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ANALYSIS OF THE ADS-B AIRSPACE MONITORING SYSTEM

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One of the most important aspects of flight safety is awareness of AC air position (AC is the short for aircraft*). The leading method of stating AC airspace location is the use of radar systems – primary, secondary, combined primary – secondary surveillance radars-though radar systems have significant drawbacks. However, at present, more advanced technologies are also in use, for example, ADS-B and multilateration. This article is focused on ADS-B broadcasting. Global coverage, low cost, great amount of obtainable information makes Automatic Dependent Surveillance – Broadcast a highly efficient system. Application of the method for AC air positioning is equally effective for helicopters, especially for those operated by special emergency services. As for the infrastructure of air navigation, the research in this sphere is focused on surveillance systems necessary for reliable control of increasing air traffic. The problem of better awareness of AC air position is still acute and has always been the object of extensive research. At present, home-manufactured civil aviation helicopters are practically never equipped with ADS-B transponders, and hardly ever use the available resources of transceiver-based surveillance systems. The objective of the analysis presented is to demonstrate the applicability of Flightradar system options, as well as implementation of ADS – B transponders for helicopter fleet. Operating surveillance systems like Flightradar may considerably increase flight safety by improving the awareness of helicopters current air position.*

Keywords: transponder, monitoring, aircraft (AC), aviation, flight safety, helicopter, airspace, control.

ИССЛЕДОВАНИЕ СИСТЕМЫ МОНИТОРИНГА ВОЗДУШНОГО ПРОСТРАНСТВА ADS-B

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Одним из важнейших аспектов в области безопасности полетов является осведомленность о местоположении воздушных судов (ВС). Основным методом определения местоположения ВС в пространстве является использование радарных систем: первичных, вторичных, совмещенных первично-вторичных обзорных радиолокаторов, но у радарных систем есть существенные недостатки. Однако сейчас используются и более современные технологии, например, такие как ADS-B и мультилатерация. В данной работе акцент будет нацелен на радиовещание ADS-B. Покрытие всей поверхности Земли, низкая стоимость, обширность предоставляемой информации делает автоматическое зависимое наблюдение – вещание крайне эффективной системой. Использование такого метода определения положения ВС является актуальным и для вертолетов, в особенности, состоящих в парке специальных служб. В области аэронавигационной инфраструктуры объектами исследования являются системы наблюдения, необходимые для безопасной организации растущих объемов воздушного движения. Проблема увеличения осведомленности местоположения ВС в пространстве является всегда актуальной и имеет обширное количество исследований в этой области. На данный момент отечественные вертолеты гражданской авиация практически не оснащаются ADS-B транспондерами, а также не используют доступные ресурсы следящей системы на базе этих приемопередатчиков. Целью исследования является обоснование применимости ресурсов системы Flightradar, а также оснащение парка вертолетов ADS-B транспондерами. Применение следящей системы, такой как Flightradar, позволит значительно увеличить безопасность полетов путем улучшения осведомленности о движении вертолетов в пространстве.

Ключевые слова: транспондер, мониторинг, ВС, авиация, безопасность полетов, вертолет, воздушное пространство, контроль.

Introduction. The awareness of AC air position is one of the most important aspects of flight safety. The leading method for AC air positioning is the use of radar systems: primary, secondary, combined primary – secondary surveillance radars, regardless of significant drawbacks of these systems [1; 2]:

1) No coverage of vast water areas and polar regions of the Earth.

2) No built-in mechanism for detecting invalid data in request or response signals.

3) The accuracy parameters are limited by the delay tolerance of the transponder, making the system unsuitable for aerodrome monitoring.

4) The high cost of radars hampers their promotion in hard-to reach regions.

However, there are such advanced technologies as ADS-B and multilateration. In the article, the main object of analysis is ADS-B radio broadcasting. Its characteristics – coverage of the entire globe, low cost, the amount of provided information – make automatic dependent surveillance-broadcast a highly efficient system. This AC air positioning method is also applicable for helicopters, in particular, for emergency helicopter fleet. This allows effective monitoring of helicopters operated in hard-to-reach areas, as well as carrying out efficient rescue operations [3].

When used for air-to-ground surveillance, ADS-B offers significant advantages in the way of flight safety compared to procedural air traffic control without radar surveillance. ADS-B data can be used in application of such automatic safety tools as short-term conflict-warning signals, ATC instructions of keeping the cleared flight level, of keeping to the routing line, warnings of entering the danger area – all these increase the level of flight safety and airspace security. With the surveillance equipment, the air traffic controller has a much better picture of the environment [4; 5].

Mathematical method. Operation of Flightradar system is based on the map showing the planes that are currently airborn.

ADS-B functions demonstrate application of various methods and frequencies, in particular, the extended 1090 MHz squitter, as well as the universal access transceiver (UAT) (978 MHz) and a VHF digital link (VDL) of mode 4 (118–137 MHz).

Considering that ADS-B messages are radio-transmitted, they can be read and processed by any suitable receiver. Consequently, ADS-B is able to support both the ground function and the ASA function.

To receive and process ADS-B messages, ground surveillance stations are set up. In case of on-board versions, aircraft equipped with ADS-B receivers can process messages from other aircraft in order to determine their air position [6].

Attitude and speed data are transmitted twice per second. The aircraft identifying code is transmitted every five seconds. The ADS-B extended squitter (ES) transmission is integrated in many S-mode transponders, although that can also be performed by a transponder without the S mode. This analysis below concerns the introduction of certain technical solutions for the systems of AC monitoring in flight, with subsequent assessment of the performed modernization. The methods of carrying out AC modernization, the validity of decisions, the efficiency assessment are presented in the form of recommendations.

The radar refresh rate is one message in 4 s, the ADS-B rate – 0.5 s, and the RTK – 0.2 s. So, within the same time interval, more messages will be transmitted through the RTK than by means of the radar and the ADS-B, and radar messages will be least frequent [7; 8].

The data must be synchronized in order to obtain the accuracy of radar and ADS-B, and to compare the performance of radar and ADS-B. For this, the asynchronous multi-surveillance data must be extrapolated to keep pace with each other. The synchronization progress of ADS-B, radar and RTK is shown in fig. 1.

First, it should be noted that the time is just the same for the ADS-B data, the radar data, and the basic data.

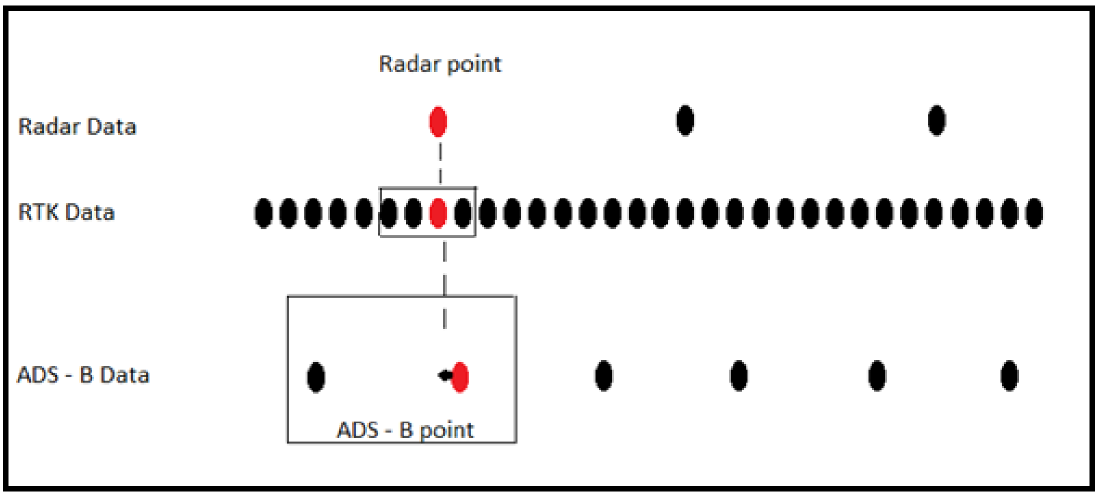

Fig. 1 The ADS-B, radar and RTK data synchronization progress

Рис. 1 Прогресс синхронизации ADS-B, РЛС и РТК

Then one can process the rest of the ADS-B data, the radar data and the basic data, so that they all are synchronized. Then, the following steps are performed [9]:

1) For the radar data, the reference time registered in the radar data is extracted, and the time T1 is marked.

2) The reference time registered in the initial data as the closest to T1 is extracted, and marked as T2.

3) Then, the location message (LA1, LO1), velocity message (V1) and heading message (H1) from T1-related radar data are received. The heading is determined as the angle between the AC flight direction and the true north heading, and H1 is taken from the radar messages of the radar station. This initially results from calculating the angle between the target and the antenna beam guidance.

4) This way, an extrapolated message of location (LA1E, LO1E) related to (LA1, LO1), V1 and H1 can be obtained.

The expressions are as follows:

$$\begin{cases} LA1E = LA1 + (T_2 - T_1)V_1 \cos H_1, \\ LO1E = LO1 + (T_2 - T_1)V_1 \sin H_1. \end{cases} \quad (1)$$

5) Further, the reference time registered in the ADS-B data as the closest to T2 is extracted, and marked as T3.

6) Then, the data on location (LA3, LO3), velocity (V3), and heading (H3) related to T3 are received from the ADS-B. H3 is taken from the ADS-B messages supplied by the station. Initially it was obtained from the navigation data source, and it is more accurate than the radar data.

7) An extrapolated message of location (LA3E, LO3E) related to (LA3, LO3), V3 and H3 can be obtained.

The expressions are as follows:

$$\begin{cases} LA3E = LA3 + (T_2 - T_3)V_3 \cos H_3, \\ LO3E = LO3 + (T_2 - T_3)V_3 \sin H_3. \end{cases} \quad (2)$$

In the radar data, the location message is expressed in polar coordinates, and the ADS-B data location message is expressed in WGS-84 coordinates. To compare the ADS-B data and the radar data, it is necessary to convert the polar coordinates to WGS-84 coordinates [10]. The conversion method presumes that, first, the oblique range, deviation angle and altitude are extracted from the radar data; next, the relative longitude and latitude of the radar station is calculated; finally, the sought longitude and latitude are obtained by adding relative longitude and latitude to the longitude and latitude of the radar station.

It is assumed that (φ, η) represent the longitude and latitude of the radar station, (latitude, longitude) are the latitude and longitude of the plane, (α, β) are the relative longitude and latitude of the radar station, h is the level of the plane, r is the oblique range, and θ is the deviation angle.

Transformation expression for latitude:

$$\begin{cases} \sqrt{r^2 - h^2} \cdot \cos\theta = R \cdot (\alpha \cdot \dfrac{\pi}{180}), \\ latitude = \alpha + \varphi. \end{cases} \quad (3)$$

Transformation expression for longitude:

$$\begin{cases} \sqrt{r^2 - h^2} \cdot \sin\theta = R \cdot \cos(latitude) \cdot (\beta \cdot \dfrac{\pi}{180}); \\ longtitude = \beta + \eta. \end{cases} \quad (4)$$

It becomes obvious that the error between the position derived from the above expressions and the actual position is considerable, because the Earth is regarded as perfectly spherical, regardless of the problem of its eccentricity (the Earth is actually an ellipse). Hence, we improve the method [11; 12]:

1) The Earth coordinates issued by the radar station are converted to the Earth-centered and fixed (ECEF) coordinates;

2) The oblique range, deviation angle and altitude are extracted from the radar data in order to calculate the Cartesian coordinates of the plane;

3) the Cartesian coordinates of the plane are converted to ECEF coordinates;

4) the ECEF coordinates are converted to WGS-84 coordinates.

The expressions for making these conversions are as follows:

1) Expressions for converting the Earth coordinates to ECEF coordinates:

$$\begin{cases} x_r = (c + H_r)\cos L_r \cos\lambda_r; \\ y_r = (c + H_r)\cos L_r \sin\lambda_r; \\ z_r = (c(1 - e^2) + H_r)\sin L_r, \end{cases} \quad (5)$$

where (L_r, λ_r, H_r) – Earth coordinates of the station radar; (x_r, y_r, z_r) – ECEF coordinates; e – oblique range

$$c = \frac{E_q}{\sqrt{1 - e^2 \sin(2L)}} \quad (6)$$

where E_q – Earth radius.

2) Expressions for converting polar coordinates to Cartesian coordinates:

$$\begin{cases} x_n = r\cos\eta\cos\theta; \\ y_n = r\cos\eta\sin\theta; \\ z_n = r\cos\eta, \end{cases} \quad (7)$$

where (r, θ, η) – polar coordinates of the plane; (x_n, y_n, z_n) – Cartesian coordinates.

3) Expressions for converting Cartesian coordinates to ECEF coordinates:

$$\begin{cases} X_{rt}(k) = X_r + RX_{rl}(k); \\ R = \begin{bmatrix} -\sin\lambda_r & -\sin\lambda_r \cos\lambda_r & \cos L_r \cos\lambda_r \\ \cos\lambda_r & -\sin L_r \sin\lambda_r & \cos L \sin\lambda_r \\ 0 & \cos L_r & \sin L_r \end{bmatrix}; \\ x_{rt}(k) = \left[x_{rt}(k) y_{rt}(k) z_{rt}(k)\right]^2; \\ x_r = \left[x_r y_r z_r\right]^T. \end{cases} \quad (8)$$

where $X_{rt}(k)$ – ECEF coordinates of the plane; $X_{rl}(k)$ – Cartesian coordinates of the plane; x_r – ECEF coordinates of the radar station; L_r, λ_r – longitude and latitude of the radar station.

4) Expressions of ECE coordinates through Earth coordinates:

$$\begin{cases} r=\sqrt{x^2+y^2}; \\ a=(r^2-A^2e^4)/(1-e^2); \\ b=(r^2-A^2e^4)/(1-e^2); \\ q=1+13.5z^2(a^2-b^2)/(z^2-b)^2; \\ p=\sqrt[3]{q+\sqrt{q-1}}; \\ t=(z^2+b)(p+p^{-1})/12-b/6+z^2/12; \\ L=\operatorname{arctg}\left\{[z/2+\sqrt{t}+\sqrt{z^2/4-b/2-t+az/(4\sqrt{t})}]/r\right\}; \\ \lambda=2\operatorname{arc\,tg}[(\sqrt{x^2+y^2}-x)/y], \end{cases} \quad (9)$$

where (x, y, z) – ECEF coordinates of the plane; (L, λ, H) – Earth coordinates of the plane; A – Earth semi-axis.

Accuracy assessment. To assess accuracy, taking the radar and the reference point data of the same time, we can obtain the distances between the synchronized ADS-B and the reference point data, and the distance between the synchronized radar and the reference point data. From the results of three flight tests performed, we can obtain the data presented in fig. 2.

The X coordinate is the error packet, and the Y coordinate is the percentage of the message. The ADS-B data are shown in blue and radar data – in red. Obviously, the ADS-B message volume is greater than that of the radar in a limited error packet, and it is less in a larger error packet, so we can conclude that the accuracy of the ADS-B data is higher than that of the radar data [13].

To present the ADS-B system in a more illustrative way, certain researches of Chinese scientists were taken as the source of data. Observations were performed at Chengdu ground station.

Accumulation of ADS-B data reports from Chengdu ADS-B ground station for flight tests helps to determine the NUC distribution. As well, in case of collecting the ADS-B reports from Chengdu ADS-B ground station for about 40 days, we can determine the NUC distribution shown in fig. 3.

The number of reports received from Chengdu ADS-B ground station amounts to 41,776,974. The x-coordinate shows the value of NUC, and the y-coordinate – the percentage of the message. The red bar indicates a report that cannot meet the requirements of the radar service, and the green bar indicates a report that meets these requirements [14]. Chengdu ADS-B ground station data integrity assessment is presented in fig. 4. Most reports where NUC is larger than 4 comply with the requirements of the radar service, and most of the messages with NUC being 6 and 7 are of high quality.

Conclusion. For Russia, it is especially important to apply ADS-B for helicopters of the Ministry of Emergency Situations. This will improve the efficiency of rescue operations, awareness of the aircraft operation in remote areas. For example, in Canada and the United States, oil companies actively use ADS-B – equipped helicopters for flights to offshore oil rigs; the same is quite acceptable for Russian distant oil platforms [15].

The above-presented method meets most requirements. Using Flightradar surveillance system will increase flight safety. When the system employs ADS-B transmitters, the coverage area extension becomes incomparably cheaper than the cost of deploying radars. As the installation of transmitters in helicopters presents no difficulty, the improvement can be made without significant engineering changes.

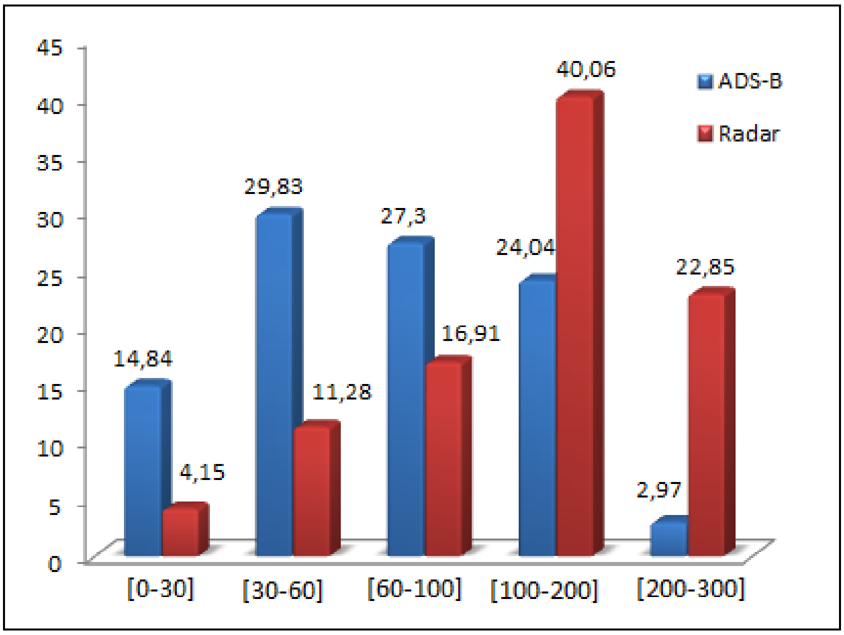

Fig. 2. The results of the accuracy evaluation of the ADS-B data in three flight tests

Рис. 2. Результаты оценки точности данных ADS-B в трех летных испытаниях

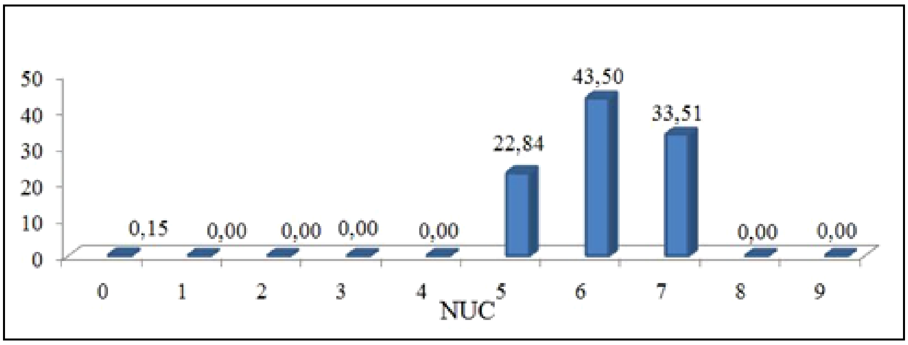

Fig. 3 Assessment of ADS-B data integrity

Рис. 3. Оценка целостности данных ADS-B

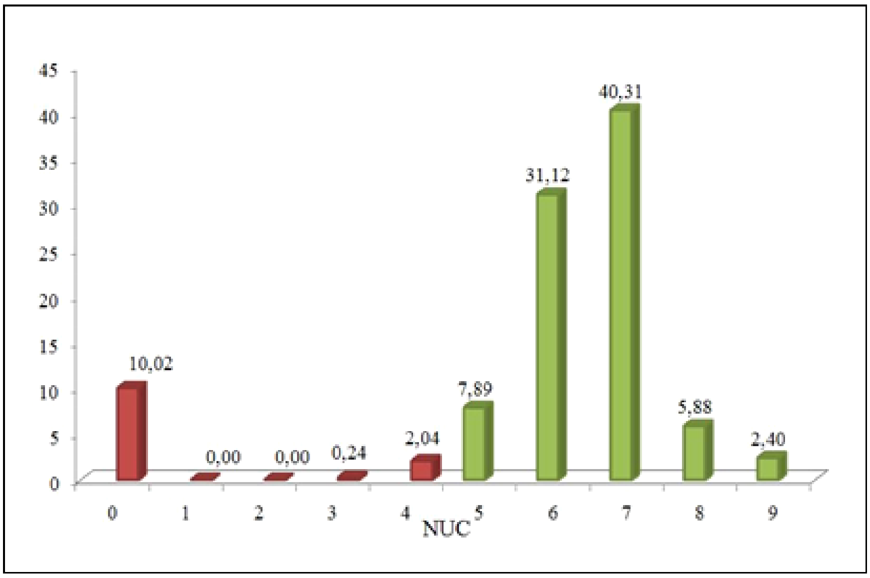

Fig. 4. Assessment of ADS-B data integrity (data of Chengdu ground station)

Рис. 4. Оценка целостности данных ADS-B наземной станции в Чэнду

The efficiency of the surveillance system is substantiated by the given comparative analysis. The general part is a review of the Flightradar system and the basic ADS-B transponder it employs; there is also a review of alternate data sources that can be processed by this surveillance system.

References

1. Lachapelle G. Navigation Accuracy for Absolute Positioning, AGARD Lecture Series 207. *System Implications and Innovative Applications of Satellite Navigation*. NATO, 1996, P. 4.1–4.10.

2. Kartsan I. N. [Method of positioning errors elimination along with operating navigation systems]. *Vestnik SibGAU*. 2008, No. 3 (20), P. 101–103 (In Russ.).

3. Weston J. L. Basic Principles Lf Strapdown Inertial Navigation Systems. Strapdown Inertial Navigation Technology. *Radar, sonar, navigation and avionics.* 2004. Ch. 3. P. 17–59.

4. Bochkarev V. V., Kryzhanovskiy G. A., Sukhikh N. N. *Avtomatizirovannoe upravlenie dvizheniem aviatsionnogo transporta* [Automated control of air traffic]. Moscow, Transport Publ., 1999, 319 p

5. Tanjila F. Performance Analysis of Low Earth Orbit (LEO). Satellite Link in the presence of Elevation Angle, Fading, And Shadowing. Bangladesh, BRAC University Publ., 2009, 66 p.

6.Minimum operational performance standards for air traffic control radar beacon sestem/modeselect (atcrbs/mode S). *Airborne equipment*. 2008, Vol. 1.6, 534 p.

7. Mohammad A. Ayoubi, Aircraft ADS-B Data Integrity Check. *Conference paper*. 2004, P. 12.

8. Dunstone G. ADS-B Technology basics. *Surveillance Program Lead Airservices.* Australia, 2010, P. 33.

9. Sukkarieh S. Low Cost, High Integrity Aided Inertial Navigation Systems For Autonomous Land Vehicles. Ph. D. Thesis Univ. of Sydney. 2000, 136 p.

10. Jun Zh., Wei L. Study of ADS-B Data Evulation. *Chinese Journal of Aeronautics*. 2011, P. 6.

11. Jun Zh., Wei L., Yanbo Zh. *Chinese Journal of Aeronautics*. 2011, Vol. 24, Iss. 4, P. 461–466.

12. Orlando V. ADS-B 1090 MOPS. Revision A. 2002, 74 p.

13. Nesenyuk L. P., Fateev Yu. L., Barinov S. P. [Integrated inertial satellite system of orientation and navigation with spaced receiving antennae]. *Giroskopiya i navigatsiya*. 2000, No. 4 (31), P. 41–49 (In Russ.).

14. Tony Delovski. ADS-B over satellite. The World's first ADS-B receiver in space. *Conference paper*. May 2014, P. 17.

15. *Demodulyator signala ADS-B* [Demodulator of ADS-B signal]. Available at: https://github.com/ chenggiant/dump1090-matlab (accessed: 10.11.2019).

Библиографические ссылки

1. Lachapelle G. Navigation Accuracy for Absolute Positioning, AGARD Lecture Series 207, *System Implications and Innovative Applications of Satellite Navigation*. NATO, 1996. P. 4.1–4.10.

2. Карцан И. Н. Метод исключения ошибок определения местоположения при одновременном использовании навигационных систем // Вестник СибГАУ. 2008. № 3 (20). С. 101–103.

3. Weston J. L. Basic Principles Lf Strapdown Inertial Navigation Systems. *Strapdown Inertial Navigation Technology*. 2nd ed. // Radar, sonar, navigation and avionics. 2004. Ch. 3. C. 17–59.

4. Бочкарев В. В., Крыжановский Г. А., Сухих Н. Н. Автоматизированное управление движением авиационного транспорта. М. : Транспорт, 1999. 319 с.

5. Tanjila F. Performance Analysis of Low Earth Orbit (LEO) *Satellite Link in the presence of Elevation Angle, Fading, And Shadowing*. Bangladesh : BRAC University publ., 2009. 66 p.

6. Minimum operational performance standards for air traffic control radar beacon sestem/modeselect (atcrbs/mode S) // Airborne equipment. 2008. Vol. 1.6. P. 534.

7. Mohammad A. Ayoubi, Aircraft ADS-B Data Integrity Check // Conference paper. 2004. 12 p.

8. Dunstone G. ADS-B Technology basics. Surveillance Program Lead Airservices. Australia, 2010. P. 33.

9. Sukkarieh S. Low Cost, High Integrity Aided Inertial Navigation Systems For Autonomous Land Vehicles : Ph. D. Thesis Univ. of Sydney. 2000. P. 136.

10. Jun Zh., Wei L. Study of ADS-B Data Evulation // Chinese Journal of Aeronautics. 2011. Vol. ??? P. 6.

11. Jun Zh., Wei L., Yanbo Zh. Название статьи? // Chinese Journal of Aeronautics. 2011. Vol. 24, Iss. 4. P. 461–466.

12. Orlando V. ADS-B 1090 MOPS. Revision A. 2002. P. 74.

13. Интегрированная инерциальная спутниковая система ориентации и навигации с разнесенными приемными антеннами / Л. П. Несенюк [и др.] // Гироскопия и навиагация. 2000. № 4 (31). С. 41–49.

14. Tony Delovski ADS-B over satellite. The World's first ADS-B receiver in space // Conferencepaper. May 2014. P. 17.

15. Демодуляторсигнала ADS-B [Электронный ресурс]. URL: https://github.com/chenggiant/dump1090-matlab (дата обращения: 10.11.2019).

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