ANNUAL OF NAVIGATION 1/99

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PRELIMINARY RESULTS OF DGPS/DGLONASS AIRCRAFT POSITIONING IN FLIGHT APPROACHES AND LANDINGS

ABSTRACT

The use of satellite navigation by aerial craft becomes more and more common. Practically every newly produced plane or helicopter has GPS receiver installed on board. This system becomes widely used because it is simple and highly reliable. To improve the Required Performance Navigation Parameters (RNP), namely, the accuracy, availability, continuity, and integrity of aircraft navigation, the integrated GPS and GLONASS techniques can be used. Users are especially interested in integrated GPS/GLONASS receivers. The appearance of new ASHTECH GG24 receiver on the market has made it possible to estimate the possibility of utilisation of this type of receivers in aircraft navigation. The main goal of performed flight trials was the use of those receivers in satellite-based approaches and landings. The authors of the report carried out an experiment aiming at data collection during flight and approach to landing of plane TS11 Iskra. The airport of Deblin was chosen as the test area. The precise trajectory of the aircraft was calculated in the global WGS'84 system of co-ordinates for subsequent positions during flight, at one-second intervals, with the use of RTK techniques in "post-processing" mode. The RTK positions were compared with DGPS/DGLONASS real-time positions and next, the estimation of real-time differential accuracy was done. The preliminary results of the accuracy analysis are given in the paper.

AIRBORNE AND REFERENCE STATION EQUIPMENT

The Airforce Academy in Dęblin has prepared TS 11 Iskra plane to this experiment, furnishing it with the following:

- GG24 and Z12 receivers;
- SATEL radio-modem for DGPS/DGLONASS data link;
- satellite aircraft GPS/GLONASS and GPS RTK antennas.

On the Navigation Department building a reference station antenna was installed (Photo 2) for GG24 receiver. Also, the base RTK Z12 receiver was set up at the point with precisely known co-ordinates in WGS'84.

Photo. 1. CXL70-5C antenna of reference station

Photo. 2. Ashtech aircraft antenna of GG 24 receiver at reference station

The receivers were installed on board of selected TS 11 Iskra on 24 May 1999. GG24 and Z12 receivers were installed on starboard because of a good access during assembly and of disassembly and because it was easy to switch them on and off after flight. SATEL radio - modems were installed in the second cabin on the external side of the ejection seat. Satellite antennas were fixed to a specially prepared rack. The distance between antennas was 10 cm.

Photo. 3. The assembly of GG 24 and of Z12 receiver receivers in TS 11cockpit

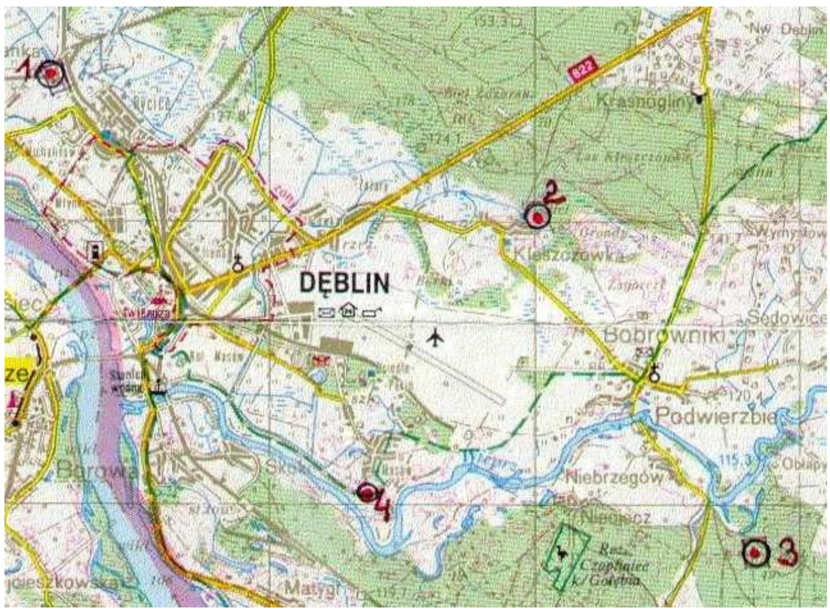

Fig. 1. Location of reference stations for the needs of RTK determinations

DETERMINATION OF REFERENCE STATIONS COORDINATES

Four points, located in direct vicinity of Dęblin runway, were chosen as reference stations in the experiment. Geometrical arrangement of the reference network is presented in Fig. 1. It can be seen that two of the stations are located on-line of the long axis of the runway, while the remaining - on both sides of it, approximately at half of its length. The stations were durably monumented.

The first task was to determine co-ordinates of the reference stations in the ETRF'89 system (European Terrestrial Reference Frame 1989). The latter constitutes a practical realisation of the WGS'84 (World Geodetic System 1984) for the area of Europe. GPS measurements were performed on 23rd May 1999, using dual-frequency Ashtech receivers. The reference stations were tied to 4 stations belonging to the POLREF network. It is Polish primary GPS network, composed of 356 stations, with average separation between the stations of about 20-25 km. For the experiment purposes, there were chosen 4 POLREF stations, located as close as possible to the area of interest. The numbers of the stations are as follows: 2703, 2704, 2706 and 2805. The claimed accuracy of POLREF stations co-ordinates determination is 10 mm for latitude and longitude and 15 mm for ellipsoidal height. Location of the POLREF stations used for our purposes provides a proper geometric configuration of the measured network.

Duration of measuring sessions ranged from 90 to 180 minutes, depending on lengths of measured vectors. Together with the reference stations for RTK purposes, also a point of location of Ashtech GG24 antenna was measured. This point was chosen on the roof of the Air Navigation Department. During the experiment it was used as a reference station for DGPS/DGLONASS determinations of the co-ordinates of the moving plane.

Approximate components of the measured vectors were computed with Ashtech GPPS (Geodetic Post-Processing Software) system of computer programmes (ver. 5.2). During processing, the tropospheric correction for standard meteorological conditions was admitted. The cut-off angle of 100 for satellite elevations was introduced into the process of computations. Adjustment of the network was carried out taking advantage of the GeoLab (ver. 1.9) computer programme (by BitWise Inc., Canada). We assumed the 4 POLREF stations as fixed, assigning them their known ETRF'89 co-ordinates. The adjusted network consisted of 9 points:

- 4 POLREF stations;
- 5 reference stations for further kinematic measurements (4 for RTK purposes, and 1 for being used as a master station for DGPS/DGLONASS measurements).

Also the vectors connecting the reference stations, emerged from kinematic measurements as static, were also admitted to the adjustment. The adjusted co-ordinates of unknown points were obtained directly in the ETRF'89 system. Parameters of error ellipses were computed at 95% confidence level. Average long axis of the ellipses amounted to 8 mm. This accuracy can be accepted for the purposes of RTK and DGPS/DGLONASS experiment.

DETERMINATION OF COORDINATES OF THE "TS11 ISKRA" AIRPLANE DURING FLIGHT

On 24 and 25 of May 1999, five observational sessions aimed at determination of successive co-ordinates of Ashtech Z-12 air satellite antenna, located at the plane "TS11 Iskra", were performed. During each session, 4 Ashtech receivers (two Z-12 and two Z-Surveyor, all of them with P-code available), located at the reference stations, recorded raw data in 1-second interval. The fifth receiver, also set for 1-second interval, recorded raw data at the plane. The air satellite antenna ware provided by the INS Inc., Cracow. The recorded data were used to compute RTK positions of the plane, in post-processing mode.

Simultaneously, during the same sessions, also real-time DGPS/DGLONASS positions of the GG24 air antenna located in close vicinity of the Z-12 antenna at the craft were determined. Distance between both antennas at the plane was equal to about 10 cm. Antenna of the base station (Ashtech GG24) for the DGPS/DGLONASS determinations was located on the roof of the Air Navigation Department building. DGPS/DGLONASS corrections were sent, using radio link, to the second GG24, located in the plane.

The raw data, recorded by on-ground and on-board Z-12 receivers were transferred to a computer and elaborated using Ashtech software PNAV (Precise NAVigation), ver. 2.1. This system of computer programmes enables carrying out computations according to the same algorithm which is used for precise real-time geodetic determinations (RTK), but in post-processing mode. This algorithm is based on the Kalman filtering technique. For each observational session four independent determinations of the plane co-ordinates, from all the four reference stations, for every second in GPS time, were computed. Thanks to having these four independent determinations for each observational epoch, it was possible to perform accuracy analysis of the obtained RTK co-ordinates. As a measure of accuracy we admitted standard deviation (S.D.), computed for each second and each co-ordinate (latitude B, longitude L and ellipsoidal height h) as follows:

$$S.D.B = \sqrt{\frac{\sum_i (B_{śr} - B^2{}_i)^2}{n-1}},$$

$$S.D.L = \sqrt{\frac{\sum_i (L_{śr} - L^2{}_i)^2}{n-1}},$$

$$S.D.h = \sqrt{\frac{\sum_i (h_{śr} - h^2{}_i)^2}{n-1}}$$

As an example, in Fig. 2 a typical trajectory (projection onto the B-L surface) of the plane is presented. Changes of its height in successive observational epochs can be seen in Fig.3. Number of satellites and PDOP coefficient for this same flight are given in Fig. 4. Continuing with the same period of observations, in Fig. 5, 6 and 7 one can see the computed values of standard deviations, for latitude, longitude and ellipsoidal height respectively, for post-processing RTK. It can be concluded, that for most observational epochs, the errors of the plane trajectory determinations from the 4 reference stations were considerably less than 10 cm. However, examining the plots, it can be observed that there are some periods when the value of S.D increases: to 0.20-0.35 m for latitude, 0.65 m for longitude and to about 0.50 - 0.65 for ellipsoidal height. Explanation of this phenomenon requires further investigations.

In the aim of finding one value that can, in some way, characterise accuracy obtained from the whole session, mean standard deviations were computed for all the epochs of each session. The results are given in Table 1.

Table 1. Mean standard deviations in RTK positions of the plane

	24.05.1999		25.05.1999		
	ses. 1	ses. 2	ses. 1	ses. 2	ses. 3
Mean S.D.B.	3.9 cm	12.1 cm	1.5 cm	4.2 cm	9.2 cm
Mean S.D.L	8.0 cm	1.6 cm	1.1 cm	5.7 cm	8.6 cm
Mean S.D.h.	11.0 cm	17.2 cm	3.6 cm	8.1 cm	12.4 cm

It should be noticed here, that in each session, the epochs with standard deviations greater than 1 m were rejected. These were mainly beginning epochs, for which Kalman filter parameters had not yet been fixed by the programme.

For further computations the arithmetic means were computed of B, L, h for each observational epoch. On the basis of the above results it can be stated that these means can be regarded as reliable and accurate enough to provide reference positions of the plane during a flight.

COMPARISON OF RTK POST-PROCESSING POSITIONS WITH DGPS/DGLONASS REAL-TIME DETERMINATIONS

The RTK positions of the plane, obtained in post-processing mode based on RTK algorithm, computed as arithmetic means from 4 independent vectors, were compared to real-time DGPS/DGLONASS determinations. The latter were recorded in on-board GG24 receiver. The second GG24 receiver located on the roof of the Air Navigation Department building sent corrections for these determinations. Its co-ordinates were determined previously, being consistent with those of RTK reference stations.

Results of comparisons are presented graphically in Fig. 8 - 12. In Fig. 8 there are given differences between latitudes obtained from GPS RTK and DGPS/DGLONASS determinations in session 1 on 24 May 1999.

It can be seen that they exceed 100 m and differences for longitudes are similar, while for ellipsoidal heights they reach 70 m. After further analysis it was found that the results obtained in real time using DGPS/DGLONASS receivers are shifted of about 1 second in time in respect to those obtained in post-processing GPS RTK (the real-time positions are backward). After shifting all the positions by 1 second the differences in B and L are of order of 2 m (Fig. 9).

Somewhat different situation was with height - it was proved that besides the above shift there was also a systematic error in all determinations equal to about 32.5 m (GPS RTK positions were lower than real-time DGPS/DGLONASS) - see Fig. 10. Probably it is a result of false settings in one of GG24 receivers (e.g. declaration that the height written down was geoidal not ellipsoidal).

To check whether in remaining sessions there was also similar shift of about 1 second in the results, we compared short intervals of the trajectories plotted for all performed sessions on the B-L surface (Fig. 10, 11). It was found that for 4 sessions the shift was almost equal to 1 second, and for one session (session 2, 24 May 1999) the shift amounted to about 0.7 second (Fig. 12). Additionally, in session 3 (25.05.99) a systematic discrepancy of about 12m in determinations of B was detected.

The obtained results were of great surprise, their explanation needs further studies. The raw data and the algorithm used for determination of Pseudo Range Correction (PRC) are not available. We do not exclude the possibility that there is some latency in PRC transmission from the reference station to the plane. We hope that further experiments will enable to explain of the obtained results.

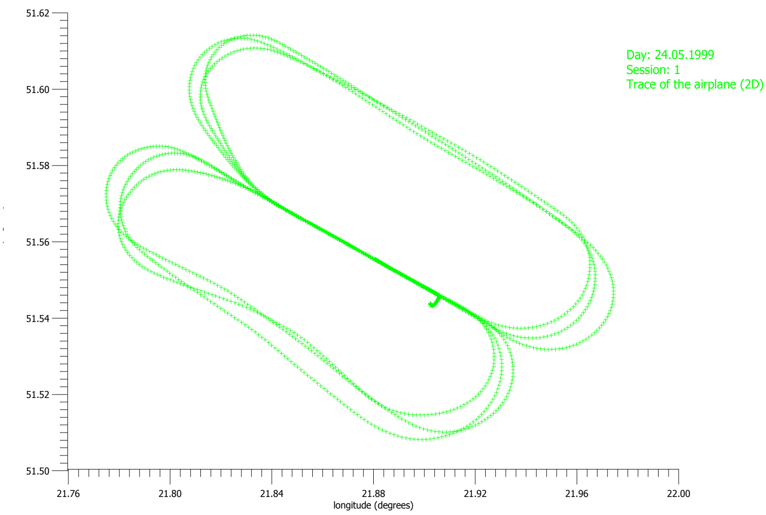

Fig. 2. 2D trajectory of the airplane

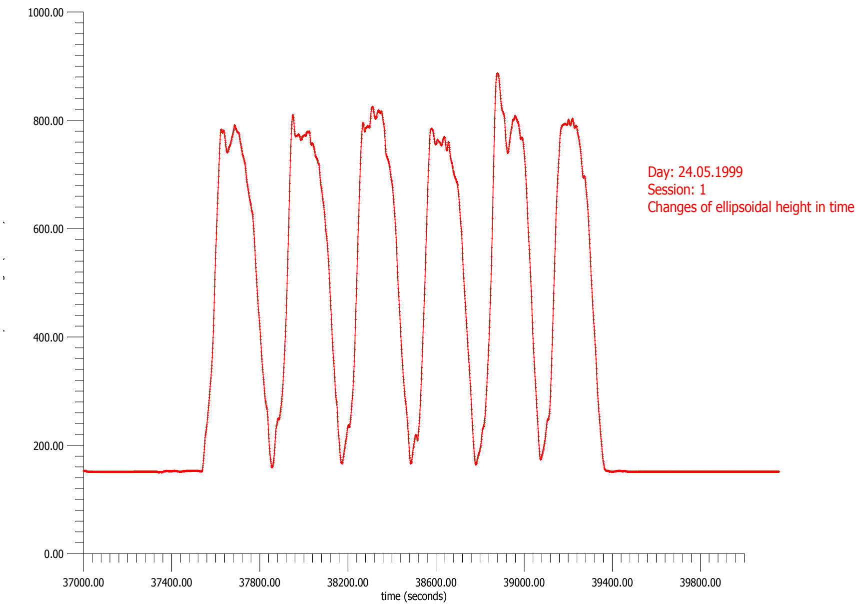

Fig. 3. Changes of WGS'84 ellpsoidal height of the plane

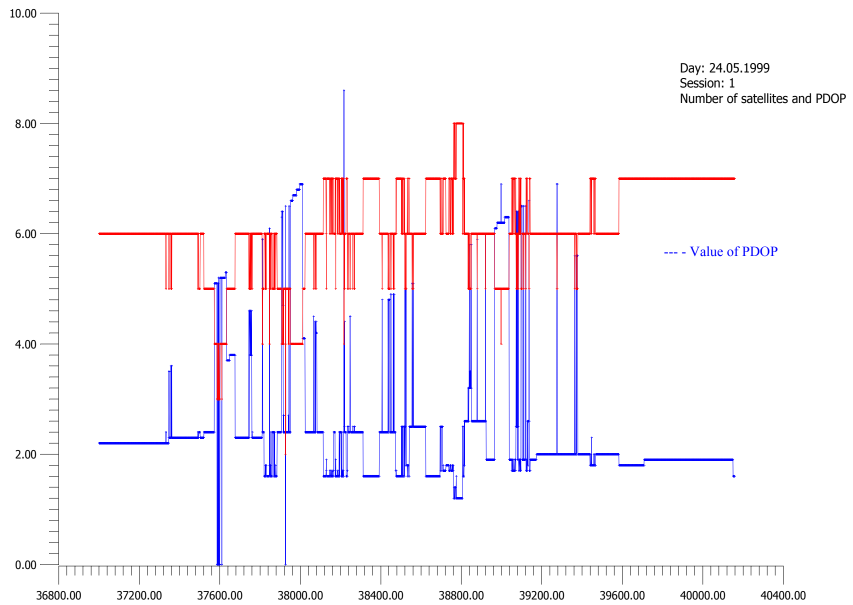

Fig. 4. Number of satellites and value of PDOP

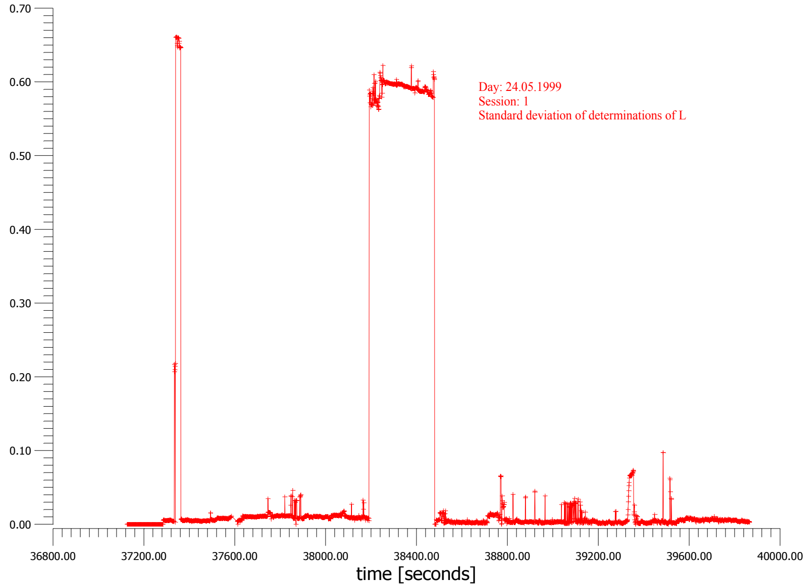

Fig. 5. Standard deviations of L computed from 4 independent determinations

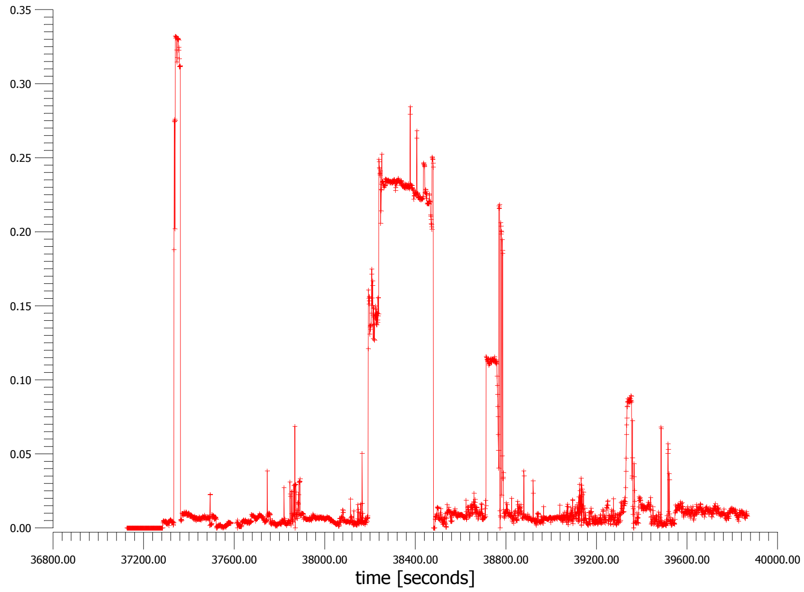

Fig. 6. Standard deviation for determinations of B

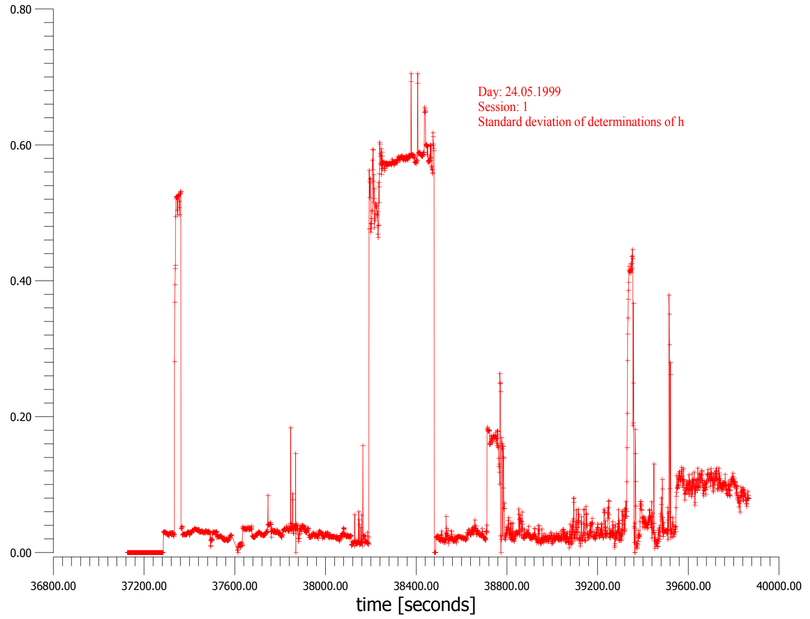

Fig. 7. Standard deviation for determinations of h

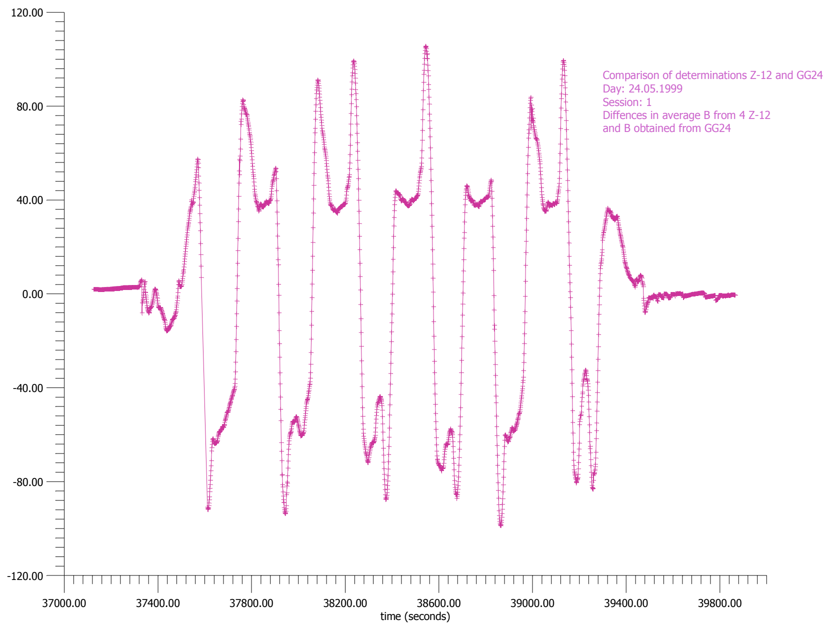

Fig. 8. Differences of B obtained from mean Z-12 and GG24 determinations

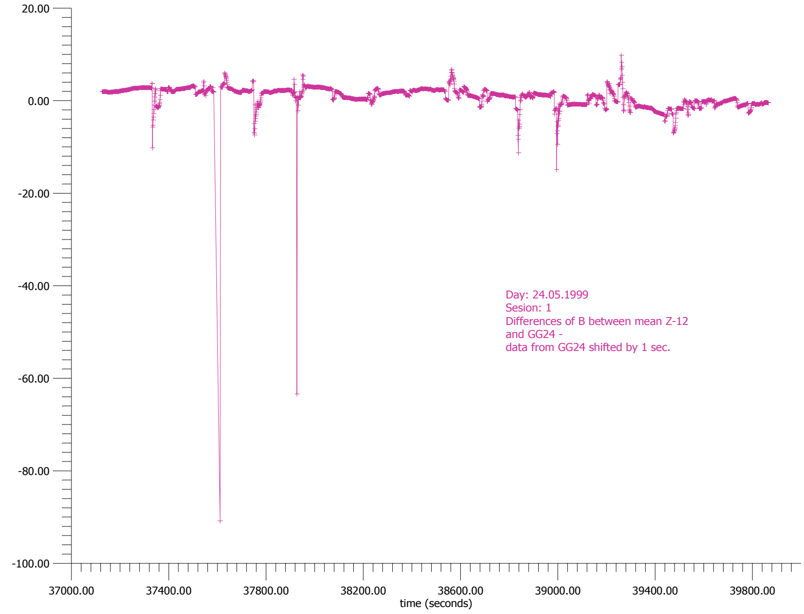

Fig. 9. Differences in mean B from Z-12 and B from GG24 – data from GG24 shifted by 1 sec.

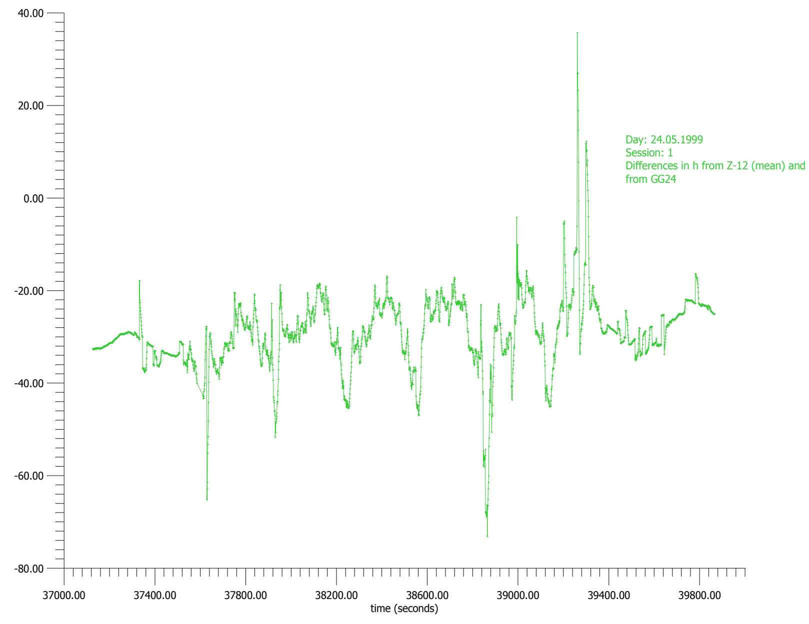

Fig. 10. Systematic differences in ellipsoidal height determinations

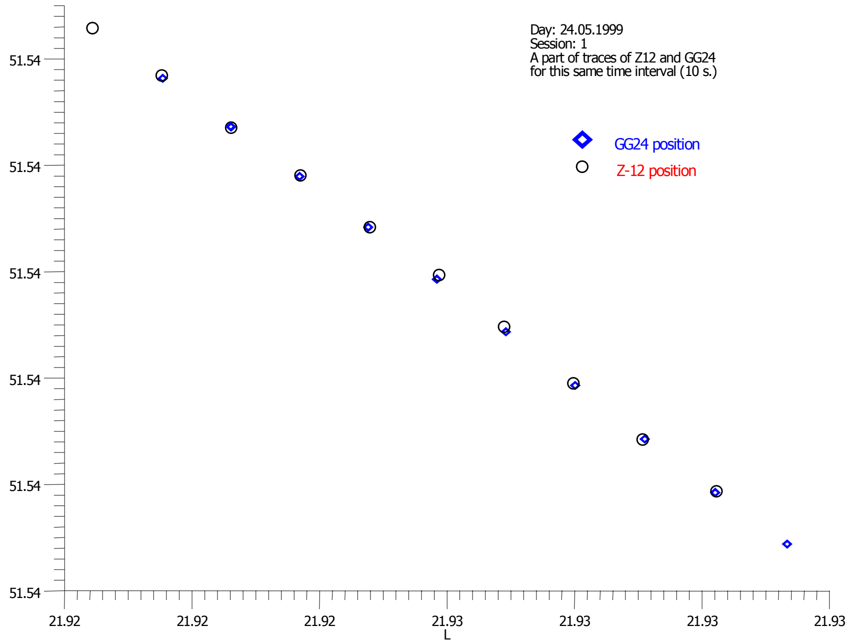

Fig. 11. Shifted positions from Z-12 and GG24

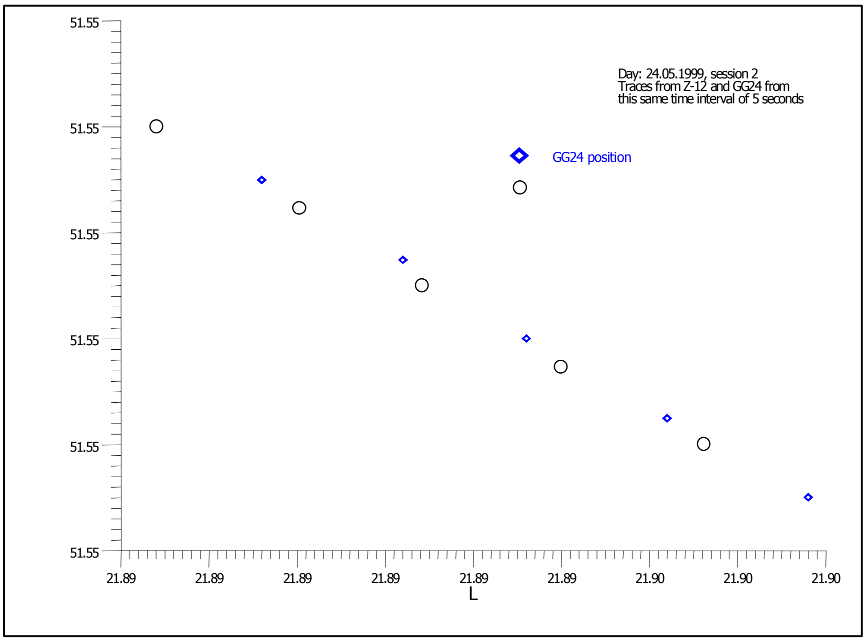

Fig. 12. Positions shifted by about 0.7 of second

CONCLUSIONS

The preliminary results of the flight trials showed that satellite based approach and landing are basically possible. The use of integrated DGPS/DGLONASS receivers can improve the Required Performance Navigation Parameters (RNP). The accuracy of real-time differential integrated positioning can be as good as 2 metres in latitude and longitude components. In determination of height of the aircraft above runway, the height of geoid and orthometric height of the runway should be correctly included.

However, the results showed that time delay can be observed in real-time differential positioning of the aircraft. To avoid this error, the algorithm for determination of Pseudo Range Correction (PRC) should be known and transmission time of PRC from the reference station to aircraft should be examined.

The other important RNP parameters such as availability, continuity and integrity of integrated DGPS/DGLONASS positioning should be also investigated.

The study has been performed and the paper prepared in the frame of the Project No9T12E01513 granted by the Scientific Research Council in Poland.

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