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Examination of the Accuracy and Usefulness of Garmin and Suunto GNSS Devices during Navigation of the TS-11 "Iskra" Jet Aircraft

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Abstract. This study was designed and performed in order to determine the accuracy and usefulness of different modern Garmin and Suunto GNSS devices – mainly smartwatches – during a flight of TS-11 "Iskra" aircraft. The plane trajectory was determined using six different navigation devices placed in a cockpit of an aircraft. To calculate reference position – Thales Mobile Mapper with post-processing option and data from Polish ASG-EUPOS network was used. The obtained results show that the tested devices gave reasonable positioning accuracy and can be used on board of an aircraft traveling at high speeds. However, it must be emphasized that smartwatches can be only used as a supplementary navigation aid during any air operation.

Keywords: GNSS, GPS, air navigation.

Conference topic: Technologies of geodesy and cadastre.

Introduction

Navigation has been a very important aspect of our lives for centuries. Since the beginning of time, mankind has been trying to figure out a dependable way to know where they were, and to guide them to where they wanted to go and get back again. In the past navigation techniques were very difficult and complicated and only known to a few. With the advent of technological development in the last century people invented satellite (GNSS) navigation which is simple to use and globally available. GPS (Global Positioning System) is currently the most popular navigation system, but positioning using other elements of the GNSS is increasingly becoming common, and most of all effective (Kaplan, Hegarty 2006; Misra, Enge 2011; Grzegorzewski *et al.* 2008). Nowadays satellite technologies are also used in geodesy, bathymetry, transport, tourism and many others (Felski *et al.* 2011; Popielarczyk 2012; Popielarczyk *et al.* 2015). This is the type of navigation, which is based on radio signals transmitted by satellites orbiting the Earth. Further dynamic technological development in recent years led to size reduction of GNSS devices which allowed to put them into a wristwatch. The mass production decreased the cost of manufacturing and today GNSS device can be easily accessible to everyone. The quality of positioning in everyday live offered by compact GNSS receivers is satisfactory for most of the users, but can these devices be used in demanding air navigation? The number of registered civilian aircraft has increased in recent years (Fellner *et al.* 2012). However, small aircraft and ground objects provide poor technical infrastructure. The perfect solution is to use the navigation system based on GNSS, which does not require any additional equipment located at the airport (Allien *et al.* 2009; ICAO 2003; Kozuba, Pila 2015). The use of GNSS systems in devices for designed air navigation is associated with meeting a number of predefined requirements (RTCA 2013). In this case, the GNSS receivers may be used in NPA, APV-1 and LPV-200 procedures. This is the subject of many research (Grunwald *et al.* 2016a, 2016b; Konin, Shyshkov 2015; Vassilev, B., Vassileva, B. 2011).

This study was designed to determine the usefulness and accuracy of popular navigation devices produced by Garmin and Suunto on board of TS-11 "Iskra" jet plane.

GNSS devices taking part in the experiment

In the practical experiment six different GNSS devices were selected for determination of navigation quality. The receivers used in the experiment are smartwatches and sport activity trackers of Garmin and Suunto. They look like common electronic watches with a touch screen and all the features of a regular digital watch. Besides they are equipped in some useful options like displaying notifications from user's phone, they are also able to control sport activities of the user, e.g. counting of the steps, measuring of heart rate, and finally determining the three-dimensional geographical position of moving user with the use of GNSS systems: American GPS and Russian GLONASS. The basic technical specification of tested receivers is presented in Table 1.

The Garmin D2 Bravo is a multifunction aviation watch that blends the company's expertise in aviation, sports and GPS services in a small but stylish package. It has omni-directional stainless steel EXO antenna, which allows the watch to be slimmer than its predecessor while providing faster and more accurate GPS/GLONASS positioning. The high-resolution colour LED screen is sunlight readable and the battery lasts up to six weeks in watch mode or 20 hours in GNSS mode.

When paired with a smartphone, the watch can display weather data such as Metars, which are color-coded based on the current conditions. The watch also has a pressure sensor and provides vibrating alerts every 30 minutes when above 12,500 feet to remind the pilot to use supplemental oxygen. Other aviation-related features include ground speed, track, distance, altitude, ETE, glide ratio, nearest features and the capability to navigate direct to airports. Some flight data, such as speed and altitude, is recorded to allow the pilot to review the flight once on the ground. The watch also provides alerts for such items as pre-set altitudes and reminders to switch tanks.

The Garmin Fenix 3 is an extremely versatile multisport watch. The durable device can be used to record data from activities ranging from cycling, running and swimming, to mountaineering and skiing. The Garmin Fenix 3 sits right at the top of the Garmin sport watch line-up. With the ability to sync to Bluetooth 4.0 equipped iPhones and Androids, the Fenix 3 can display notifications from the phone, download apps, widgets data fields and watch faces as well as firmware updates on the fly.

The Garmin Fenix 2 is the successor to the Fenix and predecessor to Fenix 3 multisport watch. Whereas the original Fenix was aimed at terrestrial sports like running, hiking and cycling, the Fenix 2 adds the functionality of the Garmin Swim. So, it can track swimming activities as well, adding on the top of that skiing and mountaineering options we have a watch with most activities covered.

The Garmin Forerunner 610 represents the series of running watches from Garmin. The GPS-enabled 610 accurately records time, pace, distance and more. It features vibration alerts, a new Virtual Racer feature that turns any workout into a virtual matchup and advanced heart rate training. The 610 is Garmin's first sport watch with Training Effect capability from Firstbeat. Training Effect measures the impact of an activity on aerobic fitness, helping runners train more efficiently.

The Garmin Foretrex 401 is a slim wrist-mounted GPS navigator perfect for outdoor activities that require the use of both hands. It combines a high-sensitivity water resistant GPS receiver, electronic compass and barometric altimeter into a lightweight device ideal for hikers, skiers and campers. To share data easily, you can connect Foretrex to your computer with USB or just send data wirelessly to another device.

The Suunto Ambit 3 is a full-featured training device for athletes of all kinds. The Ambit is a GPS watch that tracks multiple sports, including running, cycling and swimming. The Suunto Ambit3 is a great tool for athletes, but its advanced swim features are what set it apart from other multisport GPS watches. This watch can track heart rate underwater, a feature that only a few other multisport watches can match, and it can collect data about open-water swims. It also allows for receiving notifications from mobile phone on the watch, just as a smartwatch would. Incoming calls and texts can be seen on the watch, but it's not possible to respond to them.

Table 1. Technical specification of tested GNSS devices

Device / Parameter	D2 Bravo	Fenix 3	Fenix 2	Forerunner	Foretrex	Ambit 3
						
Size [mm]	51/16	51/16 mm	49/17	45/14	73/43/23	50/17
Weight [g]	85	82	85	72	61	73
GPS	Yes	Yes	Yes	Yes	Yes	Yes
GLONASS	Yes	Yes	No	No	No	No
Barometer	Yes	Yes	Yes	No	Yes	Yes
Compass	Yes	Yes	Yes	No	Yes	Yes

Practical study

The survey was carried out in the central part of Poland during the en-route flight of PZL TS-11 "Iskra" aircraft (Fig. 1). The PZL TS-11 "Iskra" (English: Spark) is a Polish jet trainer aircraft, used by the air forces of Poland and India. The aircraft was designed in response to a Polish Air Force requirement for a jet trainer. The main designer was Tadeusz Sołtyk – hence a designation letters TS. The aircraft, produced since 1963 was the first jet aircraft designed in Poland.

Fig. 1. PZL TS-11 "Iskra" aircraft

The experiment started on June 25, 2016 at 13:14:06 local time and lasted 1 hour 23 minutes and 17 seconds. The flight was scheduled for the cruising altitude of 1000 meters (QNH) at a speed of 400 km/h. The actual trajectory of the flight during test is presented in Fig. 2. Before the flight, the units involved in the study were installed in the cabin of the aircraft – Fig. 3.

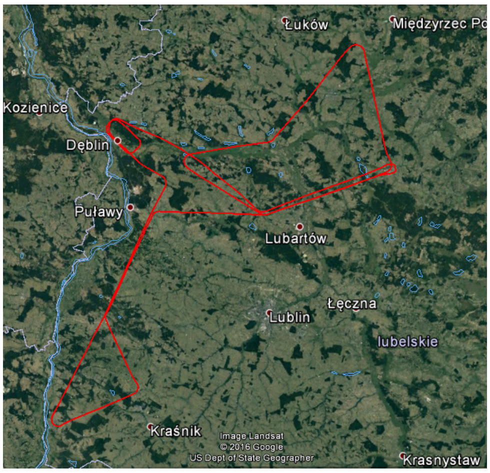


Fig. 2. Trajectory of PZL TS-11 "Iskra" aircraft during experiment

In order to compare accuracies of autonomous positioning of tested devices a "true" – reference trajectory of the aircraft was necessary. For that reason, a Thales MobileMapper receiver was also placed in the cockpit of the airplane. Thales MobileMapper is a GPS receiver which allows for raw data recording and post-processing of this data. The data collected by Thales were postprocessed with the data from ASG-EUPOS station in Ryki, located just 10 kilometres from the airfield. Calculated in such a way reference trajectory had a 3-D accuracy in magnitude of 1 meter. The "true" trajectory was exported to MS Excel for further comparisons. The next step was to compare and analyse the results from tested devices.

Then all recorded files have been extracted using dedicated software like: Garmin Connect, Base Camp (for Garmin) and Movescount (for Suunto) and exported to MS Excel. The crucial parameters were time of measurement, latitude, longitude, and altitude (except Garmin Forerunner 610 which does not have the option to record the height above the ground). The next step, for each device, was time synchronization with the reference trajectory. Preliminary analysis found out that there is a certain time shift between Thales time (GPS time) and tested devices time (similar to UTC time). The shift was not defined in technical specifications but due to very high speed of jet plane it was possible to estimate. It was also observed that although the setting was to record the position every second, there were more or less missing epochs in each of analysed files. The proper time synchronization of gathered data was essential for further analyses.

Fig. 3. Installation of GNSS equipment during the test flight. From the left: Suunto Ambit 3, Garmin D2 Bravo, Garmin Fenix 3, Garmin Fenix 2, Garmin Foretrex 401, Garmin Forerunner 610

Analysis of the Garmin Bravo D2 trajectory

The route registered by Garmin Bravo D2 consisted of 4974 epochs (1 hour 22 minutes 54 seconds), which is 99.54% out of all 4997 one-second epochs of the experiment. To achieve proper synchronization, the time was shifted by 16 seconds with regard to Thales MobileMapper receiver. The accuracy results of Garmin Bravo D2 are presented in Fig. 4.

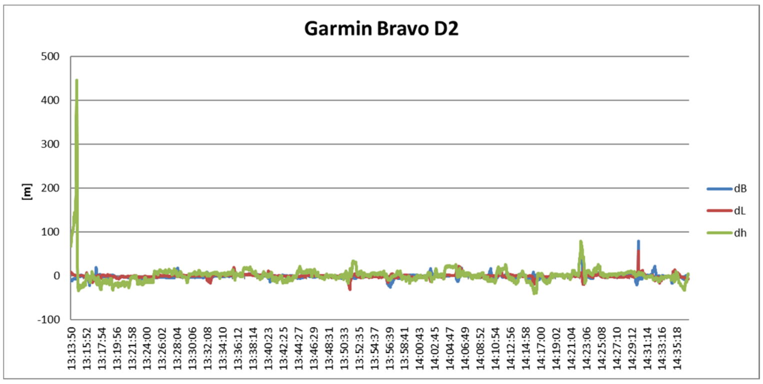


Fig. 4. Positioning accuracy of Garmin D2 Bravo (GPS time). dB – latitude error; dL – longitude error; dh – height error

The highest value of the difference in altitude was registered during take-off and acceleration of the aircraft. It was up to 445.35 meters. Such large deviations were due to the fact that the cabin for take-off was hermetically sealed so the barometer of the Garmin watch defined height relative to the level of the airfield. Incorrect measurement took place, until the plane reached the height of approx. 400 meters, when the cabin was hermetically unsealed. This error was observed for every receiver taking part in the examination. Later in the flight, the biggest height error reached 67.68 meters, at this point, the aircraft was in turn. However, the high deviation of altitude also occurred frequently during the flight along a straight line. Detailed graph of positioning errors, not including hermetic error, is presented in Fig. 5.

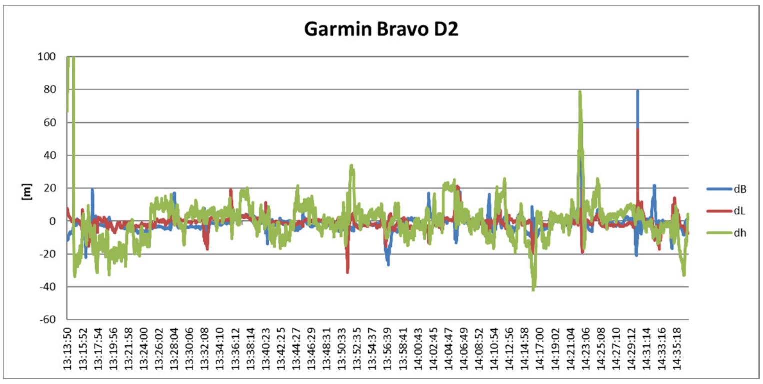


Fig. 5. Positioning accuracy of Garmin D2 Bravo (GPS time), not including hermetic error

Analysis of the Garmin Fenix 3 trajectory

The route registered by Garmin Fenix 3 consisted of 4954 epochs (1 hour 22 minutes 34 seconds), which is 99.14% out of all 4997 one-second epochs of the experiment. To achieve proper synchronization, the time was shifted by 16 seconds with regard to Thales MobileMapper receiver. The accuracy results of Garmin Fenix 3 are presented in Fig. 6. It was observed that the obtained results were very similar to the results of Garmin Bravo D2, however there were some epochs when greater inaccuracy of Fenix 3 was noted. During the flight along straight line the positioning was more accurate, and flying in the corners significantly increased errors. Flight altitude accuracy was also very similar. Again, the highest deviation was observed during acceleration of the plane, due to hermetic error.

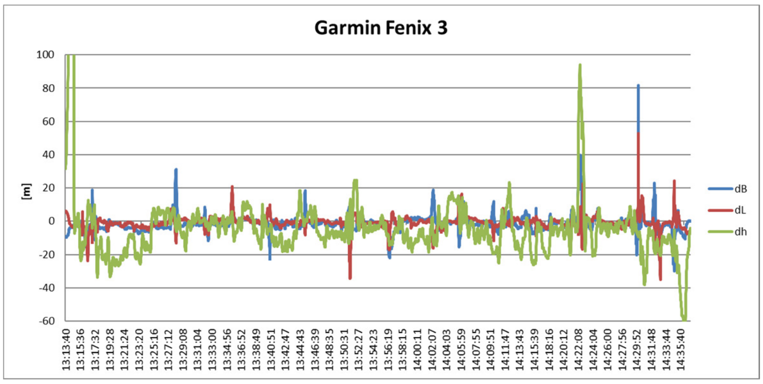


Fig. 6. Positioning accuracy of Garmin Fenix 3 (GPS time), not including hermetic error

Analysis of the Garmin Fenix 2 trajectory

The route registered by Garmin Fenix 2 consisted of 4345 epochs (1 hour 12 minutes 25 seconds), which is 86.95% out of all 4997 one-second epochs of the experiment. To achieve proper synchronization, the time was shifted by 16 seconds with regard to Thales MobileMapper receiver. The accuracy results of Garmin Fenix 2 are presented in Fig. 7. Analysing the graph, it appears that the errors are more stable in comparison of previous watches. It should be noted, however, that the number of recorded epochs is fewer by about 600 epochs than the previous devices. Moments in which the measurement took place in difficult conditions were simply discarded by the watch. Nevertheless, the observed dependence of repeating higher errors in the corners was confirmed.

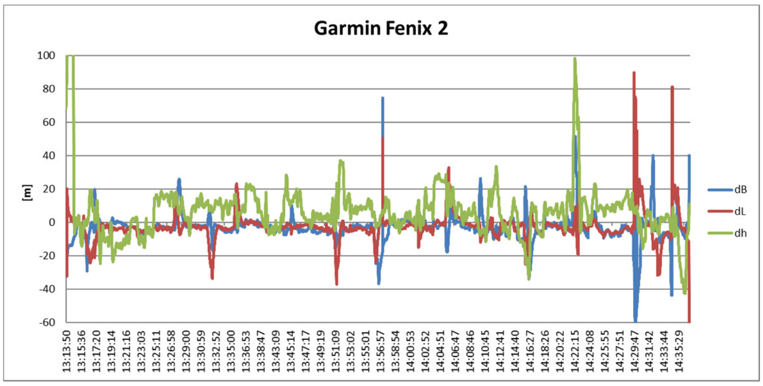


Fig. 7. Positioning accuracy of Garmin Fenix 2 (GPS time), not including hermetic error

Analysis of the Garmin Forerunner 610 trajectory

Unfortunately, the route registered by Garmin Forerunner 610 was incomplete. Due to unknown fact, the recording of the trajectory stopped just after 832 seconds of the flight, not allowing for any meaningful analyses. The Garmin Forerunner 610 was excluded from further comparisons.

Analysis of the Garmin Foretrex 401 trajectory

The route registered by Garmin Foretrex 401 consisted of 462 epochs (0 hour 7 minutes 42 seconds), which is just 9.25% out of all 4997 one-second epochs of the experiment. To achieve proper synchronization, the time was shifted by 17 seconds with regard to Thales MobileMapper receiver. The accuracy results of Garmin Foretrex 401 are presented in Fig. 8. It was observed that a small number of registered epochs is due to the fact that the device recorded epochs only when changing the direction of motion of the aircraft. It means that recording rate was increased during cornering. During the flight along a straight line the recording period was very low. Nevertheless, it was noted that the recorded trajectory was very similar to the reference, characterized by high accuracy measurements. It was also noted that the accuracy of measurement was stable in the corners of the aircraft.

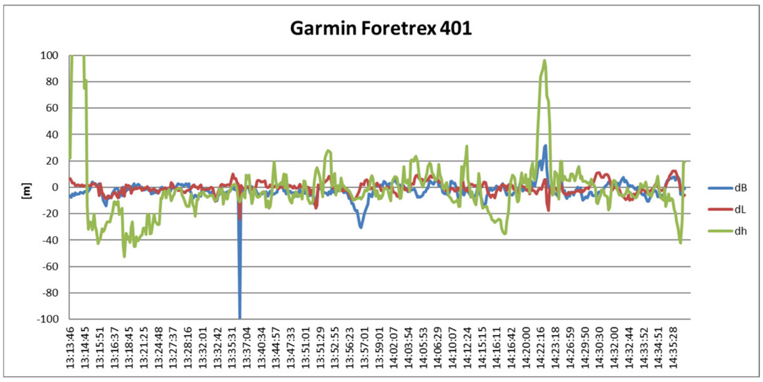


Fig. 8. Positioning accuracy of Garmin Foretrex 401 (GPS time), not including hermetic error

Analysis of the Suunto Ambit 3 trajectory

The route registered by Suunto Ambit 3 consisted of 3800 epochs (1 hour 3 minutes 20 seconds), which is 76.07% out of all 4997 one-second epochs of the experiment. To achieve proper synchronization, the time was shifted by 16 seconds with regard to Thales MobileMapper receiver. The accuracy results of Suunto Ambit 3 are presented in Fig. 9. Suunto recorded the route with good accuracy. Rarely, the error exceeded 20 meters, which in relation to large number of stored epochs is a very good result. The errors were quite stable and the fluctuations that have arisen – like in the case of other devices – emerged during the flight in the corner. However, in these fragments the differences were significantly smaller than the differences of the Garmin watches.

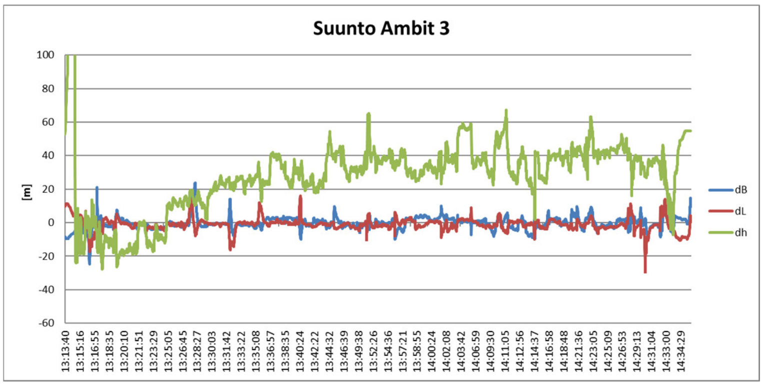


Fig. 9. Positioning accuracy of Suunto Ambit 3 (GPS time), not including hermetic error

Summary and comparison of the results

An important parameter that must be taken into consideration when analyzing the results is the number of registered epochs by the device. The most stable watches offered by Garmin are Bravo D2 and Fenix 3, their number of records differed in only 20 epochs. The worst in this respect was Garmin Foretrex 401, which saved only the moments of significant changes of course by the plane. Figure 10 summarises the number of epochs recorded by receivers.

Detailed results concerning accuracy of tested devices are presented in Fig. 11.

Based on Figure 11 it can be found that the best horizontal accuracy of determining the position of the aircraft during the flight was achieved by Garmin D2 Bravo, whose total horizontal error stood at 5.84 meters. Similar horizontal accuracy, worst only by 10 centimetres, was reached with Garmin Fenix 3. The least accurate horizontal record was achieved using Garmin Fenix 2. In this case, the total error was in magnitude of 10.80 meters.

Garmin D2 Bravo also proved to be most accurate when it comes with a record altitude. Its vertical error was less than 8 meters. Devices of Fenix series presented almost the same vertical error in magnitude of about 12 meters.

Slightly higher vertical deviation was achieved by Suunto watch, and the worst in this respect fell Garmin Foretrex 401, with the error of more than 17 meters.

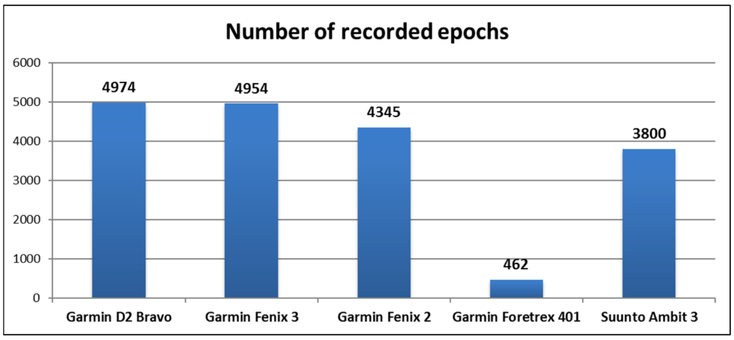
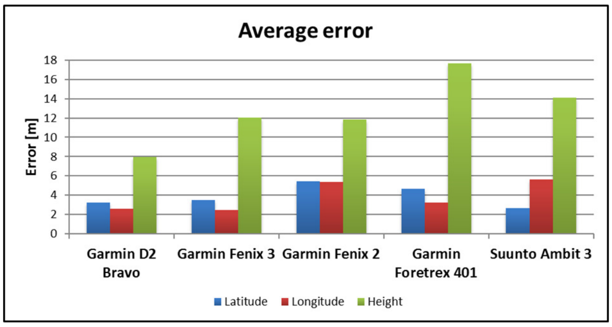


Fig. 10. The number of recorded epochs out of 4997



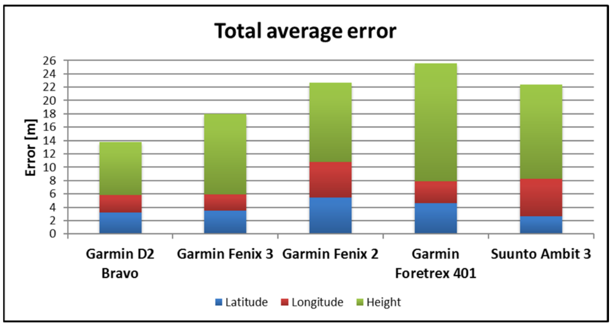


Fig. 11. The comparison of the average error of all measured parameters of individual devices

Summing up all the results, it was found that the most accurate trajectory was registered Garmin Bravo D2. Right behind it was a Garmin Fenix 3. Next device was the Suunto Ambit 3. Worse than Suunto was Garmin Fenix 2. In the end of stake there was Garmin Foretrex 401 with the total error of 25.55 meters.

Conclusions

The performed survey gave very promising results. Only one smartwatch did not registered trajectory, due to unexpected technical problem. The analyses showed that the navigation devices that cost more and can boast better specifications, in fact, performed better and registered trajectory with greater accuracy. Their potential users can thus be confident that buying more expensive receivers, they can obtain a more precise measurement. It should also be noted that tested watches were not specifically designed to operate at such high speeds like jet planes.

The largest deviation from the flight usually occurred in the corners. Probably the cockpit cover could significantly reduce the availability of satellite signals and affect measurement accuracy during these manoeuvres. If the devices were placed outside the cabin, probably it would be possible to obtain more precise results. Nevertheless, obtained results show that the tested devices can be used on board aircraft traveling at high speeds.

In summary, it should be noted that all recorded trajectories were satisfactory. It can be stated that by using the selected navigation devices of Garmin and Suunto on board the aircraft, you can accurately obtain a three-dimensional position of the aircraft during the flight.

References

Allien, A.; Taillander, C., Capo, C., *et al.* 2009. *User guide for EGNOS application development*. ESA.

Fellner, A.; Banaszek, K.; Trómiński, P. 2012. The satellite based augmentation system-EGNOS for non-precision approach global navigation satellite systems, *Transport Problems* 7(1): 5–19.

Felski, A.; Nowak, A.; Woźniak, T. 2011. Accuracy and availability of EGNOS – results of observations, *Artificial Satellites* 46: 111–118. https://doi.org/10.2478/v10018-012-0003-0

Grunwald, G.; Bakuła, M.; Ciećko, A.; Kaźmierczak, R. 2016a. Examination of GPS/EGNOS integrity in north-eastern Poland, *IET Radar, Sonar & Navigation* 10(1): 114–121. https://doi.org/10.1049/iet-rsn.2015.0053

Grunwald, G.; Bakuła, M.; Ciećko, A. 2016b. Study of EGNOS accuracy and integrity in eastern Poland, *The Aeronautical Journal*, 10.1017/aer.2016.66: 1–16. https://doi.org/10.1017/aer.2016.66

Grzegorzewski, M.; Ciecko, A.; Oszczak, S.; Popielarczyk, D. 2008. Autonomous and EGNOS positioning accuracy determination of Cessna Aircraft on the Edge of EGNOS Coverage, in *2008 National Technical Meeting of the Institute-of-Navigation*, San Diego, CA, USA, January 28–30 2008, Proceedings of the 2008 National Technical Meeting of the Institute of Navigation - NTM 2008: 407–410.

International Civil Aviation Organization (ICAO). 2003. *European Region Area Navigation (RNAV), guidance material*. 5 ed. European and North Atlantic office of ICAO.

Kaplan, E.; Hegarty, C. 2006. *Understanding GPS principles and applications*. Artech House, INC, Norwood.

Konin, V.; Shyshkov, F. 2015. Extending the Reach of SBAS. Some Aspects of EGNOS Performance in Ukraine, *Inside GNSS* 1: 50–54.

Kozuba, J.; Pila, J. 2015. Aircraft automation systems versus pilot situational awareness (SA) – Selected Aspects, in *Proceedings of 19th International Conference "Transport Means 2015"*, Kaunas–Latvia, October 22–23, Transport Means – Proceedings of the International Conference, 688–693.

Misra, P.; Enge, P. 2011. *Global positioning system: signals, measurements, and performance*. Ganga-Jamuna Press, Lincoln, Massachusetts.

Popielarczyk, D. 2012. RTK water level determination in precise inland bathymetric measurements, in *25th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2012)*, 17–21 September, Nashville, TN, USA, 1158–1163.

Popielarczyk, D.; Templin, T.; Łopata, M. 2015. Using the geodetic and hydroacoustic measurements to investigate the bathymetric and morphometric parameters of Lake Hancza (Poland), *Open Geosciences* 7(1): 854–869.

Radio Technical Committee for Aeronautics (RTCA) 2013. Minimum operational performance standards for airborne equipment using global positioning system/wide area augmentation system*, Doc. DO-229D*.

Vassilev, B.; Vassileva, B. 2011. The satellite navigation system EGNOS and safety of life service performance in Sofia, *Information Technologies And Control* 4/2011: 32–39.