The method of aviation systems diagnostics according to the admissible level of non-failure operation probability

N I Sidnyaev\textsuperscript{1}, Iu I Butenko\textsuperscript{1}, E E Bolotova\textsuperscript{1}

\textsuperscript{1} Bauman Moscow State Technical University, 5/1, 2\textsuperscript{nd} Baumanskaya str., Moscow, 105005, Russia

E-mail: Sidnyaev@yandex.ru

Abstract. The paper presents the methods of forecasting reliability of the created devices, design of devices with the given reliability and comparison of reliability of various aviation systems. Calculated relations at various types of redundancy in tests, prolongation of service life of blocks of aircraft, the basis of which is methodology of estimation of residual resource are resulted. The existing methods of reliability analysis are systematized and studied. The problems of uncertainty of information on input data at calculations by classical methods are stated. It is postulated that the principle of comparability of results of quantitative estimations of technical systems assumes the use of uniform composition of initial data for a certain reporting period of time, unity of generalized and private indicators used as well as unity of assumptions and limitations accepted. The application of general and elementary formulation of the state estimation of complex mechanisms with the use of diagnostic matrix and recognition theory to determine the state of technical objects is shown. Stages of the general process of object diagnostics are described, which consist in determination of parameter changes at influence on object elements and further processing of the obtained results using synthesis and analysis methods.

1. Introduction
Assessment of the technical condition of aircraft complexes (AC) is an important task for the enterprise-developer (manufacturer) in the analysis and evaluation of the technical condition of aircraft systems (AS) and its components development and release reports on the technical condition of the AK at the stages of production and operation.

The existing methods establish the basic principles and methods of analysis, a unified system of indicators of the technical condition of the AC, as well as the procedure for analysis and evaluation of the technical condition, the formation of conclusions and recommendations to improve the existing indicators of the technical condition of the AC and their components. The AC product includes: system, equipment, unit, device, unit, unit, electronic component base product, component element, software product, which are part of the aircraft or any of its structure. The set of properties, characterizing its ability to provide in the process of functioning, obtaining the output effect specified in the Technical Specifications under the specified conditions and operating modes. The aircraft failure is interpreted as an event, which consists in the fact that in the process of aircraft functioning the specified level of output effect is not achieved. The important role is played by experimental testing, which implies a set of works defined by a complex program of experimental testing and performed during tests on models, layouts, prototypes in order to verify compliance of product characteristics with the requirements of the Technical Specifications, ensuring the operation of
products, determining the reserves of their performance under conditions close to real operating conditions. What is important is the technical state, which is interpreted as a set of quantitative and/or qualitative parameters, subject to change, characterizing the ability of the complex (product) to perform under certain conditions at a given moment or period of time the functions inherent in it at the level established in the regulatory documentation, taking into account the period of active existence, namely the calendar period of time from the moment of withdrawal (or acceptance into operation as part of the orbital system of the aircraft) to the moment of termination of use of the aircraft for its intended purpose. The period of active existence of an aircraft, when the limit state is reached due to degradation failures or exhaustion of consumed components of aircraft on-board systems, in the absence of design, production and operation failures. Mathematical model reproducing real properties, connections and interaction of aircraft products and external conditions in the process of AS functioning and allowing to investigate different AS properties. The main objectives of the analysis of the technical condition of the AS and its components are the assessment and determination of trends in changes over a certain period of time of the AS and its components, the timely development of recommendations and preventive measures aimed at ensuring the required level of the reliability, maintenance or improvement of this level (in serial production), as well as control of the implementation of developed measures [1-5].

In the analysis and assessment of the technical condition of the aircraft should follow to the following basic principles of comparability of the results of quantitative assessment of the technical condition of the aircraft and its products, the completeness and reliability of information on failures and malfunctions identified during the reporting period, a systematic approach to the use of indicators of the technical systems of the aircraft and its constituent parts and main products, as well as the choice of the sequence of stages of analysis and assessment of the technical condition.

The principle of comparability of the results of quantitative assessments of the technical systems implies the use of a uniform composition of initial data for a certain reporting period of time, the unity of generalized and private indicators used, as well as the unity of the assumptions and limitations adopted. As a result, the technical condition indicators can be extended not only to different modifications, types, types of products (components) of the AS, but also to different complexes, calculated for the relevant reporting periods and should be comparable with each other. The principle of completeness and reliability of information about failures and malfunctions detected during the reporting period assumes that the initial data used for analysis and evaluation of technical systems fully and reliably characterize the events that took place and provide objective assessments of the AS technical condition. All failures and malfunctions revealed on the complex, regardless of whether they have affected the test results or not, should be taken into account, information documents should be drawn up on them (fault reports or claim acts, study acts, confirmed by study protocols). The initial data include all failures and malfunctions revealed on the finished products during the reporting period of time (according to the date of fault or failure detection) [6-8].

2. Diagnostic evaluation of aircraft systems
Diagnostics, i.e. an opinion on the technical condition of an aircraft, aims to determine its suitability for current and future use before the next maintenance. It follows from this that during the scheduled diagnosis, the statement of diagnosis contains elements of predicting the service life of the AS. To reduce operating costs, two types of diagnosis are used that differ in depth: general and elemental. Diagnosis of unit, system, aircraft in general is called general, and a detailed diagnosis, which determines the causes of performance degradation - elementary. Both general and elementary diagnostics are used to control technological processes and quality of aircraft service. According to the results of the general diagnosis, the AS is subjected to elemental diagnostics or sent for operation, and according to the results of elemental diagnostics, repair or maintenance is performed. Diagnosis of unit, system, aircraft in general is called general, and a detailed diagnosis, which determines the causes of performance degradation - elementary. Both general and elementary diagnostics are used to control technological processes and quality of aircraft service. According to the results of the general diagnosis, the AS is subjected to elemental diagnostics or sent for operation, and according to the results of elemental diagnostics, repair or maintenance is performed. In addition, the final diagnosis is
used to control aircraft maintenance and repair. Diagnosing the state of relatively simple mechanisms, when you have to use one diagnostic parameter, does not meet any particular methodological difficulties. It practically comes down to measuring the value of the diagnostic parameter compared to the norm [9-11].

In this case, for mechanisms with a known continuous (increasing) pattern of change in the technical state can be three diagnosis options: \( S > S_n \); \( S < S_i \); \( S < S_j \). The first option requires repair to correct the fault, the second one requires preventive maintenance due to insufficient resource, and the third one does not require restoration until the next scheduled diagnosis. For aircraft diagnosed with discrete diagnostic parameters, when it is not expedient to trace individual changes in the implementation of the technical condition, there are only two options for diagnosis: corrected and defective, i.e. \( S > S_m \); \( S < S_m \). The first option requires maintenance, while the second one does not require maintenance - the object is in good order. In this case, failure-free operation in the upcoming flight is guaranteed by early tightening of the diagnostic standard \( S_m \).

Setting the elemental diagnosis of complex AS, when you have to use several diagnostic parameters, is significantly complicated.

The point is that each diagnostic parameter can be associated with a number of structural parameters. Therefore, a certain value of each of them may indicate a malfunction of the diagnostic object. It means that if the number of diagnostic parameters used is \( n \), the possible number of technical states of the mechanism being diagnosed will be \( 2^n \).

Theoretically, the diagnosis is to select one of the many possible states of the block to be diagnosed. Therefore, the task of diagnosing many diagnostic parameters is to reveal multiple links between structural parameters \( X_1, X_2, \ldots, X_n \) and the corresponding diagnostic parameters \( S_1, S_2, \ldots, S_m \). For this purpose, diagnostic matrices are most commonly used in the practice of spacecraft components diagnostics.

The Diagnostic Matrix (Table 1) is a two-digit logical model describing the links between structural and diagnostic parameters that have reached an acceptable value. The horizontal rows of the matrix correspond to the applied diagnostic parameters. When a diagnostic parameter reaches a normative value, one or more malfunctions of the diagnostic object may occur. Vertical rows correspond to the malfunctions of the object, i.e. its structural parameters, which have reached the allowable value. A unit at the intersection of the horizontal and vertical rows means that a fault may exist. Zero indicates that there is no such possibility.

Table 1. Matrix model of links between diagnostic and structural parameters.

| Normative values of structural parameters (faults) | \( X_1 \) | \( X_2 \) | \( X_3 \) | \( X_4 \) | \( X_5 \) |
|---|---|---|---|---|---|
| \( S_1 \) | 0 | 0 | 1 | 0 | 0 |
| \( S_2 \) | 1 | 1 | 0 | 1 | 1 |
| \( S_3 \) | 0 | 0 | 0 | 0 | 1 |
| \( S_4 \) | 0 | 1 | 1 | 0 | 1 |
| \( S_5 \) | 0 | 1 | 0 | 0 | 0 |

When compiling the matrix, they strive to apply the minimum number of diagnostic parameters. Only the most sensitive and informative parameters are used for this purpose. At the same time, the number of diagnostic parameters should be sufficient to obtain a reliable unambiguous diagnosis. The analytical relationship between structural and diagnostic parameters can be written in general terms by the following equations:
automatic fault location. In cases when fault localization by means of diagnostic matrix is difficult, for
indicators, the threshold devices are adjusted. Availability of switches makes it possible to adjust the
central control station or to the operator's display. If it is necessary to enter corrected diagnostic
basis for synthesis of logical automata to determine the technical state of the diagnostic object by
classes, theory and technical means of image recognition can be used for making a diagnosis. For
example, due to a small number of measured diagnostic parameters and strong intersection of state
diagnostic matrix to other diagnostic parameters. The logical matrix of the specified type can be the
sufficient force, these signals pass through a threshold device (trigger) into its electrical circuit. Along
device to which electrical signals corresponding to the measured diagnostic parameters are fed. With
normative value. For practical formulation of the diagnosis, the matrix is performed as an electronic
detection can be considered as a reduction of entropy (the degree of uncertainty of the technical state
the existence of a certain combination of measured diagnostic parameters. The process of fault
localization can be considered as a reduction of entropy (the degree of uncertainty of the technical state
of the mechanism being diagnosed) by means of sequential introduction of information doses into the
diagnostic matrix which are incommensurate with diagnostic parameters that have reached the
normative value. For practical formulation of the diagnosis, the matrix is performed as an electronic
device to which electrical signals corresponding to the measured diagnostic parameters are fed. With
sufficient force, these signals pass through a threshold device (trigger) into its electrical circuit. Along
the circuit, the signal is sent to the matching element of the control lamp $X_1, X_2$, etc., corresponding to
the fault in which this diagnostic parameter may exist. If the lamp does not light up, it means that the
dose of information obtained from this diagnostic parameter is insufficient to localize the existing
malfunction and that additional information from other diagnostic parameters is required to make the
diagnosis. For example, the fault signal $X_1$ will only be received after entering the signals from the two
parameters $S_1$ and $S_4$, fault signal $X_2$ - after entering $S_1$ and $S_3$, etc. Consequently, the functioning
algorithm of this logic device is $X_1 = S_2 S_4; X_2 = S_1 S_3; X_3 = S_2 S_3; X_4 = S_2 S_4; X_5 = S_1 S_2 S_4$.
Such devices allow localizing faults and displaying information via appropriate channels to the
central control station or to the operator's display. If it is necessary to enter corrected diagnostic
indicators, the threshold devices are adjusted. Availability of switches makes it possible to adjust the
diagnostic matrix to other diagnostic parameters. The logical matrix of the specified type can be the
basis for synthesis of logical automata to determine the technical state of the diagnostic object by
automatic fault location. In cases when fault localization by means of diagnostic matrix is difficult, for
example, due to a small number of measured diagnostic parameters and strong intersection of state
classes, theory and technical means of image recognition can be used for making a diagnosis.

The essence of making a diagnosis using image recognition theory is as follows. Complexes of
implementations of diagnostic parameters for any mechanism (i.e., their values fixed in any coordinate
system) are some sets with characteristic properties. These properties are manifested in the fact that

$$
\begin{align*}
X_1 &= f_1(S_1, S_2, \ldots, S_m); \\
X_2 &= f_1(S_1, S_2, \ldots, S_m); \\
\vdots & \quad \vdots \\
X_n &= f_1(S_1, S_2, \ldots, S_m).
\end{align*}
$$

Here, the system of $n$ equations (where $n$ is the number of structural parameters $X$, each of which
can be associated with $m$ measured diagnostic parameters) describes all possible states of a diagnostic
object expressed by diagnostic parameters $S$. For practical compilation of these equations, it is
necessary to know the list of characteristic reactor malfunctions to be detected and the structural and
consequence diagram of the corresponding diagnostic mechanism. The list of characteristic
malfunctions of the mechanism is made on the basis of statistical indicators of its reliability [12-15].

Using such a scheme, based on the engineering study of the object of diagnosis, it is possible to
establish the initial list of diagnostic parameters and relationships between the two. However, the
logical equations compiled in this way, each of which represents a horizontal line of the matrix, may
be insufficiently informative, because the structural and consequence diagrams do not contain a
quantitative assessment of diagnostic parameters. In order to evaluate the significance of diagnostic
parameters, one should analyze their qualities: sensitivity, informativity by probabilities of their
occurrence in the presence of a given malfunction or by probabilistic links with the main parameters of
the diagnostic object performance. At relatively small probabilities, the parameter is considered
insignificant and equals zero. Otherwise, it is equated to one. The diagnostic parameters selected in
this way allow filling the corresponding matrix cells with zeros and units.

Such a matrix makes it possible to solve the problem of localization of the diagnosed mechanism
failure by the presence of the corresponding set of diagnostic parameters that have reached the
normative value.

The physical essence of the solution to this problem is to exclude malfunctions incompatible with
the existence of a certain combination of measured diagnostic parameters. The process of fault
detection can be considered as a reduction of entropy (the degree of uncertainty of the technical state
of the mechanism being diagnosed) by means of sequential introduction of information doses into the
diagnostic matrix which are incommensurate with diagnostic parameters that have reached the
normative value. For practical formulation of the diagnosis, the matrix is performed as an electronic
device to which electrical signals corresponding to the measured diagnostic parameters are fed. With
sufficient force, these signals pass through a threshold device (trigger) into its electrical circuit. Along
the circuit, the signal is sent to the matching element of the control lamp $X_1, X_2$, etc., corresponding to
the fault in which this diagnostic parameter may exist. If the lamp does not light up, it means that the
dose of information obtained from this diagnostic parameter is insufficient to localize the existing
malfunction and that additional information from other diagnostic parameters is required to make the
diagnosis. For example, the fault signal $X_1$ will only be received after entering the signals from the two
parameters $S_1$ and $S_4$, fault signal $X_2$ - after entering $S_1$ and $S_3$, etc. Consequently, the functioning
algorithm of this logic device is $X_1 = S_2 S_4; X_2 = S_1 S_3; X_3 = S_2 S_3; X_4 = S_2 S_4; X_5 = S_1 S_2 S_4$.

Such devices allow localizing faults and displaying information via appropriate channels to the
central control station or to the operator's display. If it is necessary to enter corrected diagnostic
indicators, the threshold devices are adjusted. Availability of switches makes it possible to adjust the
diagnostic matrix to other diagnostic parameters. The logical matrix of the specified type can be the
basis for synthesis of logical automata to determine the technical state of the diagnostic object by
automatic fault location. In cases when fault localization by means of diagnostic matrix is difficult, for
example, due to a small number of measured diagnostic parameters and strong intersection of state
classes, theory and technical means of image recognition can be used for making a diagnosis.

The essence of making a diagnosis using image recognition theory is as follows. Complexes of
implementations of diagnostic parameters for any mechanism (i.e., their values fixed in any coordinate
system) are some sets with characteristic properties. These properties are manifested in the fact that
familiarization of people or a machine (recognizing device) with the realizations of these sets makes it possible to recognize further belonging of a given realization to any of these sets. The sets of this type are called images.

A totality of different technical states of a diagnostic object is denoted in the case of the so-called "alphabet" of failures: \( A = A_0, A_1, A_2, \ldots, A_j, \ldots, A_M \), where \( A_0 \) is a state of a technically sound object; \( A_j \) is an object state class expressed by the set of implementations of a particular failure; \( M \) is a number of classes of possible object states.

The task of fault detection is to attribute the implementation of the diagnostic parameter, which expresses the state of the mechanism to be diagnosed, to the appropriate class \( A_j \). In this case, the implementations with common properties belong to one class.

If you measure diagnostic parameters of several identical, functional mechanisms, the parameter implementations obtained during diagnostics form the corresponding area. In doing so, they will be grouped relatively to some distribution center called \( A_0 \) reference. Occurrence of any particular malfunction in the same mechanisms will cause shift of the implementation region and its \( A_1 \) reference to another place. The presence of another fault will again change the location of the implementation area of diagnostic parameters and its reference \( A_0 \), etc. If the location of the mechanism's characteristic fault areas is known, an unknown fault can be determined knowing the implementation obtained during diagnostics by its correspondence to a certain class of the object's states.

Therefore, the recognition of the technical state of this mechanism can be understood as establishing the fact that the \( A_j \) image is similar to the reference \( A_j \) image, considering that the degree of similarity is determined by the distance between the implementation of \( A_j \) and the reference \( A_j \). There are two ways of detecting malfunctions: by including the resulting implementation (image) inside the malfunctioning state area and by the distance between its distribution center \( A_j \) and the reference image \( A_j \). In the first case, the material on which the resulting implementation (called a tutorial sequence) is formed is expressed by the boundaries between the areas of characteristic faults. In the second case, recognition is reduced to determining the distance between \( A_j \) and \( A_j \):

\[
\rho(A_j, A_j) = \sqrt{\sum_{k=1}^{N} (X_{kj} - X_{kj})^2},
\]

where \( A_k \) and \( A_k \) are the values of diagnostic parameters (implementations) presented for recognition; \( N \) is the number of diagnostic parameters characterizing the fault alphabet.

By presenting the values of diagnostic parameters, for example, in the coordinates of \( y \) - wear time, \( x \) - movement of the device, you can get an area of serviceable states, similar to area 0, and area 1-5 typical aircraft malfunctions. Similar faults can be detected with relatively inexpensive electronic devices.

The described method of applying image recognition theory to AS diagnosis can be used for other mechanisms as well. It makes it possible to determine the technical condition of an aircraft directly during operation.

3. General diagnostic process

The general process of diagnosing the technical state of the aircraft includes: test action on the object, measurement of diagnostic parameters, processing of the received information and making the diagnosis according to the specified standard.

Test impact on the object of diagnosis is carried out either during the operation of the aircraft itself at the given load, speed, thermal conditions, or using appropriate devices (stands with loading devices, rolling and portable devices, etc.). Test actions shall provide maximum information about the technical condition of the aircraft at optimal labor and material costs.

Diagnostic parameters are measured with sensors. The types and types of sensors correspond to the physical nature of the diagnostic parameters. When measuring vibration parameters piezo-sensors are used, in thermal diagnostics - thermometers, in electrical measurements - induction current collectors, etc. are used. A distinction is made between easily removable and built-in sensors. The former are installed on the object for the time of diagnosis (magnetic, hinged, on the clamps, threaded, etc.), and
the latter are standard accessories of the aircraft. Built-in sensors can be connected to control devices for permanent monitoring or to centralized plug connectors.

When using multichannel narrow information, several different types of sensors can be used, and when using wide information, one sensor can be used. On the way to the measuring instrument, the information obtained from the sensors is processed by the corresponding images. Processing consists in amplification of the received signal, removal of interferences, analysis and filtering of the signal by size and phase.

Diagnosis setting consists in comparing the obtained one or more processed diagnostic parameters with the specified standards. In the simplest case, when a single diagnostic parameter is used, the diagnostic procedure ends there.

Excess of $S_y$ means the need for technical impact of the set volume, and the absence of excess - the ability to operate until the next control.

When used for the diagnosis of a large number of parameters are used methods of synthesis and analysis of the processing of captured information. The process of diagnostics by synthesis of differentiated information obtained from several sensors and by analysis of generalized information recorded by one sensor are shown in the circuit diagram.

The essence of the process of diagnosing a complex object by synthesizing differentiated information is as follows. The mechanism to be diagnosed is usually subjected to test action. The sensors $D_1, D_2, ..., D_n$, fix the values of structural parameters $X_1, X_2, ..., X_n$ each of the elements of the object $E_1, E_2, ..., E_n$. Values of structural parameters expressed by electric signals $S_1, S_2, ..., S_n$ are received by the gain unit and after processing into the threshold device. The latter skips the signals exceeding the allowed values of $S_y$. These signals $S_1', S_2', ..., S_m'$ come to the logical device (diagnostic matrix). The matrix synthesizes the information from several sensors and generates a diagnosis. The diagnosis can be refined by differentiating the required effects on specific types: warning or repair [16].

The process of diagnostics by analysis of generalized information differs from the described one by the fact that changes of structural parameters $X_1, X_2, ..., X_n$ are fixed integrally by groups of object elements with the help of one sensor (for example, vibration parameter piezo-sensor). After amplification, the signal containing generalized information about the technical state of the object should be analyzed, highlighting the most characteristic and useful components. These components are then filtered by value using a threshold device and diagnosed. When diagnosing simple objects, the process described above is simplified by exclusion of separate stages.

4. Conclusion

One of the main factors ensuring a high level of technical condition of aviation systems, aircraft and other aerospace equipment products is the availability of a developed regulatory framework that establishes a unified approach to the order of their creation, production and operation, which is based on the latest achievements in science and technology. One of the most important elements of this regulatory framework is a set of regulatory documents that establish requirements for ensuring the necessary level of technical condition.

An indicator of the effectiveness of these activities was the fact that despite a number of accidents, including those related to the loss of aircraft and payloads, significant financial losses were avoided, while large-scale negative consequences associated with harm to personnel, the population and the environment were avoided.

At the same time there is a tendency to decrease the level of technical condition of aviation equipment products. To the main reasons of appearance of the specified tendencies it is necessary to carry: consequences of underfunding of organizations of aviation industry for the last decades which have appeared in deterioration of quality of processes of creation, manufacture and operation of products of AT and accumulation of some problems; considerable quantity of again accepted legislative and other by-laws and as consequence occurrence of the new requirements, incompletely harmonized with requirements of branch normative documents on maintenance of technical condition;
incompletely harmonized with requirements of branch normative documents on maintenance of technical condition of products of aircraft.

References
[1] Pavlov I V 1982 Statistical methods for assessing the reliability of complex systems. Moscow, RadioCommunication p 168
[2] Sidnyaev N I 2018 A Study of the Destruction of Spacecraft Surfaces at Contact Interactions with Microparticles of the Space Environment Cosmic Research Vol 56 (3) pp 213–222
[3] Gecha V Ya, Barbul R N, Sidnyaev N I and Butenko Yu I 2019 Methodology for assessing the reliability of spacecraft in the design and engineering study Nadezhnost. vol 2 pp 3-8
[4] Gnedenko B V 1965 Mathematical methods in the theory of reliability. Moscow, Nauka p 524
[5] Sidnyaev N I Stolbova VA 2019 Mathematical modeling of nitrogen flow around hypersonic bodies AIP Conference Proceedings Vol. 2171 Art.no 130015
[6] Morozov D B and Chernoshentsev S F 2019 Technique for improving the reliability of the control system of an unmanned aerial vehicle in flight in case of a failure in on-board control equipment. Nadezhnost. vol 19 (1) pp30–35
[7] Sidnyaev N I Klimova N S 2020 Changes in the Surface and Volume Properties of a Spacecraft during Absorption and Recombination of Oxygen and Nitrogen Atoms Cosmic Research Vol 56 (3) pp213-222.
[8] Morris S F 1990 Use and application of MIL–HDBK–217. Solid Slate Technology. Vol33 (6) pp 65–69.
[9] Sidnyaev N I 2020 Study of heat transfer in the boundary layer in a nitrogen flow past a catalytic graphite wall Thermophysics and Aeromechanics Vol 27(2) pp 193–203
[10] Brennam T R 1988 Should us MIL–HDBK–217 be 8888. IEEE Trans. Reliab. vol 37 (5) pp 474–475
[11] Sidnyaev N I 2019 On a theorem of impulse and energy to determine parameters of the electric jet engine KA Journal of Physics: Conference Series Vol. 1392 Art.no 012024
[12] Barlow R 1969 Mathematical theory of reliability. ed RBarlow, F Proshan. Moscow: Soviet radio p 488
[13] Lavrischeva E M, Zelenov S V and Pakulin N V 2019 Methods for assessing the reliability of software and technical systems. Proceedings of the Institute for System Programming. vol 31 (5) pp 95–108
[14] Sidnyaev N I 2016 Space weather factors affecting onboard elements of low-orbit spacecrafts. ed N I Sidnyaev, L A Makridenko, V Ya Gecha and V N Onufriev 2016 Electromechanics issues. VNIIEM Proceedings. Proceedings of the Fourth International Scientific and Technical Conference ”Actual Problems of Creation of Space Systems for Remote Sensing of the Earth”. Moscow: JSC “Corporation“ VNIIEM ” pp 90–10
[15] Pokhabov Yu P 2018 What to understand by calculating the reliability of unique highly responsible systems in relation to the mechanisms of one-time actuation of spacecraft. Reliability Vol 4 pp 28–35
[16] Antonov S G and Klimov S M 2017 Methodology for assessing the risks of violation of the stability of the functioning of software and hardware systems in the conditions of information and technical influences. Nadezhnost Vol 17 (1) pp 32–39