UDC 621.391.266, 517.972.8 DOI: 10.30748/nitps.2018.33.04

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PERSPECTIVE DIRECTION OF THE DEVELOPMENT OF ON-BOARD NAVIGATION SYSTEMS OF AIRCRAFT FOR THE ARMED FORCES OF UKRAINE

The problematic issues concerning the main ways of aircraft on-board navigation systems creating that are invariant to the influence of interference with signals of satellite navigation systems, increase of the efficiency of navigation and guidance of aircraft in the conditions of their suppression, the complex application of navigation systems based on a free-form inertial system and a correlation-extreme navigation system with the use of the Earth geophysical fields are considered as well as the priority research subjects are given. The state and level of work development in the field of navigation and coordinate-time support of leading countries of the world and requirements of NATO standards for navigational support are considered.

Keywords: *navigational support, satellite navigation system, without-platform inertial navigation systems, correlation-extreme navigation system.*

Introduction

Development of geopolitical processes in the late XX – early XXI century substantially changed the ways of the leading countries of the world to the use of armed struggle and armed forces for the achievement of the military and political goals and led to a significant transformation of the content of armed struggle. As shown by the analysis of local wars and regional armed conflicts, the main features of the transformation of the content of armed struggle in the late XX and early XXI centuries is the appearance of a new concept of military action in a single information space using joint information control networks, the concept of the so-called "Network Centric Warfare" and its various alternatives such as "Network Centric Capability", "Network Enabled Capability", "Network Enabled Warfare", "Info-Centric Warfare", "Network Centric Operations", "Networked Based Defense".

One of the features of hybrid wars is the massive destruction of radio electronic means of radio communication, radar stations, navigation systems of weapons and military equipment [1–2].

The most vulnerable in such a situation are navigation and communication control systems, built on the "classic" schemes.

At present, the without-platform inertial navigation system (WPINS) is used as the main subsystem of the navigational complex (NC) of aircrafts (A/C). Global navigation satellite systems (GNSS) are widely used as an additional tool that corrects the WPINS navigation solution as well as allows limit the growth of WPINS errors. However GNSS systems those are vulnerable to accidental and intentional interference, such interference endangers security and can have serious consequences [2; 9–12].

Therefore, the problem of taking into account the state and level of development of radio-electronic warfare (REW) means is acute, and by developing the A/C navigation system (NS) it is necessary to take into consideration the development of REW technology in the direction of navigational wars in modern armed conflicts and local wars.

The studies on this issue are carried out in the interests of the Armed Forces of Ukraine, but unfortunately they are not systematic and do not fully meet the requirements and needs of the Armed Forces of Ukraine. Thus, the scientific and technical support of works on the equipment of navigation and radio communication systems in accordance with the requirements and standards of the ICAO / NATO aircraft designated for participation in NATO training and operations under the Partnership for Peace program is being carried out.

The aim of this work. The purpose of the article is to determine the main ways of increasing the aircraft navigation and guidance efficiency in conditions of suppression or absence of signals from satellite navigation systems, the integrated application of NS on the basis of WPINS and correlation-extreme navigation system using the Earth's geophysical fields (GPF), which, unlike the existing ones, allow to determine the location and guidance of the Armed Forces of Ukraine with the given level of accuracy in the absence or suppression of satellite navigation signals.

The main material

As the [1–2; 4; 10] analysis shows, the main directions of the development of means of armed struggle in the airspace are:

a) development of military aviation complexes and means of support of the general and special aviation flights:

– the creation of multifunctional reconnaissance-strike aviation complexes capable of interacting with each other, striking air and ground targets, determining and transmitting the coordinates of terrestrial and aerial targets to ground-based control points in real time with the possibility of flying at supersonic speeds at the cruise control mode, low visibility in the whole range of wavelengths, all-angle weapons use and maneuverability;

– modernization of existing aviation equipment by replacing avionics and engines, the continuation of the assigned resources, ensuring the possibility of using a wider range of aviation means of damage;

– improvement of navigation and sighting systems, aviation controlled means of destruction of combat aviation complexes through the use of more effective methods of guidance, the implantation of the on-board expert intelligent flight and weapons control systems, and the integration of targeting systems;

– improvement of the intelligence equipment of combat aircraft complexes and ground-based means of the air reconnaissance results processing;

– increasing of aviation-controlled means of destruction range used in combat aircraft complexes;

– improvement of the supply of general and special aviation flights, means of communications and radio technical support of aviation flights, introduction of aviation simulators and simulation equipment;

– mass development and introduction into the systems of OVT complexes on the basis of barely noticeable and visible unmanned aerial vehicles (UAV) designed to solve different problems (from the conducting the all-weather intelligence to the hidden use of various types of advanced high-precision weapons).

UAVs are considered as one of the most important means of increasing the combat capabilities of the armed forces. According to the military experts of NATO countries, the UAV combat use is preferred in the conduct of missions, characterized by long duration of the flight of increased complexity.

Since the signals from the GNSS satellites are easily subjected to blocking or substitution [2; 4; 10–11], then when designing a special purpose UAV, the availability of the systems of a precise autonomous positioning is vital, duplicating the position control systems of the UAV of defense and civilian purpose will prevent the consequences of terrorist information attacks [4; 11]. In accordance with the concept of "network centric war", the radio-navigation conflict is a part of the information warfare and corresponds to a purposeful confrontation with radio-navigation systems and electronic warfare (REW) complexes.

The analysis of contemporary views on the role and place of the REW in providing of information superiority in the different zones of warfare and their actions in regional conflicts suggest that the means and complexes of radio-electronic suppression (RES) are currently used. They operate in frequency bands of the navigation module of the integrated complex NS A.

The task of creating autonomous navigation and guidance systems that satisfy the set of requirements in terms of globality, autonomous accuracy, secrecy and noise-immunity is solved by creating a correlation-extreme navigation and guidance system (CENGS) with the integrated use of information about the surface and spatial GPF of the Earth. For the present the practical application has been found by CENGS on surface fields - relief of the earth's surface (RES), radar (RLC) and optical contrast (OC) [6; 7–10].

The achievement of the necessary parameters of the A/C NS concerns the critical military technologies of the Ministry of Defense of the USA on the development and creation of UAV of the special purpose [12–17] and includes:

– unified navigational complexes on gyroscopes (ring laser, optical fiber, etc.), working in the complex with a interference-protected space radio navigational system;

– high-precision navigation modules and passive navigation modules (altimeters with accuracy not worse than ± 5%, at any altitude and speed of the aircraft above 150 m / sec, etc.)

– software of the UAV autonomous flight control (low-level flight with fly-around the ground obstacles);

– providing with maneuvering on the flight path from possible fire and electronic counteraction;

– changing of the flight profiles with the operational change of combat task.

The main documents of long-term planning in the field of development of UAV and their control systems for the NATO Air Force are:

– U.S. Air Force Unmanned Aircraft Systems Flight Plan, 2009-2047, 18 May 2009;

– U.S. Air Force Chief Scientist Report on Technology Horizons: A Vision for Air Force Science and Technology during 2010-2030, 15 May 2010.

NATO Standards for UAV Management Systems:

STANAG 4609/AEDP-8. NATO Digital Motion Imagery Format – www.nato.int/structur/AC/224/standard/4609/4609.htm. The main requirements for the speed of data transmission from the on-board UAV sensors are formulated.

STANAG 7023/AEDP-9. NATO Primary Image Format – www.nato.int/structur/AC/224/standard/7023/7023.htm. The format of the data streams transmitting from the UAV board is regulated in the AEDP-9 Standard and Manual.

STANAG 4607/AEDP-7. NATO Ground Moving Target Indicator Format. (GMTIF) – www.nato.int/structur/AC/224/standard/4607/4607.htm.

The control system of one or more UAV includes the following contours:

– contour (main) of control-piloting;

– navigation contour-routes, fly-around the ground obstacles, the time to hit the target, arrival at the designated point;

– contour of intelligence, surveillance and preliminary reconnaissance;

– the contour of the control of service and assessment of the systems state.

The use in the navigational contour of the on-board NS A, which is invariant to the influence of obstacles, will allow realizing the principle of situational control of the UAV.

In addition, the use of the GPF of the Earth, the Correlation-Extreme Navigation System (CENS) does not require the costs for operation and restoration of navigation fields.

A characteristic feature of CENS is the high degree of integration in the existing on-board radio-electronic equipment (OREE). CENS is mainly implemented as one of the modes of operation of OREE on the basis of already available computing facilities, on-board devices and sensors.

An important document outlining the technical requirements for navigation systems for geophysical fields is the list of US critical military technology – MILITARILY CRITICAL TECHNOLOGIES LIST 2014 (MCTL-2014) [17].

Section 16 Positioning, navigation and time technology contains information on passive navigation and guidance systems based on the magnetic and gravitational fields of the Earth: Section 16.4 is devoted to magnetometers and magnetic gradiometers of various types. The accent is made on a superconducting quantum interferometer (SQUID), nuclear magnetic resonators (NMR), magnetometers based on the Overhauser's effect, thin-film magnetic resonators (MR), magnetometers with optical magnification.

The CENS of surface and potential GPF is essentially the only alternative to GNSS. With the vast majority of applications practically equal with GNSS, the potential for the accuracy, versatility, low cost of user equipment, CENS exceeds the GNSS in a number of other fundamentally important indicators. CENS, having a practically complete and high degree of autonomy, are able to provide higher levels of safety, traffic stability and reliability, compared to satellite NS. CENS are oriented towards the real earth's surface, which gives advantages in combat operations, flights at low altitudes and in solving other tasks. The qualitative comparison of the GPF is given in tabl. 1. The measured parameters of the spatial fields are [6–7]:

– components of acceleration of gravity for the magnetic field of the Earth (MFE) – the module of the magnetic induction vector and components of the vector (northern, eastern and vertical);

– for the gravitational field of the Earth (GFE) – the first derivative of the gravipotential (with 9 components of the gradient of gravity) and the second derivative of the gravipotential;

– for the electromagnetic field of the Earth (EMFE) – spectral "portraits" of the A/C are associated with their electrification, spectral "portraits" of ground radiation sources – with well known coordinates of the Characteristics of the state and levels of development of the works in the field of navigation and coordinate-time assurance under the GPF [6–7; 17–18] are given in tabl. 2.

Table 1

Comparison of correlative-extreme navigation systems

Characteristics	Classification by purpose (object of measurement)				
	Terrain topography	Radar and thermal field	Optical field	Gravitational field	Magnetic field
The principle of measurement	Altimeter	Locators	Photo matrixes	Gravimeter, gradiometer	Magnetometer
Accuracy of digital maps, m	50	25	10	250	250
Advantages	Field stability, informational content , easiness of measurement	Possibility of correction by the parts of the area at a large distance from the aircraft	High accuracy	High stability	Ability to get three components of coordinates
Performance in all weather conditions	+	+	+	+	+
Disadvantages	Does not work on flat terrain, the influence of radio interference and the angular position of the aircraft	Crude algorithms, the need for operator involvement, difficulties in the preparation of standards	Work in the visible range, instability during the day and season	Complexity of measurement	A large number of detachable influences

Table 2

Characteristics of the state and level of development of works in the field of navigation and coordinate-time support

Thematic scientific and technological directions	The USA	Great Britain	France	Germany	Japan	China	Russia
Inertial Navigation Systems (INS) and their elements							
Autonomous INS	****	***	****	****	***	***	***
Integrated INS (using information about the GPF and GNSS data)	****	***	****	****	***	***	***
Gyrocomplex INS (with the determination of reference azimuths by astronomical methods)	***	**	**	***	**	**	***
Annular laser gyroscopes	****	***	***	***	***	***	***
Fiber optic gyroscopes	****	*	***	***	***	**	***
Gyroscopes and accelerometers based on microelectromechanical systems technologies	****	***	***	***	***	**	**
Accelerometers based on new physical principles	****	***	***	***	***	***	**
Accelerometers based on the technologies of nanoelectromechanical systems	*	*	*	*	*	*	*
Gravimeters and gravity gradiometers							
Gravimeters of absolute values	****	****	****	**		****	***
Gravimeters of relative values	****	****	****	**		****	***
Gravitational gradiometers	****	****	****	****		****	****
Radio navigation systems and their components							
GNSS	****	****	****	**	****	**	****
Differential radio navigation systems based on satellite systems	****	****	****	**	****	**	****
Complex non-inertial radio navigation systems	****	****	****	****	****	****	****
Radio altimeters with low energy radiation	**	***	**	**	**	*	**
Information databases for navigation systems (digital terrain maps, databases about the GPF)	***	***	***	***	***	**	**

**** –high; *** –substantial; ** – insignificant; * – limited or low.

For the GPF of the Earth of the different physical nature is characterized by a virtually unequivocal correspondence of the distribution of field parameters of a specific place on the Earth's surface. The Earth's surface is uniquely characterized by the distribution on the surface or in the space of the GPF, namely the difference in heights, vegetation, soils with different properties, rocks with different magnetization and conductivity, temperature, etc. This allows each point of the Earth's surface in any coordinate system to match certain, in quantitative sense, physical values that allow the possibility of measuring them.

The structure of one of the alternatives of construction CENGS-CENS with the point-probing of relief of the Earth's surface is presented in fig. 1.

It consists of:

– INS, miscalculations of the coordinates of the spatial position of the aircraft, which increase over time;

– relief field sensor, special computing device, bank of cartographic information form parts of the extreme coordinator.

The field sensor includes:

– radio altimeter (RA) measuring the distance to the underlying surface vertically;

– barometric altimeter (BA) measuring the altitude of the aircraft relative to the sea level or altitude at the take-off point;

– vertical channel of the INS, to control the rapid movement of aircraft in the vertical plane.

Fig. 2 shows the intersection of the relief field along the predictable by data of INS trajectory (1), the trajectory corresponding to the extremum position (2) and the actual trajectory (3). Before comparing the intersection, the fields are usually centered by sliding averaging or by calculating increase in heights at a certain interval (base of increase). The field sensor determines the height concerning sea level or ellipsoid equalization surface. In the special computing device, the measurements of the field with a given discreteness and the corresponding planar coordinates of the A/C according to the data of the INS (Λ^i,Φ^i) are recorded. Correspondingly to these coordinates, the reference values of Δh_k^{ijn} of the terrain altitudes in the area of the probable position of the aircraft are selected from the cartographic information database and compared by a certain criterion J (ΔΛ, ΔΦ) with the measured values of $\Delta h_{д}^{i}$i. Each measured value is associated with the M reference values that cover the area of possible INS errors.

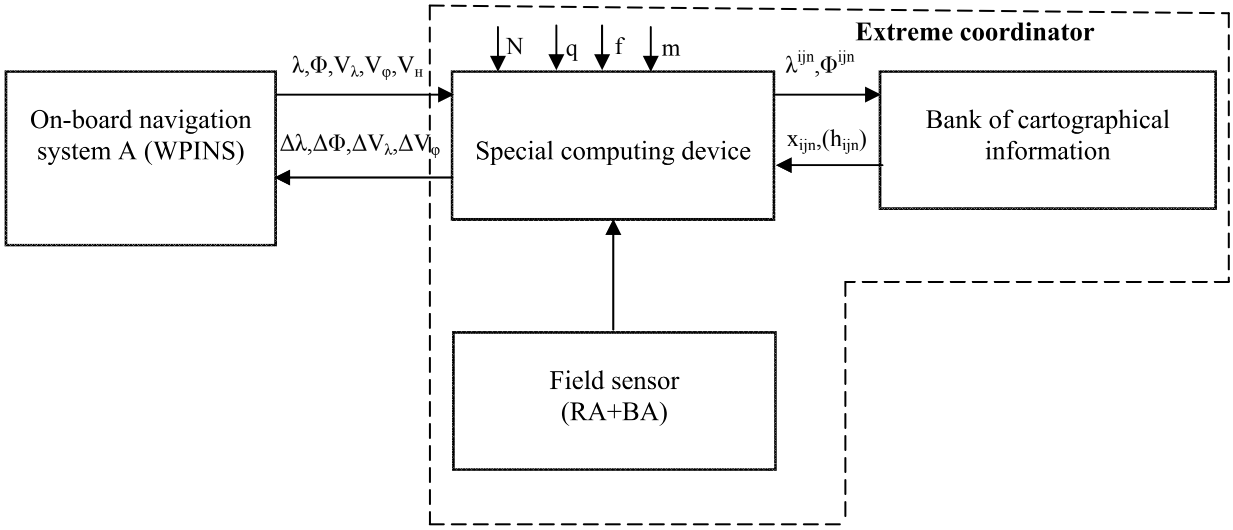

Fig. 1. Structure of CENS on terrain with point probing

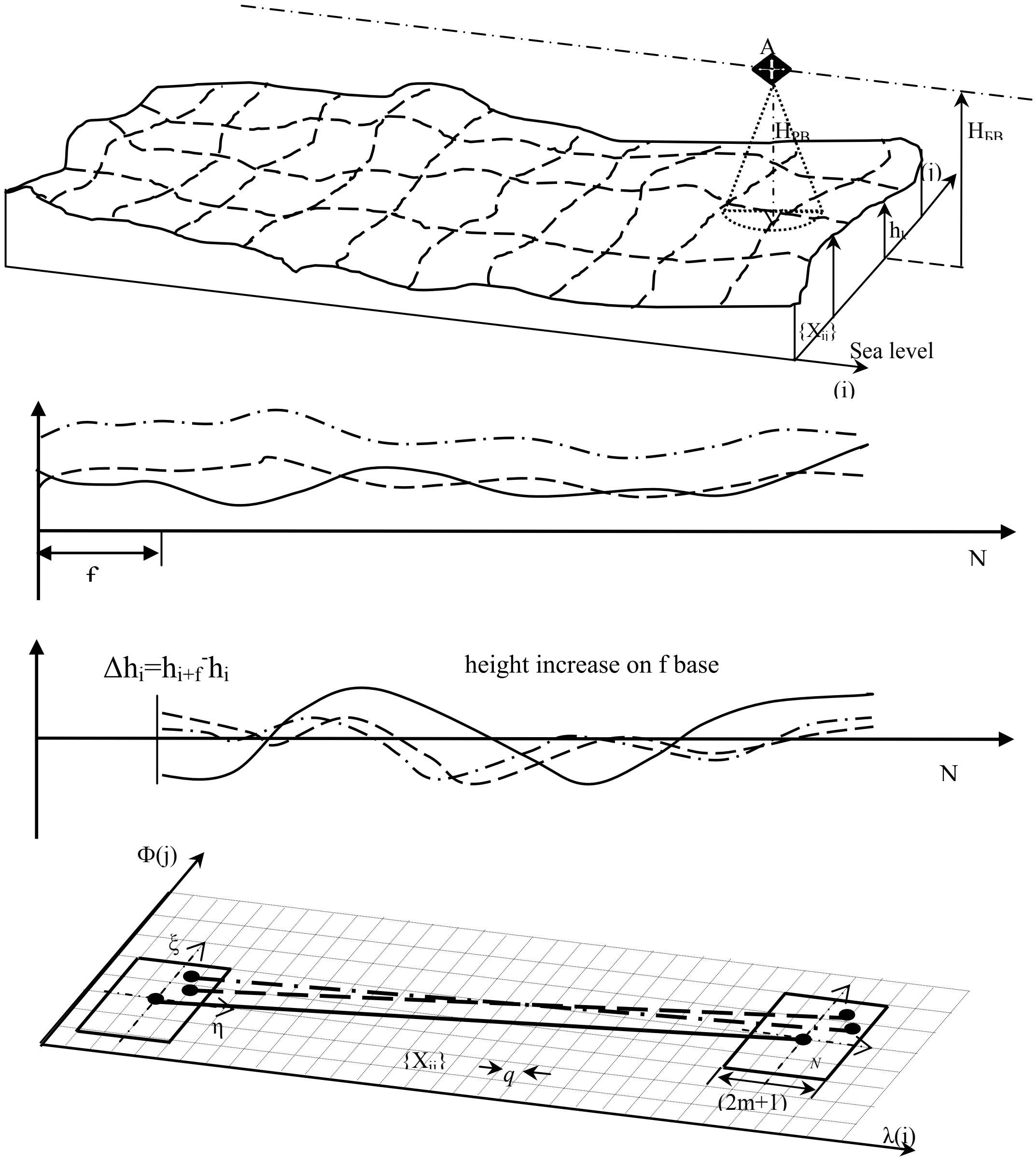

Fig. 2. Intersection of the relief field along the trajectory of the aircraft predicted from the INS data

By the results of comparison of the measured and reference values of the field, decisions are taken on the location of the aircraft and the corresponding errors of the INS. It is reasonable to use the complex navigation systems (for example, INS + CENS MB (MB – micron band) + CENS IB (IB – infrared band) + optical range CENS) to improve the quality of the sight-navigation complex of the aircraft, which will give the possibility of the adaptive application of different systems on different classes of ground objects and the possibility of ranking objects by degree of importance. Information sensors of navigation systems can be unified rows with operatively interchangeable functional elements.

Conclusions

Thus, the task of ensuring the operation of the A/C on-board NS in terms of natural and artificial interferences is a task which solution requires significant changes in the aircraft on-board NS and algorithms for data processing, derived from navigation measurements.

The use of the A/C integrated NS in terms of jamming of GNSS signals is critical.

Ways of the effectiveness growth of navigation and aircraft guidance in the appropriate conditions are the complex application of navigation systems based on the inertial navigation system and the correlation-extreme navigation system using the geophysical fields of the Earth.

The use of complex systems in the navigation loop structure based on the CENGS on the GPF of the Earth and the INS will make it possible to provide the A/C, including the UAV, with the necessary data for autonomous functioning under conditions of the enemy's use of the REW methods.

Navigation systems based on the inertial navigation system and the correlation-extreme navigation system allow the determination of the location and guidance of A/C of Armed Forces of Ukraine with assigned level of accuracy under conditions of satellite navigation signals absence or jamming.

The analysis of the capabilities of native factories capable of mastering the issue of such navigation devices showed that Ukraine has all the possibilities to develop and manufacture the domestic integrated navigation system for the needs of the Armed Forces of Ukraine, but they require further research to create a modern navigation support system of the Armed Forces of Ukraine.

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Received by Editorial Board 4.10.2018
Signed for printing 5.11.2018

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ПЕРСПЕКТИВНІ НАПРЯМКИ РОЗРОБКИ БОРТОВИХ НАВІГАЦІЙНИХ СИСТЕМ ЛІТАЛЬНИХ АПАРАТІВ ДЛЯ ПОТРЕБ ЗБРОЙНИХ СИЛ УКРАЇНИ

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Розглянуті основні напрями трансформації збройної боротьби на сучасному етапі і вплив засобів радіоелектронної боротьби на бортові навігаційні системи літальних апаратів та питання створення бортових навігаційних систем літальних апаратів. Показана необхідність створення бортових комплексованих навігаційних систем літальних апаратів інваріантних до дії перешкод сигналам глобальних супутникових навігаційних систем. Розглянуті напрями розвитку засобів збройної боротьби в повітряному просторі і шляхи підвищення ефективності навігації і наведення літальних апаратів з урахуванням можливостей придушення навігаційних сигналів, стану і рівню розвитку робіт в області навігації і координатно-часового забезпечення провідних країн світу та вимоги стандартів НАТО до навігаційного забезпечення застосування навігаційних систем на базі бесплатформної інерціальної і кореляційно-екстремальної навігаційної систем по геофізичним полям Землі. Показана актуальність створення комплексованих систем навігації і наведення, які задовольняють вимогам по глобальності, автономності і точності, скритності і перешкодозахищеності, необхідності створення кореляційно-екстремальних систем навігації і наведення з використанням інформації про геофізичні поля Землі. Розглянуті документи і стандарти НАТО з вимогами до бортових навігаційних систем літальних апаратів і систем навігації по геофізичних полях. Приведена порівняльна характеристика кореляційно-екстремальних навігаційних систем по геоінформаційних полях Землі: геомагнітному, оптичному, радіолокації, тепловому і гравітаційному.

Ключові слова: *глобальна навігаційна система, бортова навігаційна система, геофізичне поле, кореляційно-екстремальна система навігації, інформаційні параметри геофізичних полів.*

ПЕРСПЕКТИВНЫЕ НАПРАВЛЕНИЯ РАЗРАБОТКИ БОРТОВІХ НАВИГАЦИОННЫХ СИСТЕМ ЛЕТАТЕЛЬНІХ АППАРАТОВ ДЛЯ ВООРУЖЕННЫХ СИЛ УКРАИНЫ

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Рассмотрены проблемные вопросы создания бортовых навигационных систем летательных аппаратов инвариантных к воздействию помех на сигналы спутниковых навигационных систем, пути повышения эффективности навигации и наведения ЛА в условиях их подавления и применения НС на базе БИНС и корреляционно-экстремальной навигационной системы геофизическим полям (ГФП) Земли. Рассмотрены состояние и уровень развития работ в области навигации и координатно-временного обеспечения ведущих стран мира и требования стандартов НАТО к навигационному обеспечению.

Ключевые слова: *глобальная навигационная система, бортовая навигационная система, геофизическое поле, корреляционно-экстремальная система навигации, информационные параметры геофизических полей.*