L1 frequency. This solution, which is called the SPP method, uses pseudorange measuring [6], with the coordinates of an aircraft determined by the ECEF geocentric system, as well as the clock correction of the receiver. The SPP mathematical model may be solved with Kalman filtering or the least squares method [4].

The aim of this paper is to show the possibilities of the SPP method when applied to determine an aircraft's position while using the GNSS sensor in air navigation. To verify the research method, numerical calculations were performed with gLAB software using the SPP method for GPS code observations. GPS observations were registered by a Topcon Hiper Pro receiver during two flight tests at the military airport in Dęblin. A description of the research based on kinematic tests and its results are presented in this scientific paper.

2. RESEARCH METHODS

The mathematical model for the SPP method is described by the following observational equation (1) [6]:

$$C1 = \rho + c \cdot (dto - dts) + Ion + Trop + Rel + TGD + \varepsilon \qquad (1)$$

where:

C1 – C/A code measurement at the L1 frequency in the GPS system

ρ – satellite-receiver geometric distance

$$\rho = \sqrt{(x - X_{GPS})^2 + (y - Y_{GPS})^2 + (z - Z_{GPS})^2}$$

(x, y, z) – aircraft position in the ECEF geocentric system

$(X_{GPS}, Y_{GPS}, Z_{GPS})$ - GPS satellite position on the orbit

c – speed of light

dto – receiver clock correction

dts – satellite clock correction

Ion – ionospheric correction

Trop – tropospheric correction

Rel – relativistic correction

TGD – satellite's instrumental error for code observations

ε – C/A code measurement noise

From equation (1), we receive four parameters, i.e., three coordinates of the aircraft in the ECEF geocentric system (x, y, z) and the receiver clock correction. The parameters of the model, such as the satellite-receiver geometric distance, satellite clock correction, ionospheric correction, tropospheric correction, relativistic correction and the satellite's instrumental error, are determined with the use of navigational data from broadcast ephemeris. The unknown parameters from equation (1) are determined with the use of the least squares method or Kalman filtering for each measurement epoch.

3. RESEARCH EXPERIMENT AND ITS RESULTS

As part of the presented research, aircraft coordinates were determined using the SPP method in gLAB software, which is an open-source programming tool that was created by experts from the Polytechnic University of Catalonia in Spain. This software offers every user two calculation modules, namely, the SPP method and the precise point positioning method. It is worth mentioning that, in its present form, gLAB only uses data from the GPS system for numerical calculations [3].

While performing numerical calculations in gLAB, the following initial parameters were set for SPP module [3, 5]:

- RINEX observation file version 2.11
- RINEX navigational data: applied
- source of ephemeral data and GPS satellite clocks: on-board ephemeris
- source of ionospheric correction: Klobuchar model
- troposphere model: simple model
- mapping function: simple mapping
- source of TGD instrumental errors: on-board ephemeris
- relativistic correction: applied
- the Sagnac effect: applied
- user's initial coordinates: based on the observation file
- calculation interval: 1 s
- elevation mask: 5°
- positioning mode: kinematic
- code observations type: C/A code measurement at the L1 frequency
- a priori value of code measurement standard deviation: 1 m
- measurement scaling: applied
- calculation method: forward Kalman filtering

In numerical calculations, raw GPS data registered and collected by a dual-frequency Topcon Hiper Pro receiver were used. GPS code measurements came from two flight tests, which were made using a Cessna plane on 16 June 2010 at the military airport in Dęblin [2]. The Cessna plane flight trajectory for both flight tests is presented, along with the BLh geodetic coordinates, in Fig. 1 and Fig. 2. During the kinematic tests, the Topcon Hiper Pro receiver was used to register GPS observations in order to reconstruct a plausible aircraft position during post-processing. The first flight test started at 11:58:38 and finished at 12:34:57, according to GPS time. The second test started at 14:31:44 and lasted until 15:00:04, again according to GPS time. The main aims of both flight tests were the implementation of GNSS satellite technology for use in air navigation and the determination of the accuracy of kinematic positioning using a GNSS sensor. It should be mentioned that both flight tests were carried out as part of a development project called "GNSS-based aircraft and commercial vehicles' traffic monitoring systems using public services".

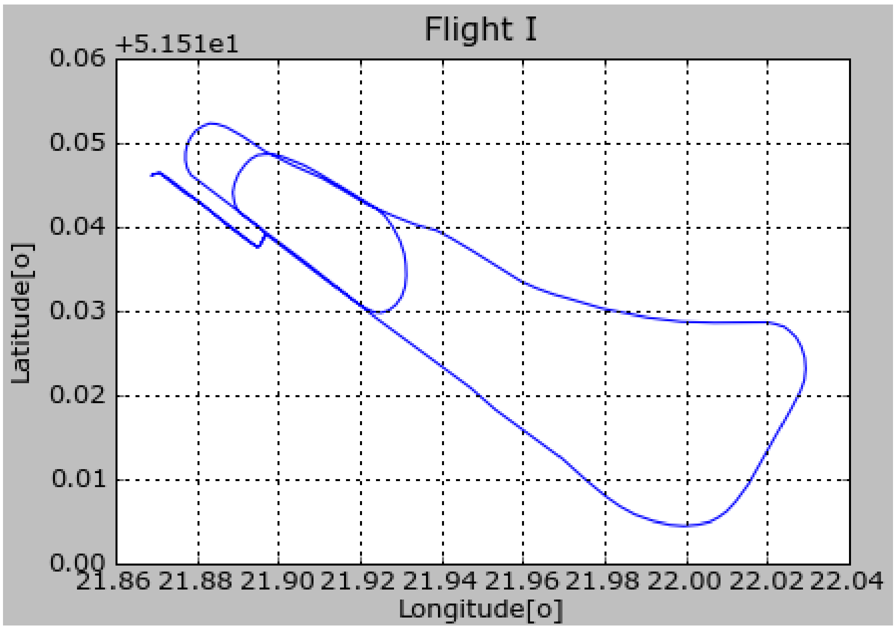

Fig. 1. The horizontal trajectory of the aircraft in flight test I.

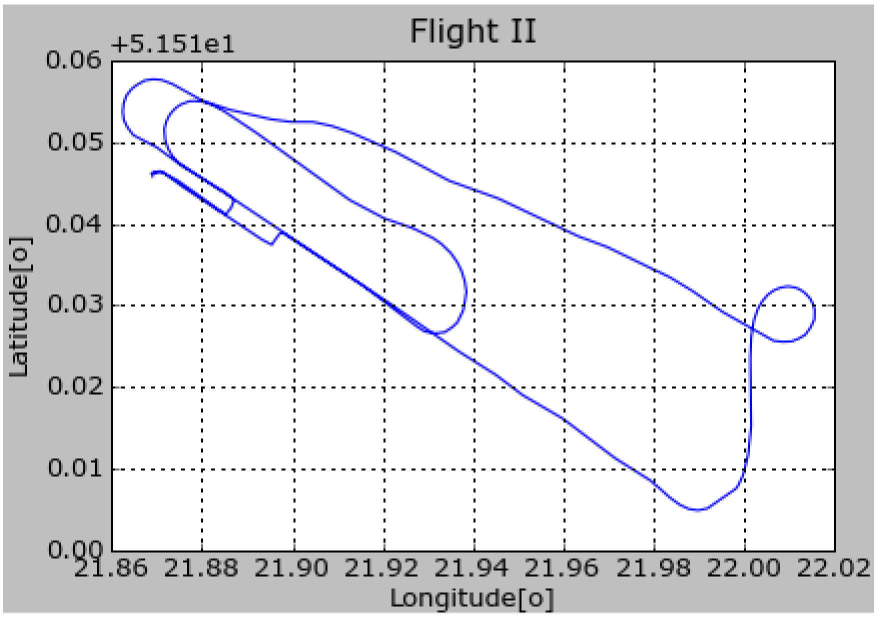

Fig. 2. The horizontal trajectory of the aircraft in flight test II.

Fig. 3 and Fig. 4 present the ellipsoidal height of the Cessna flights. During the first flight, the ellipsoidal height reached between 150 and 640 m. In the second test, the ellipsoidal height was between 120 and almost 380 m. In the second test, more frequent changes in the ellipsoidal height during the take-off phase and during the landing approach may be observed.

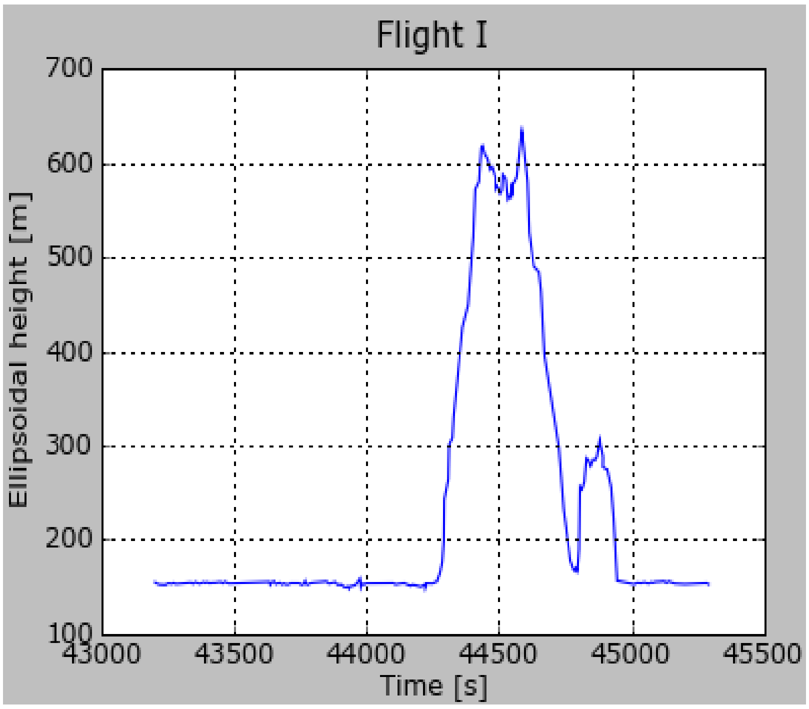

Fig. 3. The vertical trajectory of the aircraft in flight test I.

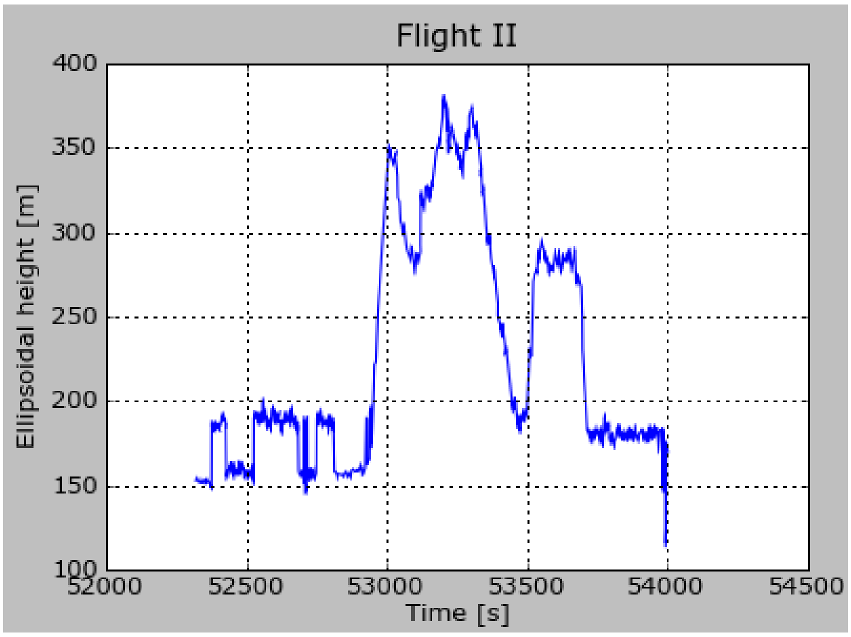

Fig. 4. The vertical trajectory of the aircraft in flight test II.

Fig. 5 and Fig. 6 highlight the accuracy of the Cessna plane position in the BLh geodetic frame. In the case of flight, I, the accuracy of geodetic latitude B was between 0.5 and 8.1 m. Furthermore, the accuracy of geodetic longitude L was between 0.2 and almost 4 m, while the values of standard deviation for the ellipsoidal height were from 1 to almost 10 m. It is worth noting that, during most of flight I, the accuracy of the aircraft coordinates was above 3 m.

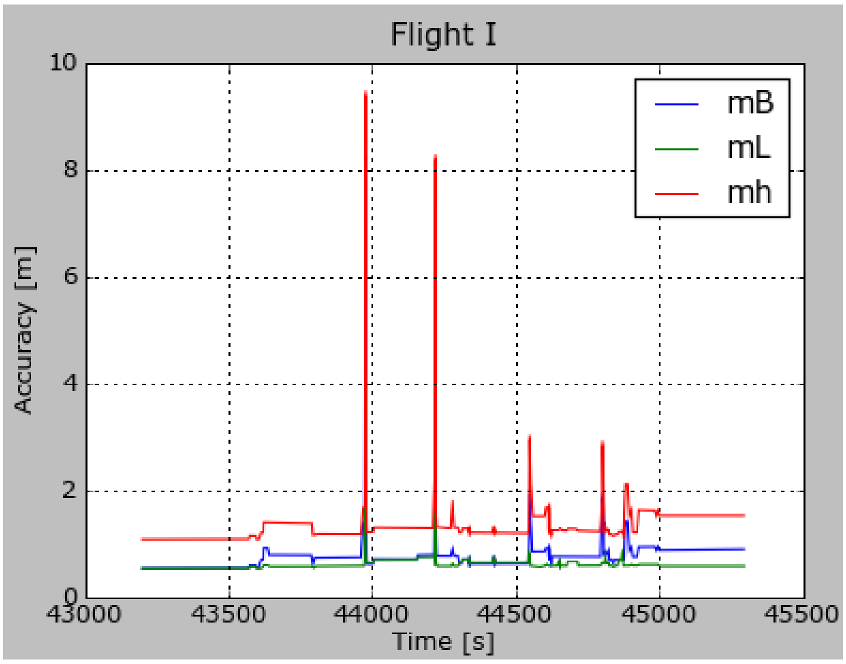

Fig. 5. The accuracy of the aircraft coordinates in flight test I.

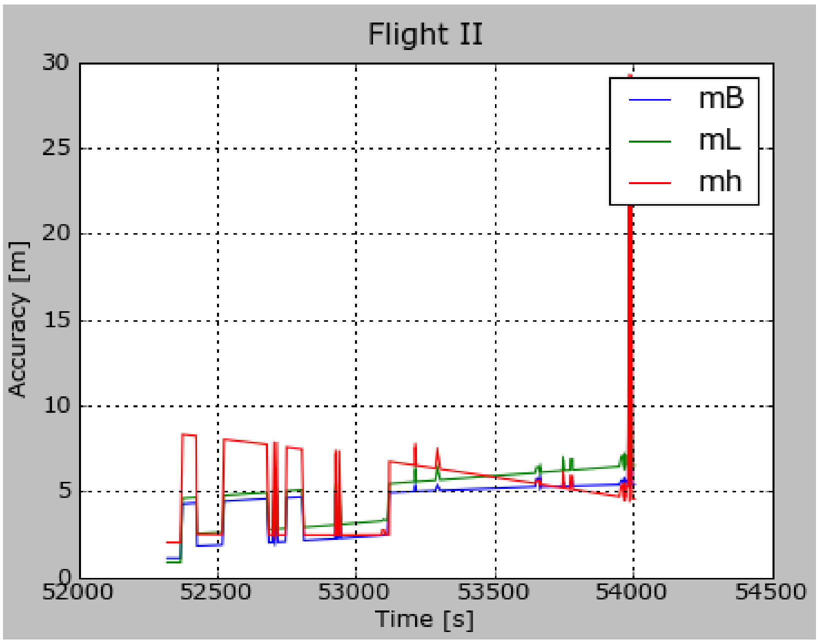

Fig. 6. The accuracy of the aircraft coordinates in flight test II.

In the case of flight II, the accuracy of the Cessna aircraft coordinates was: from 1.1 to 16.1 m for geodetic latitude B; from 0.8 to 11.1 m for geodetic longitude L; and from 2 to 29 m for ellipsoidal height h. The noteworthy fact is that, during flight II, the spread of the accuracy results received is significantly wider than during flight I. Moreover, the accuracy of the Cessna plane coordinates during flight II worsened by around 300% in comparison to the results from flight I.

Table 1. The accuracy of the aircraft's coordinates in comparison to the official standards, as per ICAO recommendations.

Flight test	Accuracy of the aircraft's coordinates [m]	Theoretical accuracy of the aircraft's coordinates, according to ICAO recommendations [m]
Flight I	For latitude: 0.5÷8.1	For latitude: 17
	For longitude: 0.2÷4	For longitude: 17
	For ellipsoidal height: 1÷10	For ellipsoidal height: 37
Flight II	For latitude: 1.1÷16.1	For latitude: 17
	For longitude: 0.8÷11.1	For longitude: 17
	For ellipsoidal height: 2÷29	For ellipsoidal height: 37

Table 1 compares the accuracy of the aircraft's coordinates received during both flight tests with the ICAO's official standards. Today, in aviation, only the GPS and GLONASS navigational systems and the SBAS support system are certified and accepted for use in air operations. In the case of the GPS system, the ICAO has specified two standards for aircraft positioning accuracy on the horizontal and vertical planes. On the horizontal plane, the accuracy of an aircraft's coordinates cannot be higher than 17 m, whereas, on the vertical plane, it cannot be higher than 37 m [1]. The two flight tests performed at Dęblin Airport on 16 June 2010 prove that the accuracy of the Cessna aircraft's positioning was kept within the limits of the ICAO standards. For flight I, the maximum accuracy of the Cessna aircraft coordinates on the horizontal plane was 8.1 m, while, on the vertical plane, it was around 10 m. In both cases, the achieved accuracy of the aircraft's coordinates stayed within the limits specified by ICAO technical standards. In flight II, the accuracy of the Cessna aircraft coordinates on the horizontal plane was 16.1 m, while, on the vertical plane, it was around 29 m. For test flight II, the accuracy of the Cessna aircraft coordinates did not exceed the ICAO technical standards.

4. CONCLUSIONS

The article describes the results of tests on aircraft positioning during post-processing using GNSS satellite technology. As part of the experiment, a Cessna aircraft position was recovered during two flight tests, which were performed on 16 June 2010 at the military airport in Dęblin. The calculations were carried out with gLAB software, while the SPP method was used for C/A code observations at the L1 frequency in the GPS system. GPS code observations were registered by a Topcon Hiper Pro receiver placed in the pilot's cabin during the tests. As a result of the performed tests, the following conclusions can be made:

- The accuracy of the geodetic latitude B during flight I reached values between 0.5 and 8.1 m; during flight II, the values were between 1.1 and 16.1 m.
- The accuracy of geodetic longitude L during flight I reached values between 0.2 and almost 4 m; during flight II, the values were between 0.8 and 11.1 m.
- The accuracy of ellipsoidal height h during flight I reached values between 1 and almost 10 m; during flight II, the values were between 2 and 29 m.
- The achieved accuracy of the aircrafts' positioning for BLh coordinates in the gLAB software did not exceed the technical standards specified by the ICAO recommendation in Annex 10, Volume I, "Radio navigation aids".

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