THE IMPROVEMENT OF METHODS AND PROCESSES TO ENSURE THE RELIABILITY OF RADIONAVIGATION SYSTEMS

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Abstract. *In the practice of flight, there continue to be cases of complete and functional failures of navigation sensors and computers, measurement errors of navigation parameters that go beyond permissible limits, as well as various violations in the functioning of the air navigation of flight support system. Such situations reduce the ability of navigation to meet the requirements for air navigation accuracy established in the given region, that is, they lead to a decrease in the navigation ability of aircraft.*

The technique of improving the integrated inertial-satellite radio navigation systems (ISNS) is considered, with the help of the proposed methodology, it was possible to form a unified series of ISNS for aviation facilities in the short and medium term.

Keywords: *failure, reliability, error, navigation sensors, inertial radio navigation system, gyroscope.*

INTRODUCTION

With the development and improvement of aircraft (AC), the complication and expansion of the flight tasks they perform, flight navigation instruments and systems developed and improved, which, with the introduction of high-performance computer technology into the onboard equipment, began to be combined into flight navigation systems (FNS). FNS is a logical consequence of the evolution of navigation and control systems and represents a qualitatively new degree in the automation of aircraft navigation. The FNS of a modern aircraft of any class includes several navigation systems, in particular, inertial (INS) and satellite (SNS) navigation systems. Due to the different physical nature and different principles of the formation of navigational algorithmic support, INS and SNS complement each other well, which naturally determined their integration into modern FNS. The joint use of these systems allows, on the one hand, limiting the growth of errors of a less accurate, but more informative inertial system, and on the other hand, to increase the rate of information output to onboard consumers, increasing the level of noise immunity and reducing the noise component of satellite system errors.

MATERIALS AND METHODS

For decades, the main direction in the development of navigation science has been the improvement of technical means of navigation, increasing their accuracy, reliability and functionality [1, p. 12].

Theoretical and experimental research methods were used in order to solve the research problems in the scientific work. Theoretical methods included the theory of designing digital and radio engineering systems, methods of statistical radio engineering. Also used the basic provisions of mathematical statistics, statistical analysis and linear algebra. To test the theoretical provisions, mathematical modeling and experimental studies using signal simulators, as well as full-scale tests under flight conditions, were applied.

RESULTS

One of the central ideas for the development of aircraft navigation equipment is the functional, information and hardware integration of navigation meters into an integrated navigation complex. Most aircraft have a number of navigation systems as part of their on-board equipment, among which the most common are radio systems: the equipment of radio engineering systems for near (RSNN) and far (RSFN) navigation systems, radar stations, heading-Doppler systems, satellite navigation systems (SNS), as well as autonomous non-radio engineering navigation systems. The main autonomous means of aircraft navigation are inertial navigation systems (INS), which are used on aircraft for various purposes. Heading-air systems are used on airplanes and helicopters equipped with heading systems and means for determining airspeed.

All aircraft also have means for measuring barometric and geometric flight altitude. On some aircraft, in addition, there is a data bank on the height of the terrain. Many navigation systems for moving objects include time sensors (on-board time standards). Combining (integrating) such equipment into a single functionally, structurally and constructively interdependent navigation complex allows for a better use of excessive information available on board the aircraft, which makes it possible to expand the range of tasks to be solved and improve the quality of their implementation. The purpose of the integration of navigation equipment is to combine various meters into a single navigation complex (NC), which has higher accuracy, noise immunity and reliability characteristics of navigation definitions compared to individual meters. An increase in the level and degree of integration of equipment as part of the navigation complex is manifested in the implementation of the following integration principles:

- combining the functions of various radio engineering systems, which leads to the emergence of conjugated systems and multifunctional integrated complexes;
- the combination of technical means that measure the same or functionally related navigational parameters. The communication of radio engineering systems, which often use complex radio signals, makes it possible to create multifunctional complexes that have attractive design and operational characteristics.

When implementing the first principle of integration, multifunctional radio engineering systems are created based on existing single-functional communication and navigation systems. An example of such integration is the combined satellite navigation system GPS / GLONASS, as well as the integration of SNS with radio systems of short and long-range navigation. With the second principle of integration, joint (complex) processing of information from several devices or systems of the navigation complex is carried out, which determine the same or functionally related navigation parameters. For example, with the help of INS, RSNN, RSFN, SNS and other meters, it is possible to find the location coordinates and speed of the consumer with a certain redundancy. The ultra-high accuracy of the SNS in determining navigation parameters makes it the most attractive for integration. The progress in satellite navigation has accelerated sharply due to the creation of not only American (GPS) and Russian (GLONASS) satellite systems, but also with the connection of the European Union countries to the development of a common network of satellite systems (EGNOS, Galileo projects). This has led to the emergence of an entire industry for the production of satellite navigation systems for a wide variety of applications. At the same time, the use of these systems for the tasks of navigation and flight control of the aircraft is clearly not enough. The current practice of creating and using integrated navigation systems is based on the use of integrated inertial satellite navigation systems (ISSN). At the same time, ISSN can, in turn, be integrated with barometric or radio altimeters and other onboard meters.

DISCUSSION

SNS belong to the class of radio navigation systems - satellite radio-navigation systems and implementing the positional method of determining the location by the information parameters of the radio signal, which correspond to the navigation parameters of the distance to transmitters - artificial earth satellites with known coordinates. The coordinates of the intersection of three position surfaces determine the location of an object, which is the locus of points with the same value of the navigation parameter.

The generally accepted abbreviation for such systems is GPS (Global Positioning System). However, the abbreviation GPS, which has taken root in world practice, most often refers to the American NAVSTAR system and the Russian system is usually called GLONASS GPS or simply GLONASS. As part of the GLONASS and GPS satellite navigation systems, there are three main segments:

– space segment;
– management segment;
– customer segment.

The basis of the concept of satellite navigation systems GLONASS and GPS is the independence and impartiality of solving navigation problems by the segment of consumers. The independence of the solution of navigation problems involves the calculation of the desired navigation parameters only in the consumer's equipment. The concept of impartiality implies the absence of transmission from the consumer to the navigation satellite (NS) of a request for its service. The solution of navigation problems determining the location of consumers is implemented based on duty-free (passive) ranging measurements. The combination of independence and impartiality provides unlimited SNS bandwidth (any number of consumers can simultaneously use satellite signals). The main difference between the SNS and other radio navigation systems is the need to constantly determining the current coordinates of the radio beacons - the coordinates of the NS, in contrast to radio systems such as RSNN and RSFN, where the coordinates of the beacons are known in advance. The satellite coordinates are determined using the ground control segment. At the first stage of solving this problem, in the control segment, the coordinates of the satellites in the visibility zone are measured and the parameters of their orbits are calculated. These data are predicted for fixed (reference) points in time. Predicted coordinates and their derivatives are formed in the so-called ephemeris table and transmitted to the satellite, and then in the form of a navigation message, which corresponds to certain points in time, are relayed to all terrestrial consumers. These tables are similar to astronomical tables, which contain data on the predicted position of planets and stars in the celestial sphere. At the second stage, the following prediction of the satellite coordinates is carried out in the consumer equipment according to the ephemeris data, that is, the exact coordinates of the NS are calculated in the interval between the reference points of the orbit trajectory. The procedures for primary and secondary coordinate prediction are carried out according to certain patterns of satellite motion in orbit. Consequently, the navigation problem is solved in the consumer's equipment - for the information parameters of the radio signal (delay and frequency). The primary navigation parameters (range and its derivatives) are measured relative to the corresponding NS, and the consumer's coordinates are calculated from information about the range of up to three or four satellite transmitters with known coordinates as point's intersections of position surfaces - locus of points with the same value of the navigation parameter.

Noise immunity depends on a combination of a large number of factors: the shape of the useful signal, the type (form) of interference, its intensity, the structure of the receiver, the methods used to combat interference, etc. [2].

Satellite radio navigation systems (SRNS) in most cases guarantee sufficient accuracy if there are at least 4 navigation satellites in the line of sight, but they are characterized by low noise immunity [3, 4]. In the case of electronic jamming of SRNS signal receivers, the tasks of navigating aviation objects without an inertial system become impossible. Therefore, in the absence of SRNS signals, most modern aviation facilities navigate using INS information. Such a system is autonomous, and therefore protected from the action of electronic countermeasures. However, it is inherent in the accumulation of errors, which leads to a significant deviation from the flight task of aviation objects. Therefore, improving the accuracy of navigation of aviation objects in the conditions of electronic suppression is relevant.

It is known that increasing the accuracy of determining the navigation parameters of objects in space is possible due to the functional, informational and hardware integration of navigation meters of various physical nature into a single integrated navigation complex. But the integration of SRNS data and strap down INS does not allow solving the existing problem due to the lack of information from the satellite component of the navigation complex in the conditions of electronic suppression.

Achieving a certain goal is possible through the use of additional autonomous sources of navigation information, which could not be influenced from the outside, for example, an onboard radio direction finding system. In this case, such sources of navigation information are own bearings to radio beacons, the coordinates of which are known in advance. They allow calculating the position of aviation objects using the direction finding method. Base stations of cellular communication systems, television towers of the terrestrial television system can be used as radio beacons. With the integrated use of information from the main INS and additional (radio direction finding) navigation systems to solve the problem of inertial navigation correction, the redundancy of information can potentially improve the accuracy of the system.

Inertial navigation systems, being the most informative, allow obtaining the entire set of necessary parameters for object control, including the angular orientation. At the same time, such systems are noise-proof and completely autonomous, that is, their normal functioning does not require the use of any information from other systems.

Another advantage of these systems is the high speed of providing information to external consumers: the speed of restoring orientation angles is up to 100 Hz, navigation information - from 10 to 100 Hz. The most promising INS is a strap down inertial navigation system (SINS) built on angular velocity sensors and accelerometers.

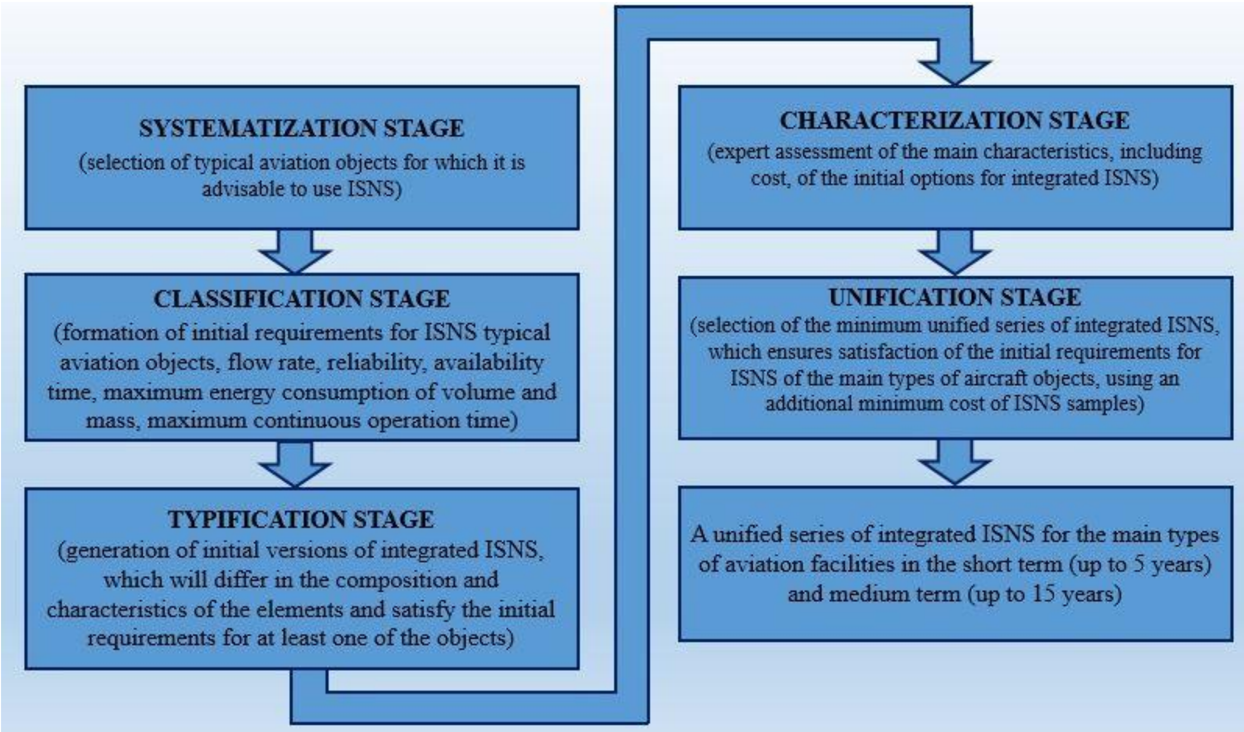
It should be noted that the standard ICAO accuracy of aircraft INS (1.85 km per hour of flight) is provided by inertial sensors with a subsequent level of accuracy - gyroscope errors - no more than 0.01 deg / h, accelerometer errors - no more than 10 μ g. The fundamental disadvantages of INSs are that it is necessary to set the initial conditions for speed, coordinates and orientation parameters, as well as the fact that the errors in determining the coordinates increase with time. Therefore, in addition to the SINS, the composition of the onboard navigation system includes additional navigation aids of a non-inertial type (correctors). The most promising correctors include SNS [4].

The main advantage of using SNS is the high accuracy of determining the coordinates of the location of moving objects. The disadvantages include low noise immunity and lack of information about the angular orientation. The integration of INS and SNS makes it possible to improve the accuracy in terms of coordinates and speed, as well as increase the reliability and noise immunity [5]. In conditions of limited funding during the modernization of different types of aircraft, the issue of unifying inertial satellite navigation systems (ISNS) becomes acute, in order to significantly reduce the cost of equipping aviation facilities with these systems.

The proposed methodology for determining the unified series of INS for military aviation is shown in Figure 1 [3].

Figure 1.

Block diagram of the methodology for constructing a unified series of integrated ISNS for the main types of aviation objects



The proposed methodology is applied for two options for the prospect of introducing ISNS to civil aviation facilities:

– short term perspective(up to 5 years);
– medium-term perspective (up to 15 years).

At the systematization stage, promising aviation facilities were selected, on which it is advisable to install ISNS in the near future. These include civil aircraft and helicopters.

At the classification stage, based on an analysis of the operational and tactical requirements for modernized aircraft, the requirements and recommendations of ICAO and the ARING Corporation, the main requirements for the ISNS of promising aviation facilities were formed by expert way. In addition to the characteristics of accuracy and time of readiness, the mean time between failures, energy intensity, volume, mass, unloading and duration of operation were taken into account.

At the typification stage, ISNS variants were generated (which will differ in inertial sensors of initial information, SNS receivers and integration schemes) that meet the requirements for at least one of the objects selected at the systematization stage.

It is proposed to include a modern multi-channel receiver of the GLONASS / GPS / GALILEO satellite navigation system, which has the ability to operate in the mode of differential navigation measurements, as part of the integrated strap down inertial satellite system.

Currently, there are known schemes for the possible integration of SNS and ANN in four main variants [3]:

– separate scheme;
– weakly coupled scheme;
– rigidly connected scheme;
– deeply integrated scheme.

The analysis shows that the level of potential noise immunity of integrated ISNS increases significantly with an increase in the depth of integration, which is shown in Fig. 2. The graphs are given that characterize the "interference / signal" ratio for various powers of the jamming transmitter as a function of the range to it, as well as the threshold "interference / signal" ratio, above which the SNS receiver is disabled. Effective ways to increase noise immunity are also an increase in the power of satellite radio navigation signals and the introduction of multi-element adaptive receiving antennas that provide identification of interference sources and deformation of antenna patterns (zero - directional antennas) [7].

All ten types of blocks of inertial sensors of primary information are proposed to be integrated with a multi-channel SNS receiver using the most promising version of the integration scheme (deeply integrated scheme). Thus, ten options for building an integrated strapdown inertial satellite navigation system have been generated. At the characterization stage, an expert assessment of the main characteristics, including cost, of the initial versions of the integrated ISNS was carried out.

At the stage of unification, the selection of the minimum unified series of ISNS was carried out. To eliminate the redundancy of the initial options and justify the minimum unified number of systems at this stage, the criterion for the cost of ISNS samples was used.

The analysis carried out showed that in the short term:

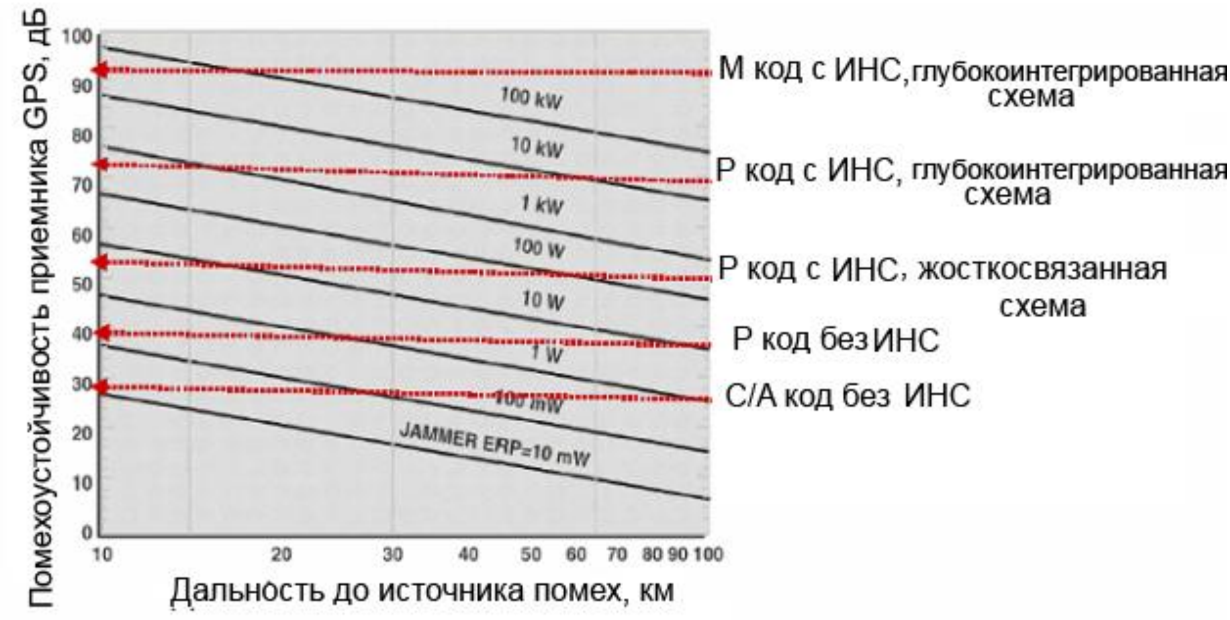
– for objects that require high-precision navigation support for long intervals of operation, it is recommended to have an integrated ISNS based on “accurate” laser gyroscopes and pendulum compensation accelerometers, the cost of which will be ~ $ 100, 000;

– for objects where the average accuracy of navigation support is sufficient, the option of an integrated ISNS based on “medium-precision” fiber-optic gyroscopes and pendulum compensation accelerometers is recommended, the cost of which is estimated at $30,000;

– for short-term objects, a variant of an integrated ISNS based on “coarse” micromechanical sensors is proposed, the cost of which is estimated at $1.5 thousand.

Figure 2.

Potential noise immunity of ISNS to a single source of broadband radio interference



For the medium term:

– for objects that require high-precision navigation support for long intervals of operation, it is recommended to use an integrated ISNS based on “precise” fiber-optic gyroscopes and pendulum compensation accelerometers, the cost of which will be $25,000;

– for objects where the average accuracy of navigation support is sufficient, as well as for short-term objects, the option of an integrated ISNS based on "medium-precision" micromechanical sensors is recommended, the cost of which is estimated at $2,000.

CONCLUSION

Inertial navigation systems, as the most informative, allow obtaining the entire set of necessary parameters for controlling an aircraft object, including angular orientation. It is proposed to include a modern multi-channel receiver of the GLONASS / GPS / GALILEO satellite navigation system, which has the ability to operate in the mode of differential navigation measurements, into the integrated strap down inertial satellite system. Ten options for building an integrated strap down inertial satellite navigation system were generated. Thus, with the help of the proposed methodology, it was possible to form a unified series of ISNS for aviation facilities in the short and medium term.

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