ISSN 2720-197X / eISSN 2956-3380

**Adam CIEĆKO**
University of Warmia and Mazury in Olsztyn
e-mail: a.ciecko@uwm.edu.pl; ORCID: 0000-0002-3984-0846

**Grzegorz GRUNWALD**
University of Warmia and Mazury in Olsztyn
e-mail: grzegorz.grunwald@uwm.edu.pl; ORCID: 0000-0001-9252-7624

**Natalia MALINOWSKA**
Polish Air Force University
e-mail: n.malinowska5666@wsosp.edu.pl; ORCID: 0009-0003-6157-5406

**Artur GOŚ**
Polish Air Force University
e-mail: a.gos@law.mil.pl; ORCID: 0000-0002-4268-8830

DOI: 10.55676/asi.v4i2.63

# ACCURACY ANALYSIS OF AIRCRAFT POSITION PARAMETERS PROVIDED BY GCA 2000 AIRPORT SURVEILLANCE RADAR

## ANALIZA DOKŁADNOŚCI PARAMETRÓW POZYCJI STATKU POWIETRZNEGO WYZNACZONYCH PRZEZ RADAR KONTROLI LOTNISKA GCA 2000

### Abstract

The aim of this article was to investigate the accuracy of determining the position parameters of an aircraft by the GCA 2000 airport control radar located at Deblin Airport (EPDE). In order to analyse the accuracy of determining the position of an aircraft by the GCA 2000 radar, a research flight was carried out. The position of the aircraft was recorded by the GCA 2000 radar and the Thales Mobile Mapper Pro GPS receiver on board the aircraft. The resulting position parameters were compared with each other to investigate the accuracy of the radar's coordinate determination. In addition, a number of analyses and comparisons were performed to determine the reasons for the interruptions in the radar detection of the aircraft. Based on the study, it can be concluded that the GCA 2000 radar located at Deblin airport meets the requirements set by the International Civil Aviation Organisation (ICAO) for radar performance. According to ICAO, the standard deviation of the distance error should be 70–130 metres and the azimuth error for primary radars should be 0.15–0.2°, and for secondary radars 0.2–0.3°. The standard deviation of the distance error during a research flight by the GCA 2000 radar is 81.1 metres and the standard deviation of the azimuth error is 0.19°.

**Keywords**: GNSS positioning, radar, ICAO requirements

### Streszczenie

Celem artykułu było zbadanie dokładności określania parametrów położenia statku powietrznego przez radar kontroli lotniska GCA 2000 znajdujący się na lotnisku w Dęblinie (EPDE). W celu dokonania analizy dokładności określania pozycji statku powietrznego przez radar GCA 2000 został wykonany lot badawczy. Pozycja samolotu została zarejestrowana przez radar GCA 2000 oraz odbiornik GPS Thales Mobile Mapper Pro, umieszczony na pokładzie statku powietrznego. Otrzymane parametry położenia zostały ze sobą porównane w celu określenia dokładności wyznaczania współrzędnych pozycji. Dodatkowo wykonano szereg analiz i porównań w celu ustalenia przyczyn występowania przerw w wykrywaniu statku powietrznego przez radar. Na podstawie przeprowadzonego badania można stwierdzić, że radar GCA 2000 znajdujący się w Dęblinie spełnia wymagania stawiane przez Organizację Międzynarodowego Lotnictwa Cywilnego dotyczącą wydajności pracy radarów. Według ICAO odchylenie standardowe błędu odległości powinno wynosić 70–130 metrów, a błędu azymutu dla radarów pierwotnych 0,15–0,2°, zaś dla radarów wtórnych 0,2–0,3°. Odchylenie standardowe błędu odległości podczas lotu badawczego przez radar GCA 2000 wynosi 81,1 metra, a odchylenie standardowe błędu azymutu wynosi 0,19°.

**Słowa kluczowe**: pozycjonowanie GNSS, radar, wymagania ICAO

Artykuł wpłynął do redakcji: 20.08.2023 / Zatwierdzono do publikacji: 30.12.2023

## 1. INTRODUCTION

Radars are one of the most important instruments used to provide air traffic control[1,2,3]. With the use of radar, it is possible to detect an object and determine its position[4,5]. The history of radar is quite short, dating back to the 1930s. Radars were developed for military purposes due to the development of military aviation, and after World War II they also found civilian applications. The principle of radar operation is the use of a focused beam of electromagnetic radiation to locate objects that have the ability to reflect electromagnetic waves. Nowadays, due to the very rapid development of air transport, when at one time there are tens of thousands of aircraft in the air performing flights around the world, radar is one of the most essential elements of air traffic control[6]. Through the use of radars, it is possible to ensure the smooth, orderly and safe movement of aircraft. Air traffic control radars detect and determine the location of objects within their search area[7]. Depending on the type of radar, it is also possible to determine additional parameters such as altitude, speed or transponder code. With the development of technology, more systems appear to assist the work of air traffic controllers[8], however, the use of primary radars is still the most reliable way to detect an object.

Radar is a device used to detect and locate objects, such as aircraft, ships, vehicles, spacecraft, people and environmental objects, using electromagnetic waves[9]. The biggest advantage of radar is its ability to determine position at different distances and in different atmospheric conditions. The operation of radar can be described as sending an electromagnetic wave into space and detecting an echo signal flung from an object. The distance of an object from the radar antenna can be determined by one of three methods. The first is to measure the time required for the signal to reach the object and for the echo signal to return to the radar. Another way is to calculate the frequency difference between the transmitted wave and the received echo, if linear frequency modulation is used. The last method is to calculate the differential phase of a double echo detection obtained using two transmissions with different frequencies. Using the timing method, the radar signal should be sent in short pulses. The distance of the object from the radar antenna ($R$) depends on the

1 E. Byron, Radar: Principles, Technology, Applications, Prentice Hall, INC., Upper Saddle River 1995.
2 Z. Czekała, Parada radarów, Bellona, Warszawa 2014.
3 P.R. Morris, Powstanie radaru, PWN, Warszawa 1967.
4 A. Goś, Charakterystyka porównawcza radarów AVIA i GCA-2000, [in:] Wybrane aspekty zabezpieczenia nawigacji lotniczej, ed. J. Ćwiklak, "Współczesna Nawigacja", T. I, LAW, Dęblin 2019.
5 M.I. Skolnik, Introduction to Radar Systems, 3rd Edition, McGraw-Hill, New York 2001.
6 Z. Polak, A. Rypulak, Awionika, przyrządy i systemy pokładowe, WSOSP, Dęblin 2002.
7 ICAO, International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Aeronautical Communications Volume 1 Radionavigation Procedures, 2020.
8 K. Krasuski, M. Lalak, P. Gołda, M. Mrozik, J. Kozuba, Analysis of the precision of determination of aircraft coordinates using EGNOS+SDCM solution. Archives of Transport, 2023, 67(3), https://doi.org/10.5604/01.3001.0053.7264, pp. 105–117.
9 P. Lacomme, J.P. Hardange, J.C. Marchais, E. Normant, Air and Spaceborne Radar Systems, William Andrew Publishing, LLC, Norwich 2001.

 DOI: 10.55676/asi.v4i2.63

speed of light ($c$) which is 300.000.000 m/s, and the time ($t_R$), it takes for the radar signal to reach the target and return to the radar[10].

The formula for the distance of an object from the radar antenna can be written as follows:

$$R = \frac{c \cdot t_R}{2} \quad (1)$$

The detection range of objects at low altitudes is related to the curvature of the Earth and the physical phenomena of radio wave propagation near the Earth's surface. These phenomena can include atmospheric refraction, attenuation of the propagation medium, diffraction, and wave interference. It is also crucial to choose an appropriate place for the location of the radar for the sake of very difficult and sometimes even impossible to eliminate errors caused by terrain and the presence of objects that interfere with the propagation of electromagnetic waves. We can distinguish two types of obstacles that cause interference with radar signal propagation, natural terrain obstacles and artificial obstacles, which are related to human activity. Natural obstacles include: elevated terrain, rocks, bodies of water, clusters of trees and bushes, and single tall trees. Artificial obstacles include: buildings of all kinds, urbanized areas, chimneys, masts, power poles. Interference is also caused by industrial machinery and equipment and all communications systems[11, 12].

This article attempts to study the accuracy of determining aircraft position parameters by the GCA 2000 surveillance radar located at Deblin Airport (EPDE). An attempt has also been made to study the effect of existing terrain obstacles on the radar's performance, depending on the distance and altitude of the aircraft being tracked.

## 2. GCA 2000 SYSTEM

The GCA 2000 system consists of an Airport Surveillance Radar (ASR), a Secondary Surveillance Radar (SSR) and a Precision Approach Radar (PAR)[13, 14]. The GCA 2000 consists of three main components, which include an electronics container, a set of antennas and a power generator. It is also possible to include an additional component, which is an air traffic control container (Figure 1)[15].

10 H. Meikle, Modern Radar Systems, Artech House, INC., Norwood 2001.

11 M. Brzozowski, U. Kołodziejska, Problemy identyfikacji przeszkód powodujących przesłanianie wiązki radaru na przykładzie radaru meteorologicznego, WITU, Warszawa 2010.

12 ICAO, Guidance Material on Comparison of Surveillance Technologies (GMST), edition 1.0, 2007.

13 Ground Controlled Approach System GCA-2000 – Technical documentation, Van Nuys, USA 2016.

14 A. Łydka, Kwalifikacja przedsięwzięcia pod względem konieczności uzyskania decyzji o środowiskowych uwarunkowaniach dla przedsięwzięcia pn. "Radar GCA-2000 - DĘBLIN, Gliwice 2015.

15 A. Goś, Charakterystyka porównawcza radarów…., op. cit.

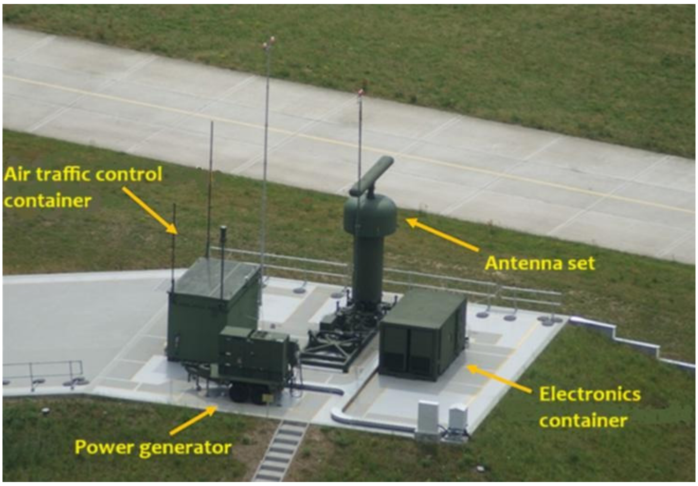


Fig. 1. The structure of the GCA 2000 radar
Source: https://zbiam.pl/wp-content/uploads/2021/04/GCA-2000.jpg [access: 31.10.2022].

The antenna system consists of two primary radar antennas (course radar antenna and descent path radar antenna), secondary radar antenna, and MTI reflectors (used to verify the correct operation of the PAR radar).

The electronic system is composed of the following components: transceiver, SSR query device, data processing unit, transmission path, antenna drive control unit, AC/DC and DC/DC power source, fiber optic link and Ethernet. The GCA 2000 makes it possible to detect aircraft in harsh atmospheric conditions and in the presence of terrain interference[16].

## 3. EXPERIMENT DESCRIPTION

In order to test the accuracy of determining the aircraft's position parameters by the GCA 2000 surveillance radar, a research flight was carried out and recorded by the radar located at Deblin Airport (EPDE). The aircraft's position was also determined by a GPS receiver on board the aircraft[17, 18]. An analysis of the accuracy of the aircraft's position determination was carried out on the basis of data obtained from the GCA 2000 radar and data obtained by the Thales MobileMappper Pro receiver[19].

16 K. Burbo, Urządzenia radionawigacyjne, WSOSP, Dęblin 2004.

17 A. Leick, L. Rapoport, D. Tatarnikov, GPS Satellite Surveying, Fourth Edition, John Wiley&Sons, Inc., Haboken, New Jersey 2015.

18 Thales Navigation, MobileMapper Pro Technical Specifications, 2005.

19 A. Goś, K. Krasuski, Model matematyczny wyznaczenia pozycji statku powietrznego na podstawie danych radarowych, [in:] Wykorzystanie technik nawigacyjnych w lotnictwie. Część I, ed. M. Grzegorzewski, "Współczesna Nawigacja", T. III, LAW, Dęblin 2021, p. 75–83.

 DOI: 10.55676/asi.v4i2.63

The flight took place on October 13, 2022 at 14:06:28 local time (12:06:28 UTC) from the EPDE airport in a Diamond DA20-C1 Eclipse aircraft. The route passed through Laskarzew, Garwolin, Grojec, Bolimowski National Park, Bialobrzegi and Kozienice (Fig. 2). Over Laskarzew, the aircraft made circles at 1.500 feet and 3.000 feet to test the radar's ability to detect the aircraft at different altitudes. The average altitude of the flight was 1275 feet and the average speed was 103 knots. The research flight took place in very good atmospheric conditions, there was little cloud cover and the temperature was about 14°C. The duration of the flight was 1 hour 52 minutes 2 seconds, which makes it possible to analyse 6722 seconds of the flight to determine the accuracy of the GCA 2000 radar's determination of position parameters and to identify the causes of the aircraft's interruption in detection.


Fig. 2. Aircraft trajectory during test flight

Source: Flightradar24 [access: 6.12.2022].

The aircraft position parameters recorded by the Thales MobileMapper Pro receiver were used to analyse the accuracy of the position determination by the GCA 2000 radar[20]. The receiver was configured in 'post-processing' data recording mode, which enabled a subsequent differential correction to be made to the resulting geodetic coordinates.

## 4. RESEARCH METHODOLOGY

In order to analyse the accuracy of the position determination, it is necessary to use a common coordinate system. The position of the aircraft determined by the GCA 2000 system is determined by polar coordinates $R$ and $\beta$. On the other hand, the

[20] K. Banaszek, M. Malarski, Dokładność pozycjonowania współczesnych systemów nawigacji satelitarnej a przepustowość portów lotniczych, "Logistyka" 2011, vol. 4.

position points recorded by the GPS receiver are represented by ellipsoidal coordinates $\mathrm{B}$, $\mathrm{L}$, $\mathrm{h}$ in a system that is an implementation of the WGS-84 datum[21, 22].

The GCA 2000 radar local reference system considers the position of the radar antenna as the centre of the system, the polar axis is directed towards magnetic north, the radial distance was defined as the slant distance $R$, and the polar angle $\beta$ is the azimuth, which is measured clockwise from 0° to 360°. In order to analyse the accuracy of the position determination, the polar coordinates determined by the radar and the ellipsoidal coordinates determined by the GPS receiver were reduced to a common plane Cartesian coordinate system.

In the study carried out, the aircraft position parameters determined by the Thales MobileMapper Pro receiver in post-processing mode were considered true. For each pair of position coordinates determined by the radar, the coordinates determined by the receiver were assigned. The calculations were performed for polar coordinates and Cartesian coordinates. The determined position coordinates in the Cartesian system were presented in graphs that depict the route of the research flight. The standard deviation, mean absolute error, maximum error and minimum error were calculated as measures of accuracy. The last parameter determined is the radar distance determination error, caused by the fact that the distance R determined by the radar is a slant distance and not a horizontal distance. When determining the slant distance, the radar does not take into account the elevation. As a result, two aircraft that are at the same horizontal distance from the radar, but a different altitude, will be depicted by the radar as two points at different slant distances. An object flying at a higher altitude will be seen as an object further away from the radar. An illustration of this situation is shown in Figure 3.

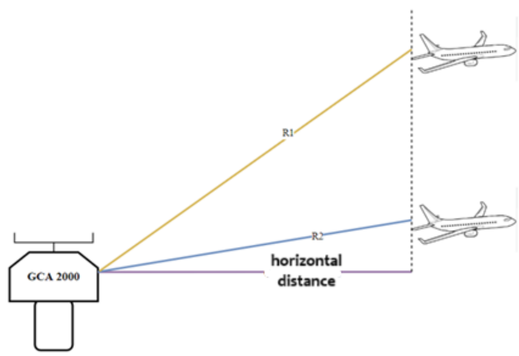


Fig. 3. Illustration of radar misdetermination of distance
Source: own study.

21 A. Ciećko, A. Goś, K. Krasuski, K. Krześniak, Accuracy analysis of aircraft positioning using real radar and GPS data, “Scientific Journal of Silesian University of Technology. Series Transport” 2022, vol. 116, p. 71–82.

22 D. Dzwonkowski, A. Goś, J. Ćwiklak, K. Krasuski, Research and comparative analysis of the accuracy in determining the parameters of the position of aircraft by air traffic control radars Avia-W and GCA-2000, “Journal of KONBiN” 2022, vol. 52(2), p. 35–46.

 DOI: 10.55676/asi.v4i2.63

## 5. ANALYSIS OF THE ACCURACY OF DETERMINATION OF AIRCRAFT POSITION COORDINATES BY GCA 2000 RADAR

In Figure 4, the aircraft's flight trajectory after departure from Deblin airport is shown until it 'exited' the radar range of the GCA 2000. The GCA 2000 system detected the aircraft at a distance of approximately 3 km from the radar. The Diamond DA20 disappeared from radar detection range at a distance of approximately 62.5 km. The route depicted was determined from the converted coordinates recorded by the GCA 2000 and by the GPS receiver into Cartesian coordinates. The centre of the coordinate system is the centre of the GCA 2000 radar antenna.


Fig. 4. Research flight track after departure from EPDE recorded by GCA 2000 radar and GPS receiver

Source: own study.

The effect of the distance from the radar on the position determination error was then calculated, as shown in Figure 5, together with the marked trend line. In the next step, the effect of the aircraft's flight altitude on the object's position determination error by radar was determined (Figure 6).

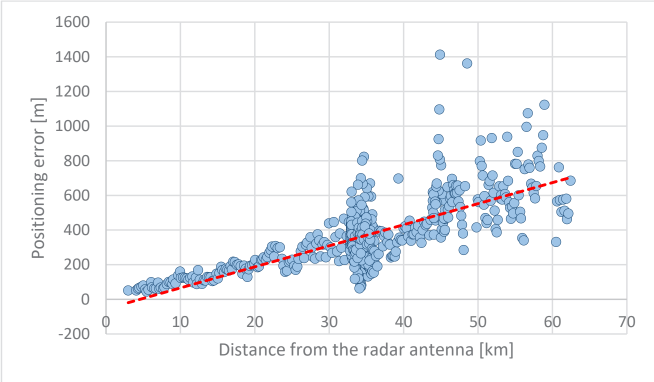


Fig. 5. Influence of distance from radar on accuracy of aircraft attitude determination
Source: own study.

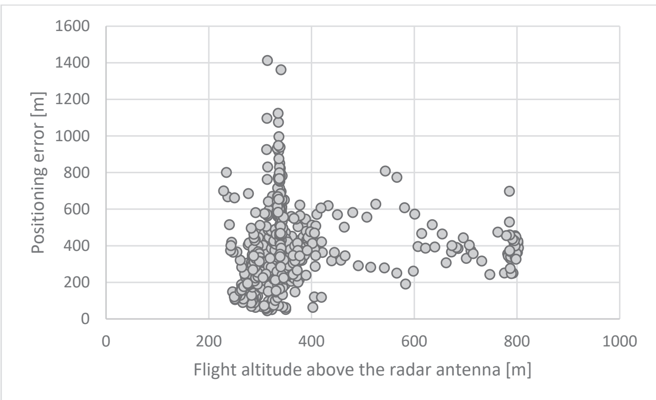


Fig. 6. Influence of flight altitude above GCA 2000 radar antenna on radar positioning accuracy
Source: own study.

Based on Figures 5 and 6, it can be concluded that, as the distance of the aircraft from the radar antenna increased, the position determination error of the GCA 2000 also increased. In addition, the determination of position parameters was also affected by the execution of turns, which were carried out at distances of approximately 35 and 45 km from the radar. The densities of the points depicting the position determination error of the aircraft at a distance of approximately 35 km from the radar are due to the loops performed by the aircraft. The flight altitude above the GCA 2000 radar antenna during the survey was a minimum of 229 m and a maximum of 803 m.

 DOI: 10.55676/asi.v4i2.63

Based on the analysis, it can be concluded that the flight altitude between 200 m and 800 m above the radar antenna did not have a major impact on the accuracy of the aircraft's positioning parameters. The mean value of the position determination error was 369.1 m. The standard deviation had a value of 192.91 m. The smallest value of the position determination error was 44.1 m, while the largest value was 1411.9 m. The largest error value occurred when performing 360° loops.

The distance determination error $R$ was then determined in relation to the distance of the aircraft from the radar as shown in Figure 7, together with a trend line. The polar coordinates R determined by the GCA 2000 radar and by the GPS receiver were compared.

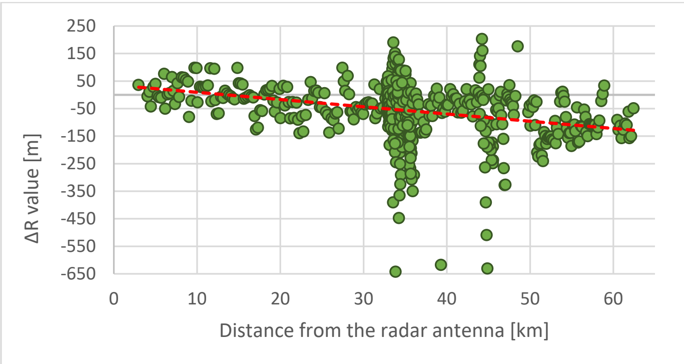


Fig. 7. Radar distance determination error values R in relation to aircraft distance from GCA 2000 radar antenna

Source: own study.

From the data shown in Figure 7, the error in determining the distance up to 35 km from the radar was small, with a maximum of about 150 m. As the distance from the radar antenna increased, the error values also increased and were more variable. The largest values were recorded when making turns at distances of around 35 and 45 km from the radar. During the turns, the aircraft dynamically changed speed and altitude, resulting in sudden changes in position. The standard deviation was 81.10 m, indicating that the GCA 2000 radar meets the requirements of the International Civil Aviation Organization. The mean error was 79.66 m. The minimum value was 0.56 m and the maximum value was 642.62 m.

Another parameter analysed was the absolute error of azimuth determination. The dependence of the magnitude of the azimuth determination errors and the distance from the radar antenna, together with the trend line drawn, are shown in Figure 8.

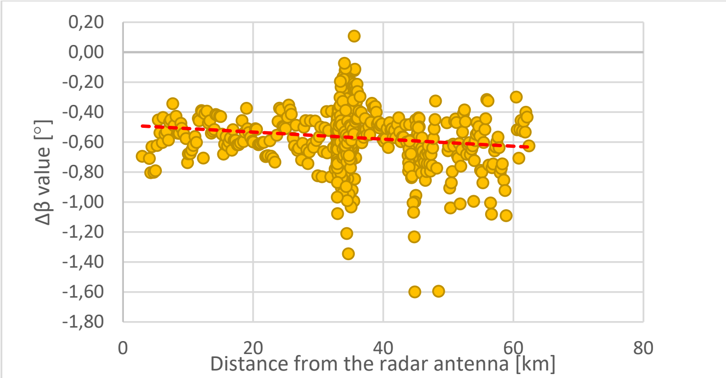


Fig. 8. Error values of GCA 2000 radar azimuth determination in relation to aircraft distance from radar antenna

Source: own study.

Azimuth determination error values do not depend on the distance of the aircraft from the radar. The difference in standard deviation values is due to the execution of turns. The largest variation in error values occurred at 35 km when making turns and at 45 km when making an orbit. The standard deviation was 0.19°, indicating adequate operation of the GCA 2000 radar, within ICAO guidelines. The mean error was 0.57°, the minimum value was 0.08° and the maximum value was 1.6°. The maximum value of the azimuth error occurred at the same time as the very high value of the distance error, when the aircraft was making the turn.

## 6. ANALYSIS OF INTERRUPTIONS IN AIRCRAFT DETECTION BY GCA 2000 RADAR

The aircraft took off from Deblin airport at 12:06:28. The aircraft's position was first recorded by GCA 2000 radar at 12:08:51 at a distance of approximately 3 km from the radar. During the aircraft's departure from EPDE airport, another aircraft was on a short straight line, which may be the reason for the delayed detection of the aircraft performing the research flight. The radar last determined the position parameters of the aircraft at a distance of 62.5 km at 12:51:55, while performing a flight at 305 m above mean sea level. The detection of the aircraft performing the research flight while returning to Dęblin airport was very late. The position was determined at 12:46:53 at a distance of 35 km from the GCA 2000 radar, at an altitude of approximately 381 m above mean sea level. The radar last recorded the coordinates of the aircraft's position at 13:58:12 at a distance of approximately one kilometre from the radar antenna. A total of ten interruptions in object detection occurred during the research flight. On departure from Dęblin airport, the radar stopped registering the aircraft's coordinates six times and on arrival four times.

 DOI: 10.55676/asi.v4i2.63

Six intervals marked 1–6 in Figure 9, of radar interruption of aircraft detection were analysed in detail in terms of terrain – three intervals of radar interruption on departure and three on arrival, see Figure 9.

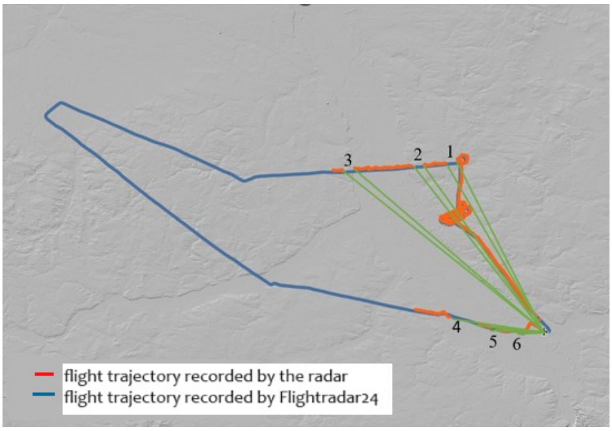


Fig. 9. Analysed interruptions in aircraft detection by GCA 2000 radar
Source: own study.

The first interruption in detection that was analysed occurred after making an orbit, when the aircraft was flying at an altitude of approximately 400 m above sea level. Radius 1 in Figure 9 indicates the direction of the signal emission at the last recorded position of the aircraft before the detection interruption occurred. The terrain along radius 1 varied greatly, with terrain heights ranging between 117 m and about 180 m (Figure 10a).

The second gap occurred during the flight at an altitude of approximately 404 m above mean sea level. The terrain was between 113 m and about 180 m above mean sea level. The terrain along radius 2 varied considerably (Figure 10b).

The third break occurred during the flight at 380 m above sea level. The altitude of the terrain along radius 3 was much lower than during the occurrence of the previous two detection breaks, and the terrain was not as varied (Figure 10c). The disappearance from the radar indicator occurred when the aircraft passed the river. The path of the radar signal was over the river, which may have been the reason for the aircraft disappearance from the radar indicator. Another factor that may have influenced this is the long distance from the radar.

The fourth interruption occurred approximately 22–15 km from the radar, at a flight altitude of 328 m above mean sea level. The break occurred during a flight over the lower-lying terrain in the Vistula River basin, where there was a change in terrain. The terrain along radius 4 was not varied (Figure 10d). The path of the electromagnetic wave passed over a river, which may have influenced the occurrence of interference due to the phenomenon of signal reflection from the water body.

The fifth interruption in detection occurred at a distance of 1–11 km from the radar while flying at an altitude of 335 m above mean sea level. The elevation of the terrain along radius 5 did not vary (Figure 10e). The aircraft was flying along the Vistula River during the occurrence of this break.

The sixth interruption in detection occurred when the aircraft was 9 km from the radar and flying at 366 m above mean sea level (Figure 10f). The flight at the point where the interruption occurred was done close to the river.

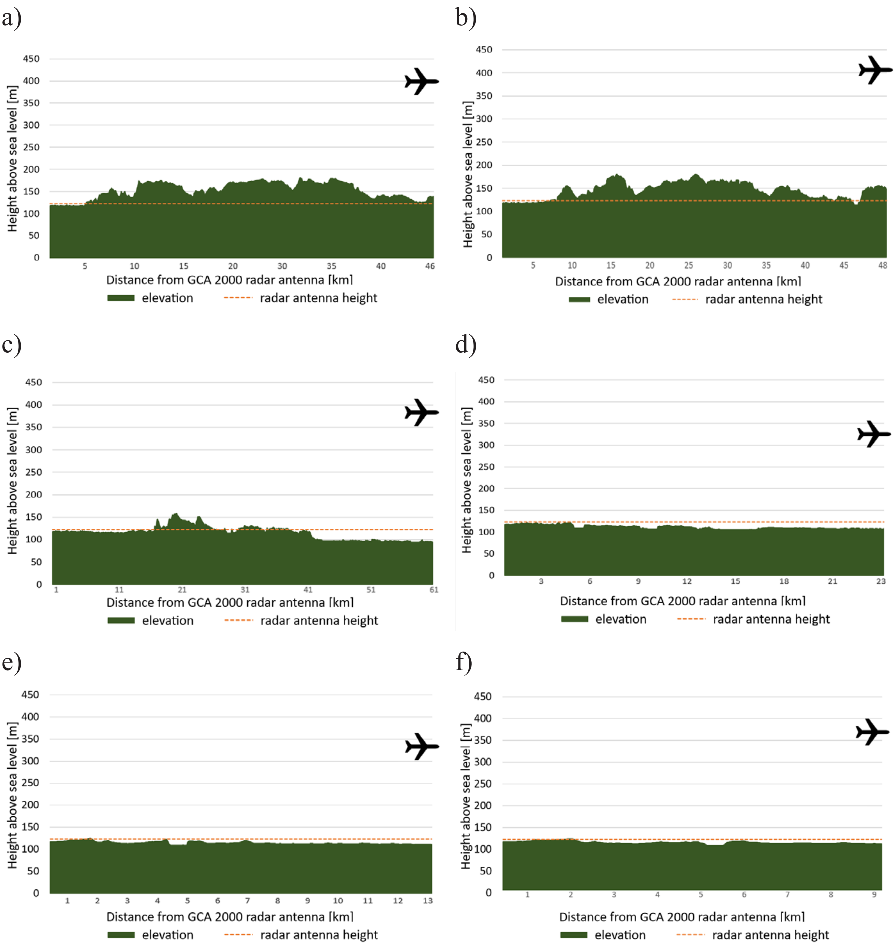


Fig. 10. Terrain along rays 1–6 during occurrence of detection interruptions

Source: own study.

 DOI: 10.55676/asi.v4i2.63

## 7. CONCLUSIONS

As a result of the analysis, it is possible to determine the influence of distance from the radar, flight altitude and the performance of particular manoeuvres on the accuracy of determining aircraft position parameters by the GCA 2000 radar located in Dęblin.

Based on the study, it can be concluded that the GCA 2000 radar meets the requirements set by the International Civil Aviation Organisation for radar performance. According to ICAO, the standard deviation of the distance error should be 70–130 m and the azimuth error for primary radars should be 0.15–0.2°, and for secondary radars 0.2–0.3°. The standard deviation of the distance error during a test flight by the GCA 2000 radar is 81.1 m and the standard deviation of the azimuth error is 0.19°.

The distance of the object from the radar antenna has a very strong influence on the accuracy of position determination. Another factor affecting the accuracy of position determination is the execution of dynamic turns. The largest value of the error in determining position coordinates occurred at a distance of about 45 km from the radar when making an orbit. The smallest error values were observed during straight flight up to a distance of about 35 km. The flight altitude between 200 m and 800 m above the antenna of the GCA 2000 radar has no significant effect on the accuracy of position determination.

The distance determination error of the radar compared to the distance determined by the GPS receiver increases and varies more as the aircraft moves away from the radar. The highest values of the $R$-coordinate determination error are observed during turns. The occurrence of the distance-determination error is caused by an incorrect azimuth determination, and thus the value of the distance error increases as the distance increases. Another cause may be the time synchronisation between the radar and the GPS receiver. Synchronisation with an accuracy of one second can cause a distance measurement error of approximately 50 m.

The error in radar azimuth determination during the test flight is constant at approximately 0.57°. The distance from the radar has no effect on the accuracy of the radar's azimuth determination. The greatest variation in the error value occurs during rapid position changes when making turns.

Thanks to the analysis, it can be concluded that the most significant influence on the accuracy of determining the position parameters is exerted by the execution of sharp and dynamic turns by the aircraft and increasing its distance from the radar antenna. During the execution of turns, there is a sudden change in altitude and speed, and therefore in the position of the object. Consequently, the number of dynamically changing data causes a decrease in the accuracy of the GCA 2000 system's determination of position parameters.

The radar's distance determination error, which is caused by the determination of slant distance rather than horizontal distance, has also been analysed. This error decreases as the distance from the radar increases. It increases when ascending and decreases when descending the aircraft. The error values during the test flight were small due to the flight altitude of no more than 800 metres above the radar antenna.

During the analysis carried out, an incorrect orientation of the radar's magnetic north was detected. The aircraft position parameters determined by the radar were shifted to the right side of the coordinate system relative to the position coordinates determined by the GPS receiver. The reason for the occurrence of this error can be attributed to the fact that the annual correction of the magnetic declination, which is currently 8'E was not taken into account. The value of magnetic declination has changed by about 0.67° from 2017, when the GCA 2000 started working at Deblin airport, until 2022, when the research flight was performed. The average absolute error of the azimuth determination is 0.57°. In order to determine the aircraft's azimuth more accurately, it would be necessary to update the magnetic north orientation each year.

The radar range when performing a departure to the northwest of Deblin airport was approximately 62.5 km when the aircraft was at an altitude of approximately 305 m above mean sea level. However, the distance at which the aircraft was detected on its return to EPDE airport was approximately 30.5 km, when flying at an altitude of approximately 381 m above mean sea level. This varied detection range was not influenced by the flight altitude. The likely reason was the terrain over which the research flight was performed and the presence of the Vistula River a short distance from the airport.

The occurrence of gaps in the detection of the aircraft by the GCA 2000 radar was influenced by the terrain between the radar and the aircraft. On departure, interruptions only occurred at distances greater than 45 km from the radar when there were changes in terrain. On arrival at Dęblin airport, the occurrence of gaps in detection may have been influenced by the changing terrain and the presence of a river in the flight area. Interruptions occurred during changes in terrain and at times when the path of the radar pulse crossed a river. The occurrence of interruptions in aircraft detection may have been caused by multipath and the phenomenon of interference of the direct signal with the signal reflected from the terrain and terrain obstacles.

## REFERENCES

Banaszek K., Malarski M., Dokładność pozycjonowania współczesnych systemów nawigacji satelitarnej a przepustowość portów lotniczych, "Logistyka" 2011, vol. 4.

Brzozowski M., Kołodziejska U., Problemy identyfikacji przeszkód powodujących przesłanianie wiązki radaru na przykładzie radaru meteorologicznego, WITU, Warszawa 2010.

Burbo K., Urządzenia radionawigacyjne, WSOSP, Dęblin 2004.

Byron E., Radar: Principles, Technology, Applications, Prentice Hall, INC., Upper Saddle River 1995.

 DOI: 10.55676/asi.v4i2.63

Ciećko A., Goś A., Krasuski K., Krześniak K., Accuracy analysis of aircraft positioning using real radar and GPS data, “Scientific Journal of Silesian University of Technology. Series Transport” 2022, vol. 116, DOI: https://doi.org/10.20858/sjsutst.2022.116.4.

Czekała Z., Parada radarów, Bellona, Warszawa 2014.

Dzwonkowski D., Goś A., Ćwiklak J., Krasuski K., Research and comparative analysis of the accuracy in determining the parameters of the position of aircraft by air traffic control radars Avia-W and GCA-2000, “Journal of KONBiN” 2022, vol. 52(2), DOI: 10.2478/jok-2022-0013.

Goś A., Charakterystyka porównawcza radarów AVIA i GCA-2000, [in:] Wybrane aspekty zabezpieczenia nawigacji lotniczej, ed. J. Ćwiklak, “Współczesna Nawigacja”, T. I, LAW, Dęblin 2019.

Goś A., Krasuski K., Model matematyczny wyznaczenia pozycji statku powietrznego na podstawie danych radarowych, [in:] Wykorzystanie technik nawigacyjnych w lotnictwie. Część I, ed. M. Grzegorzewski, “Współczesna Nawigacja”, T. III.

Ground Controlled Approach System GCA-2000 – Technical documentation, Van Nuys, USA, 2016.

https://www.flightradar24.com/how-it-works [access: 6.12.2022].

https://zbiam.pl/wp-content/uploads/2021/04/GCA-2000.jpg [access: 31.10.2022].

ICAO, Guidance Material on Comparison of Surveillance Technologies (GMST), edition 1.0, 2007.

ICAO, International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Aeronautical Communications Volume 1 Radionavigation Procedures, 2020.

Krasuski K., Lalak M., Gołda P., Mrozik M., Kozuba J., Analysis of the precision of determination of aircraft coordinates using EGNOS+SDCM solution, Archives of Transport, 2023, 67(3), https://doi.org/10.5604/01.3001.0053.7264.

Lacomme P., Hardange J.P., Marchais J.C., Normant E., Air and Spaceborne Radar Systems, William Andrew Publishing, LLC, Norwich, 2001.

Leick A., Rapoport L., Tatarnikov D., GPS Satellite Surveying, Fourth Edition, John Wiley&Sons, Inc., Haboken, New Jersey 2015.

Łydka A., Kwalifikacja przedsięwzięcia pod względem konieczności uzyskania decyzji o środowiskowych uwarunkowaniach dla przedsięwzięcia pn. Radar GCA-2000 - DĘBLIN, Gliwice 2015.

Meikle H., Modern Radar Systems, Artech House, INC., Norwood 2001.

Morris P.R., Powstanie radaru, PWN, Warszawa 1967.

Polak Z., Rypulak A., Awionika, przyrządy i systemy pokładowe, WSOSP, Dęblin 2002.

Skolnik M.I., Introduction to Radar Systems, 3rd Edition, McGraw-Hill, New York 2001.

Thales Navigation, MobileMapper Pro Technical Specifications, 2005.