MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONICS AND TELECOMMUNICATIONS
DEPARTMENT OF AVIONICS

APPROVED
Head of department
________S.V. Pavlova
‘___’___________20

GRADUATION WORK

(EXPLANATORY NOTES)

FOR THE DEGREE OF BACHELOR
SPECIALTY 173 ‘AVIONICS’

Theme: ‘Cyclic prediction of failure of aircraft components in flight’

Done by: __________ Y.I. Vitruk
(signature)

Supervisor: __________
(signature)

Standard controller: __________ V.V. Levkivskyi
(signature)

Kyiv 2020

NATIONAL AVIATION UNIVERSITY

Faculty of Air Navigation, Electronics and Telecommunications

Department of avionics

Specialty 173 ‘Avionics’

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TASK

for execution graduation work

Y.I. Vitruk

1. Theme: ‘Cyclic prediction of failure of aircraft components in flight’, approved by order №1804/ст of the Rector of the National Aviation University of.
2. Duration of which is from to.
3. Input data of graduation work: Operational or negative state of avionics modules and others aircraft components (AIR) are fixed by built-in controls that implement the concept of "Built-In-Test Equipment" (BITE); Monitoring of the working condition is carried out on the basis of control over the operational tolerance; on the defining parameters of the module; To provide the account of influence of disturbances on probability of control of a technical condition.
4. Content of explanatory notes: Introduction; Modular (block) principle of construction of modern avionics; Reliability model and model of the process of restoration of typical replacement elements in the system; Analysis of the capabilities of ground-based automated diagnostic tools for the efficiency of airlines; Assessment of the quantitative composition of avionics spare units with the most effective concept of recovery.
5. The list of mandatory graphic material: sufficient to explain (illustrate) the research performed and the results obtained.

6. Planned schedule

№	Task	Duration	Signature of supervisor
1.	Validate the rationale of graduate work theme		
2.	Carry out a literature review		
3.	Develop the first chapter of diploma		
4.	Develop the second chapter of diploma		
5.	Develop the third chapter of diploma		
6.	Tested for anti-plagiarism and obtaining a review of the diploma		

8. Date of assignment: ‘____’___________ 20

Supervisor ______________
(signature) (surname, name, patronymic)

The task took to perform ______________
(signature) (surname, name, patronymic)

ABSTRACT

Explanatory notes to bachelor work ‘Cyclic prediction of failure of aircraft components in flight’ contained pages, figures, tables, references.

The object of the research - a set of avionics modules that perform flight functions and contain built-in means of monitoring the technical condition of the aircraft onboard equipment complex.

The purpose of the bachelor work – development of a method for determining the accuracy classes of meters as part of built-in controls, the implementation of which provides a given probability of diagnosing the functional structures of modules.

Research Method – logical-analytical analysis of situations that are possible with a single measurement of the defining parameters of the object of diagnosis and derivation of the working formula for calculating the probability of control, as well as simulation computer modeling of stages of implementation of methods for measuring accuracy classes of meters.

The scientific novelty of the research:

- ***For the first time***: show the need for high reliability of functional structures that implement flight functions, and high probability in the operation of built-in controls.

- ***Improved***: analysis of diagnostic characteristics of monitoring on the basis of control over the admission, and normalization of these characteristics.

Keywords: SPECIAL SITUATIONS, LINEAR FORECAST, AVERAGE RESIDUAL LIFE, CYCLIC FORECAST, MAINTENANCE, ERROR, RELIABILITY.

CONTENTS

LIST OF CONDITIONAL TERMS AND ABBREVIATIONS

TCAS	Traffic alert and Collision Avoidance System
ACAS	Airborne Collision Avoidance System
BCAS	Beacon Collision Avoidance System
PPC	Controllers of parallel ports (selector channels)
SPC	Serial port controllers (selector channels)
DMXC	Controller of parallel multiplex channel
ICAO	International Civil Aviation Organization
AMXC	Analog multiplexer
ADC	Analog-to-digital converter
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
TA	Traffic Advisory
RA	Resolution Advisory
SBC	A serial multiplex channel
HMDF	Horizontal Miss Distance Filter
SPU	A specialized processor (so-called accelerator)
VSI	Vertical Speed Indicator

INTRODUCTION

It is said that the science of reliability is a young science, but this does not mean that people were not interested in and engaged in ensuring the reliability of the technology they create.

Regarding the concept of "reliability", the primary term is "quality". The quality of any product is a set of properties and characteristics that ensure its ability to meet specified needs in accordance with its purpose and reflect its specificity and difference from other products. The change in product quality over time can be absolute and relative. Absolute change in quality is associated with various internal and external destructive processes that affect the product during operation and change the properties and condition of the materials from which it is made. Due to this, there is a decrease in the quality of the product and its physical degradation (physical aging). The relative change in product quality is associated with the emergence of new similar products with more advanced characteristics, in connection with which the indicators of this product become below the average level of the set of products with a similar purpose, at least their absolute values may not change (moral aging). The science of reliability studies only the absolute changes in product quality indicators, ie changes associated with the course of various degradation processes. It is obvious that the design of new equipment without the development of special

These measures to ensure its reliability are meaningless. The danger is not only that this sophisticated new technique will not work, but mainly that failure to do so could lead to catastrophic consequences. The science of reliability produces and systematizes knowledge about the preservation of the efficiency of products in the process of their intended use.

It has all the features inherent in an independent scientific discipline, namely:

- specific object of research (preservation of working capacity products);
- fundamental categories and concepts (reliability, reliability, fault tolerance, durability, failure, failure, etc.);
- own research methods (calculation of reliability, testing reliability, reliability modeling);
- methods of quantitative measurement of reliability indicators;
- reliability management methods (recovery, restructure configuration, redundancy, etc.).

The stage of application (flight operation) of an aircraft (aircraft) covers, as a rule, a long period of time. Under the influence of various factors there is a change in the level of properties that determine the quality of the components of the onboard equipment (and the aircraft in general) and the efficiency of their operation. Therefore, the most important property of any technical product is reliability, which determines its ability to perform the required functions for a long time.

The most pressing problem of civil aircraft is the safety of flights. The loss of flight-critical functions relevant to avionics applications directly affects flight safety, which depends, in particular, on the level of reliability of aircraft and the reliability of information on the technical condition of aircraft components . In modern civil aviation, avionics is one of the important factors that determine flight safety, efficiency and competitiveness of aircraft. Today, avionics is defined as a set of on-board electronic equipment of the aircraft, which performs:

1) data collection on:

- environment,
- the state of functional systems that solve the target tasks of the flight,
- condition of aircraft engines and aircraft glider construction;

2) processing of the collected information by on-board computers;

3) issuance of crew processing results for decision making and or transmission of control signal directly to actuators (electromechanical, hydraulic), as well as transmission of information to ground services accompanying the flight of the aircraft . Obtaining data on the environment and the condition of the aircraft is usually carried out using a system of internal and external sensors, recently called the sensor system. External sensors provide information about the position of the aircraft in space and other objects located in this space. Internal state sensors provide information about the phase coordinates of systems, units and mechanisms of the aircraft.

CHAPTER 1
ENSURING THE EFFICIENT OPERATION OF AIRCRAFT BASED ON INTEGRATED LOGISTICS SUPPORT

The issues of aircraft flight safety management are considered from the perspective of the theory of highly reliable technical systems with discrete states defined in fuzzy subsets of the original universal set of elements. It is proposed to evaluate the risks of critical conditions under which aircraft can fall into catastrophic scenarios depending on a combination of hazardous factors.

1.1 Indicator assessment of aircraft safety

The relevance of the topic is due to the need to assess the ability to predict the behavior of complex systems, taking into account the uncertainty of external influences. Scientific and technical problems of this kind are being solved using various tools not only in civil aviation, but also in other transport sectors.

For example, in the railway industry, the method of probabilistic safety analysis (PSA) is mainly used. It is based on the interpretation of risk as the probability of hazardous events and the comparison of risk with acceptable risk in determining the level of safety of the systems under study. Acceptable risk is found by regulatory indicators through a certain acceptable amount of damage that inevitably occurs during the operation of transport systems or in the provision of certain transport services.

The use of this approach is apparently the most justified at the present time, although it has long been known. In the presented publication, it is indicated that one of the authors of the approach is M. Kumamoto. However, for civil aviation (GA), such a definition is difficult to adapt to the indicator safety assessment methods recommended by ICAO and Boeing Corporation.

<table>
<tr><td colspan="4">Department of avionics</td><td colspan="6">NAU</td></tr>
<tr><td>Done by</td><td></td><td></td><td></td><td rowspan="5">THE TWO BASIC APPROACHES OF DEVELOPING MAINTENANCE PROGRAMS</td><td colspan="3">Letter</td><td>Page</td><td>Pages</td></tr>
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<tr><td>S.Controller</td><td></td><td></td><td></td></tr>
<tr><td>Head of dept.</td><td>S.V.Pavlova</td><td></td><td></td></tr>
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The risk level adopted in is difficult to verify experimentally with examples of the operation of technical systems due to the objective existence of rare events and insufficient statistics about serious air accidents. It seems promising to build fractal models according to the scheme for identifying dangerous scenarios of aircraft (AC) flights arising from the idea of synergetics of complex technical complexes. However, with a variety of hazardous factors, it is difficult to derive equations for the trunk of a fractal tree of events (such as scenarios) and construct an appropriate methodology within the framework of the traditional risk-based approach to solving safety issues.

Attention is focused on the synthesis of possible dangerous scenarios of events in the form of chains leading to disaster, therefore it is advisable to take as a first approximation a compromise scheme for determining safety indicator indicators taking into account the properties of fuzzy subsets of elements from a clear universal set of discrete elements of the system mentioned above: BC - LE - Wednesday. Necessary catastrophic event scenarios can be constructed using standard algorithms from FMEA and others indicated.

Developments in this direction are carried out jointly at St. Petersburg State University of Civil Aviation (Russia) and the National Aviation University of Baku (Azerbaijan) with the prospect of implementation in flight training centers, where A-320, B-737 and etc. The problem of assessing and predicting the properties of rare events is to develop principles for determining the conditions of accidents and disasters in civil aviation that arise with a probability of "almost zero". Under a certain rare set of circumstances in the behavior of the system, the operator (pilot, automatic) - aircraft - operational environment may form a chain of critical cause-effect relationships that will irreversibly lead to a flight accident (LP).

The occurrence of hazardous events and processes in the GA, as in other transport sectors, is due to the cross influence of several heterogeneous operational factors (EF), inconsistent actions of the pilot and automation, the influence of the environment, etc. In almost every LP, you can find a point of no return - the last the moment when it is still possible to restore safe mode and get away from catastrophic consequences. It is important to determine such points in advance in order to teach them the necessary skills during pilot classes in training centers.

1.2 Statement of the problem to identify safety threats and the occurrence of accidents

The flight safety of aircraft is interpreted by ICAO as the state of systems in which the risk of low-level aircraft is low. Drugs include special situations (OS) with different levels of consequences for certain threats.

The causes of disasters are the complexity and ambiguity of changes in system states in a multifactorial situational space of flight, the lack of a priori information on the dynamics and logic of the development of such situations. Gaps in knowledge about possible non-standard variants of system behavior and errors of a specialist (designer, tester, instructor, pilot) are responsible for the “residual risk” of catastrophes. (The risk is where the person is.) The occurrence of “residual risk” in the indicated drugs is explained by the fact that the constructive hazards in the systems are manifested in the form of a mismatch between a previously unknown non-standard (dangerous) and prescribed (safe) scenario.

When studying complex (multifactor) drugs, it is necessary to take into account nonlinearity, multidimensionality, the combinatorial nature of the behavior of a real system, which causes a disruption in the functioning of systems and, most importantly, the severity of consequences in rare events such as disasters in highly reliable systems. Rare events are less common than one event per 10 million flights. Therefore, with a risk-based approach to flight safety (BP) problems, it is the event / flight ratio (we emphasize: not the event / hour ratio) that makes it possible to create a methodology for the indicator assessment of the level of flight safety in airlines and training centers.

According to the Aircraft Flight Operation Manual (RLE), the aircraft crew is obliged to fly only under the expected operating conditions, including design conditions and operational limitations, as well as recommended flight modes established for this type of aircraft during its certification. In the practice of flight operation, however, there are many cases where the crew finds themselves in unexpected operating conditions for the crew - aircraft - environment system. Note that some operating conditions are not expected, but they do exist and are classified according to documents (Appendix 8 to the Chicago Convention) as non-calculated or extreme.

At the same time, extreme conditions that can be effectively prevented by the introduction of operating rules are so rare that their compensation requires such high levels of airworthiness at which the operation of the aircraft becomes practically impossible. This is the essence of the problem solved in this article.

1.2.1 Possible ways to build flight hazard models

Hazard models in flight situations describe the interconnection of groups of events characterizing a change in the state of the aviation system under the influence of disturbing factors. This is most fully presented in the works, which can be taken as the starting point of the research. The primary triple of some elements in the form of an initial event — a process — an end event — is an elementary situation called a “cube”. From such elements, one can assemble a drug model of almost any type: a catastrophic version, a test flight, a training flight, etc. Operational flight factors specify variations in the parameters of a system with a given structure. As a result, unified computer models of scenario scenarios can be created for the main stages, modes and flight conditions. However, approximately 20% of the OS occurs in extreme conditions not provided for by airworthiness standards, and are not represented in the RLE.

In the article, the security postulates specified in and written down as recommendations for the crew members of the main aircraft are used as initial conditions: disasters are never the result of any particular reason and occur as a result of the interconnection of several different reasons. In this regard, disaster prevention consists in proactively (preventatively) identifying and eliminating such causes before they can occur in real flight. This is achieved through safety management procedures based on an a priori database of hazardous factors and criticality assessments of forecast scenarios. It is proposed here to evaluate the risks of consequences using the concept of risk as a measure of danger (we emphasize not probability) of events. In GA, one of the important factors is the human factor.

1.2.2 Assessing the significance of the human factor in the form of a fractal model to ensure flight safety

A fractal is a set of special elements in the form of a special geometric image (for example, Koch Island, a branching tree), convenient for displaying some branching processes in various systems. In the works of the Russian Academy of Sciences [5] and in the publication, many possible scenarios of the development of events during aircraft operation are studied, depending on the completeness of the database of catastrophic situations according to the scheme. The approach is considered promising for building models of the influence of the human factor on the chain of events, taking into account parameters such as the professional level of crew members and the level of threat from environmental influences.

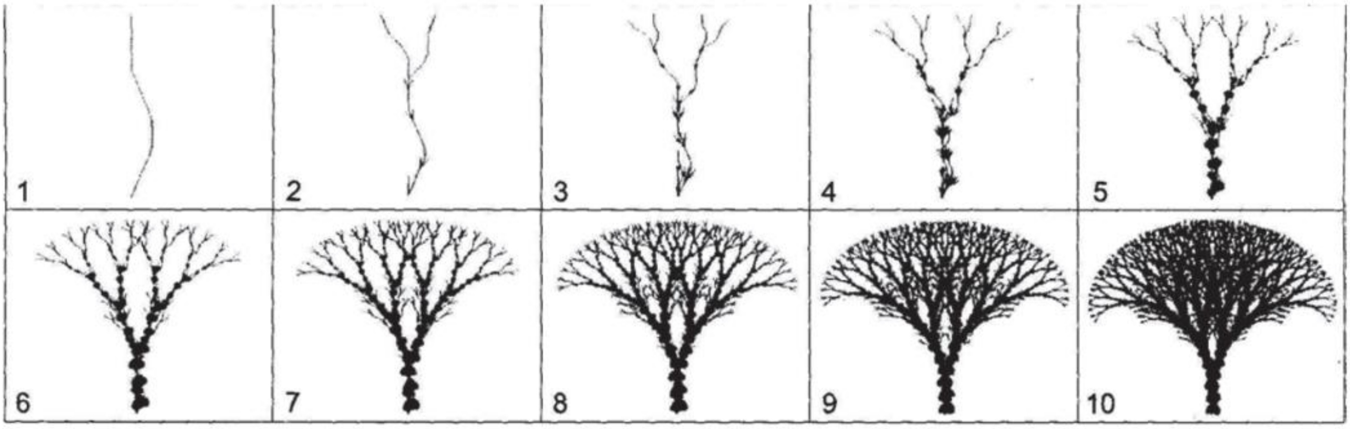


Figure 1. Fractal growth steps k

The figure (Fig. 1) shows the steps k of the growth of a fractal with the tree genotype. It can be seen that the number and thickness of the connection branches increase in proportion to the pilot's flying hours (k) and the number of types of difficult situations mastered by him. These characteristics, in particular, determine the specialization and competence of the operator (pilot). Fractal analogy allows you to identify the roots of inadequate or erroneous decisions of the pilot, taken in non-standard operating conditions. Such gaps in the system of situational and tactical knowledge reflect the logical defects of the pilot's experience in the form of a loose crown of the situational flight tree near restrictions on the change in the functional characteristics of the aircraft flight.

In the development of a special situation, the components of the human factor appear in different ways, taking into account the state of individual branches in the crown of a tree (fractal). In particular, the figure shows fractal tree defects due to a lack of pilot knowledge and experience necessary to overcome special situations.

The fractal model of the flight situation is convenient for analyzing the (geometric) formation of the pilot's adequate internal flight model in multifactorial conditions.

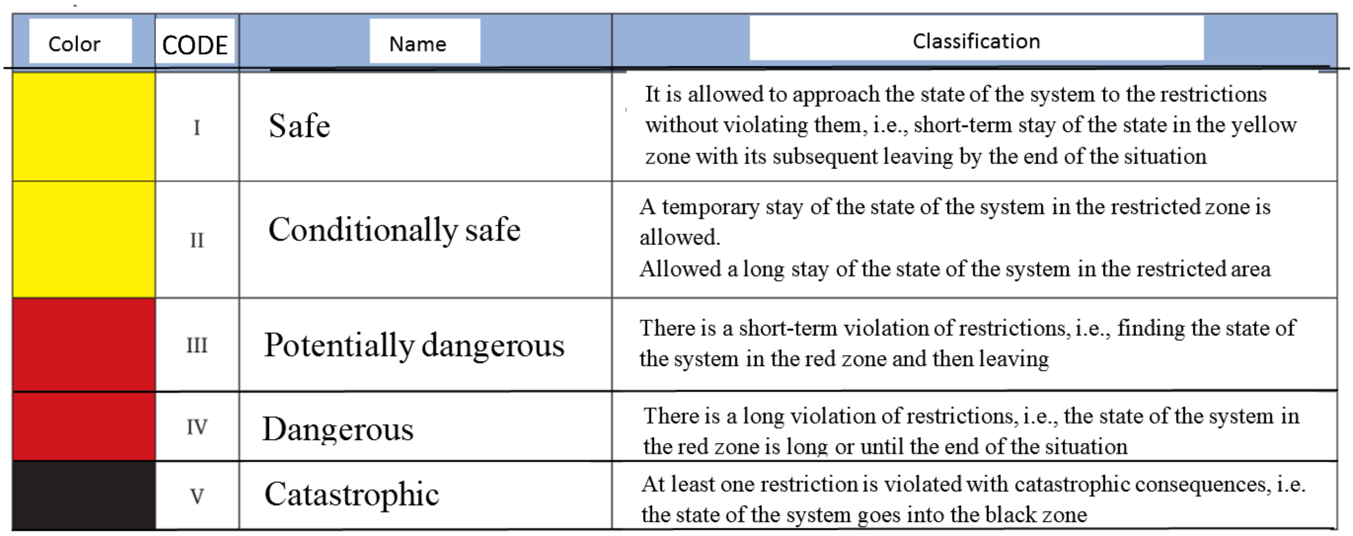
This is evidenced by the following assessments by test pilots of the severity of situations: “a combination of flight circumstances”, “an analytical description of the behavior of the aircraft in different flight modes”, “a clear understanding of the limit”, “a variety of factors”, “an unfavorable combination of circumstances”, “many possible solutions "," Simultaneous parallel analysis of <...> different, almost impossible intersecting solutions ". The above concepts are based on the well-known fuzzy linguistic variables L. A. Zade.

A fuzzy restriction describes the transition from unacceptable (dangerous) values of the chosen variable to acceptable (safe by the level of integral risk) values. The features of the presented model for identifying many combinations of hazardous factors (on a fractal) serve as the basis for the search for safety indicators. This allows you to completely abandon the probability indicators adopted, for example, which it is impossible to calculate (and predict in situations for GA). Fractal geometry in flight safety theory is extremely interesting and useful for creating “virtual” analogies of flight situations. But this approach is still practically useless, since the equations of the “root and trunk" of the tree cannot be described analytically due to the complexity of real flight situations.

Significant successes were achieved through the creation of stochastic simulation combinatorial computer models. However, this significantly increases the complexity of research and is not always justified, so the transition to BP indicators in accordance with the recommended ICAO practice is inevitable. It is advisable to implement the example of systems with many distinct discrete states and its subsets with fuzzy elements.

1.2.3

The rules are correctly borrowed from a table (Table 1), where five categories of flight safety are defined: safe (I), conditionally safe (II), potentially dangerous (III), dangerous or prohibited (IV), and catastrophic (V). This scale allows you to automate the task of splitting any situational tree or many related situations combinations of events with the same levels. Based on the recommendations known from ICAO and from, it is necessary to accept the default postulate: reliability is the basis of security, but with the help of provisions only reliability cannot be evaluated and, moreover, effectively ensured. It is incorrect to enter, by analogy with reliability, the indicator “average time before the disaster” in case of rare events. Methods of hazard (safety) assessment using additional information sources without statistics are unreliable.



Color	CODE	Name	Classification
🟨	I	Safe	It is allowed to approach the state of the system to the restrictions without violating them, i.e., short-term stay of the state in the yellow zone with its subsequent leaving by the end of the situation
🟨	II	Conditionally safe	A temporary stay of the state of the system in the restricted zone is allowed. Allowed a long stay of the state of the system in the restricted area
🟥	III	Potentially dangerous	There is a short-term violation of restrictions, i.e., finding the state of the system in the red zone and then leaving
🟥	IV	Dangerous	There is a long violation of restrictions, i.e., the state of the system in the red zone is long or until the end of the situation
⬛	V	Catastrophic	At least one restriction is violated with catastrophic consequences, i.e. the state of the system goes into the black zone

Table 1. Safety indicator assignment rule

1.2.4 Definitions and principles of safety management based on risk calculation models

According to the following definition: a flight safety management system is a set of interconnected and ordered elements and modules of the Sets type (in the minimum composition according to ANNEX-19), designed to achieve the management goal of ensuring the necessary level of flight safety in accordance with the adopted system approach. At the same time, it is recommended to use “preventive” (proactive) management of the STS state taking into account risk factors based, for example, on ICAO algorithms with limited statistics (if the occurrence of rare events is uncertain).

Due to the difficulties with a reliable assessment of the safety indicators of systems in rare events, one has to switch to approaches like Fuzzy Sets. In the theory of flight safety, types of uncertainties can be distinguished by signs of the functioning of systems: deterministic; statistically defined (clear statistically determined); fuzzy models on fuzzy subsets of objects; game models and "fractal" processes.

A random variable is a parameter or physical quantity whose value cannot be predicted in advance, but its probabilistic (statistical) properties are deterministic and clear. The uncertainty of the type of randomness reflects the property of the measurability of functions from a random event in the form of a set of clear probability density functions, the existence of mathematical expectation, variance, etc. in the case of reliable statistics. The integral levels of risks and chances in the problem of rare events should be assessed in the absence of reliable statistics on the occurrence of disasters. Preventive control actions on the state of the system make it possible to exclude the occurrence of accidents or disasters before they can occur with a known set of threats. For situations with rare events, a number of statements must be made. Risk - a fuzzy measure of the amount of danger in the conditions of STS with the identified threat and hazardous factors (risk - large, small, permissible).

Chance is a fuzzy (predicted) measure of the amount of “good luck” in an experiment or in a system state under the conditions necessary for the implementation of a favorable forecast event B (chance is negligible, small, there are few chances for a favorable forecast event B inverse to risk event R). The probabilistic approach does not ensure the reliability of calculations in rare events, therefore it is necessary to determine only indicator estimates of the PS level in the STS state in the form [0, DR, 1] for admissible STS states based on the DB: 0 - safe, 1 - dangerous, DR - acceptable (with fuzzy indicators “not very”, “completely”, “enough”, etc.).

Preventive (proactive) control decisions are found on the basis of categories of events of type R, B in case of refusal of "process" according to ICAO. The significance of risks can be estimated on the basis of a two-dimensional risk assessment model (E. A. Kuklev's formulas are an analogue of the ICAO concept, but in a mathematical form), while it is proposed to adopt the following relationships (Fig. 2):

$$\widetilde{R} = \left(\mu_1 ,\ H_R \,\middle|\, \Sigma_0 \right);$$

$$\hat{R} = \hat{f}\left(\widetilde{R} \,\middle|\, \Sigma_0 \right) = \hat{f}\left(\mu_1 , H_R \middle| \Sigma_0 \right)$$

Figure 2. Formula for preventive control decisions

The safety management of the considered complex technical systems is formed for structures and states defined in fuzzy sets in the Fuzzy Sets class based on risk level assessments. The logical conditions of the possibility of disasters due to the loss of the properties of the functionality of systems under the influence of some external flow of damaging factors, including the failure of physical elements, are checked using the equation of the logical conditions of disasters. The interpretation of the physical meaning of danger, adopted in documents not only in the technical, but also in the financial sphere, is as follows: in the danger zone, objects may fall and injuries to personnel and casual visitors may occur. An event has not yet occurred in this zone, but if it does, damage will occur with serious consequences. This defines the vulnerability window.

1.2.5 Weighting risks and odds

It is proposed to take as a basis some recommendations from. As in the PSA, failures are considered only of the type of functional failures A (t) *, which are in the logical sense inverse to the main event A (t) or to a set of events - normal functioning in normal mode. But at the same time, instead of “probabilities” in a system with a general set of events, it is now proposed to search for conditions for “loss of a property of functionality” in a conditional binary outcome space without probability indicators.

Acceptable decisions on the preventive (proactive) management of the state of the systems are made on the basis of “clean strategies” by weighing the risks and chances estimated using the indicators from the table, without calculating probability indicators. In the investigated states of systems, clearly predictable events in conditional binary outcome spaces with indicators of the possibility of occurrence in fuzzy subsets should be identified. The importance of integrated risks can be estimated using the ICAO risk matrices (NASA) or the well-known risk analysis matrices (according to the Ministry of Emergencies or ICAO) using indicator estimates of the level of danger, which follows from the methodological principles of the theory of fuzzy sets (and subsets). Interpretations of the concepts introduced reflect the concepts of Fuzzy Sets.

The scientific problem consists in constructing functions of quality estimates from the set of elements forming a tuple (note: not space). Moreover, in the proposed approach in this article, it is possible to use combinations of the classical PSA method and new provisions of the risk-based approach. The basic position is as follows: the fuzziness of information about the uncertainty of the occurrence of a rare event in the STS is a scientific objective fact, therefore it is most important to study the physical possibilities of the occurrence of conditions for the system to lose its functions with some fuzzy measure of the level of the studied possibilities.

For situations with rare events, it is necessary to take the following: risk - a fuzzy measure of the amount of danger in the conditions of the STS with the identified threat and dangerous factors (the risk is large, small, acceptable). Thus, a fractal analysis of special situations taken from the practice of flight operation of aircraft of various types showed the prospects of the method for assessing and predicting rare events in aviation in combination with a risk-based approach to finding scenarios of catastrophes in systems with many discrete states.

The methodology of preventive (proactive) safety management allows to identify features and anomalies in the behavior of the system operator (pilot, automatic) - aircraft - operational environment in multifactorial situations and near flight restrictions. The criticality of the predicted scenarios can be determined using the FMEA standard, which allows us to establish that the cause of the accident is a chain of events or a scenario with the system getting into a dangerous state in the form of chains of events. The likelihood of such scenarios does not matter if the damage from the accident is significant and unacceptable to system users. The only important thing is the assertion that a critical scenario is possible even with a probability of “almost zero”.

1.3 Use of CALS/PLM technologies

With the introduction of digital computer technology into the on-board equipment complexes, its specific features became apparent. Among the list of on-board equipment failures, the most problematic for monitoring and diagnostics should be recognized as intermittent failures, also called short-term, latent, floating, self-clearing or flickering failures. Such failures cause failures of all on-board equipment and can lead to catastrophic situations. Failure is understood as a self-eliminating violation of the normal functioning of on-board equipment due to short-term effects on some element (or set of elements) of external and internal factors.

After a failure, the equipment can operate normally for a long time, but information may be distorted during transmission or processing operations. The problem of failures in on-board equipment has recently been given increased attention. At the same time, the key problem of dramatically improving the reliability of equipment, which includes tens of thousands of potential sources of failure (multi-pin connectors, contacting BIS and VLSI devices, printed conductors, communication lines - interface buses, power buses, and others), is a failure diagnosis directly related to detection and registration of sources of failures in the equipment.

1.3.1 At the junction of CALS and SCM

The need to support all stages of the product’s functional life cycle is becoming increasingly apparent for domestic manufacturers. The full use of CALS / PLM technologies requires the consolidation of the efforts of a large number of fairly independent participants in the production process, which sometimes form complex, logistic chains. Thus, achieving the effectiveness of solving the above problem is impossible without the involvement of supply chain controls. One vivid example of the need for such a combination is the aviation industry. A certain mess that has occurred in it in recent decades, which has given rise to a real “zoo” of technological and organizational standards and solutions, makes the creation of an integrated industry-specific PLM / SCM solution relevant.

Integrated Continuous Acguisition and Lifecycle Support is inextricably linked to supply chain management. This is especially important in the event of a return of goods as a result of a complaint or the movement of the material flow “back” So, such a movement can occur in the framework of after-sales and customer service.

Let us dwell on the relationship of these processes on the example of the interaction of the aviation industry with civil aviation. Such interaction should be considered within the framework of a unified supply system of aviation resources. An integrated supply chain provides logistical support for the operation, maintenance and repair of aircraft and components. Aviation industry enterprises supply aviation technical equipment, including spare parts, to operational enterprises - airlines, repair plants and other industry service organizations. Thereby, the resource component of the airworthiness of the operated aviation equipment is maintained throughout the entire product life cycle (LCI).

Unfortunately, at present in Russia there is no experience in organizing after-sales support for the operation of aircraft based on international standards and logistics information systems. Meanwhile, enterprises of the domestic aviation industry have significant potential, while possessing colossal experience in organizing cooperation. Indeed, up to one and a half thousand enterprises of machine building, instrument making, radio electronics and other related industries participate in the creation of only one aircraft in cooperation. At the same time, there is a gradual stabilization and even revitalization of the airline industry; According to the forecasts of the State Center for System Research, the passenger turnover in air transport will increase by 5% per year. That is why qualitatively new approaches to the supply of aviation technical equipment that ensure the efficient use of airline resources are becoming in demand.

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The aviation industry launched mass production of new types of aircraft, such as the Il-96-300, Tu-204, Tu-214. (True, the production process is constrained by the lack of the necessary funds to purchase new equipment from most airlines, with the exception of several of the largest.)

When solving the problems of the effective functioning of the domestic economy, the use of logistic information technologies for coordinating intersectoral interaction is of particular relevance. Further deepening the specialization of production and marketing of products involves the formation of integrated supply chains that unite various industries. For example, participation in the design and creation of aviation equipment naturally interests the aviation industry enterprises in its effective application in the operating industry, that is, in airlines. Thus, it is necessary to ensure the fruitful interaction of all participants in the chain: "design - production - purchase - operation - maintenance and repair."

Enterprises involved in the supply of aviation technical equipment (it includes aircraft products, systems and products of lighting equipment, radio equipment for flight support and communications, ground-based aviation equipment and spare parts for them) can be attributed to various categories of participants in the aviation market. It should also be noted that a number of regulatory bodies, including the Ministry of Transport, the Interstate Aviation Committee, Rosaviakosmos, and Gosstandart, have a significant influence on the market of aviation technical equipment and intersectoral supplies of resources. The direct participants, represented by suppliers, manufacturers and airlines, are largely divided, which affects the overall efficiency of the industry and end users.

The multiplicity and heterogeneity of participants in the aviation market, along with the lack of mechanisms for intersectoral interaction and self-regulation of flows of aviation technical equipment, has a negative impact on the quality of service for participants in supply chains and end users, the state of flight safety and the level of operating costs. In maintaining the airworthiness of aircraft, a significant role is given to spare parts and components. They must fully comply with all production and technical parameters declared and confirmed at the stage of certification and production of the aircraft.

A large number of legal, and sometimes “gray” suppliers, including uncertified re-exporters, pose a lot of problems, not allowing the state control over the flows of aviation technical equipment to be properly implemented. Without this, it is impossible to fully monitor flight safety and achieve an increase in airline profitability and an increase in tax revenues. Improving the supply of aviation parts is an important technological and economic problem. It can be solved with the help of integrated logistic support.

Delivery participants are:

- manufacturers and / or suppliers of aircraft, spare parts and assemblies, including wholesale companies and warehouses;
- operators and consumers of aircraft, spare parts and assemblies;
- exporters and aircraft, spare parts, assemblies;
- bodies performing a control function to ensure the supply processes (certification system);
- executive authorities coordinating the work of supply parties and responsible for the development of decisions and departmental documents related to the regulation of interaction of aviation resources market entities.

1.3.2 CALS and SCM - integrated supply chain

Cancellation of a flight due to the absence of any part is very expensive. It is quite natural that in conditions of high competition, the need to reduce production costs and airline inventories are increasingly showing interest in integrated logistics methods and technologies that affect the maintenance of high reliability of scheduled flights. The biggest problems arise at the planning stage. We need not only a good statistical record of the reliability of spare parts, but also the management of their life cycle using CALS technologies. The entire supplier-consumer chain involved in the production and supply of aircraft equipment must have a common understanding of the challenges and risks associated with the efficiency of logistics processes. The initial prerequisites for this are: the growing needs of airline consumers in the reliability of spare parts and aircraft technology itself; growth in passenger and cargo traffic; application of safety criteria for the supply chain and its participants.

FIRST LEVEL. Manufacturers of gliders and aircraft engines. These are the few enterprises that produce the largest blocks and assemblies. They are called upon to exercise global control over all stages of the product life cycle.

SECOND LEVEL. Suppliers / subcontractors who are involved in the manufacturing process of the airframe and a large number of components.

THIRD LEVEL. Suppliers / subcontractors / brokers whose activities in the aviation industry do not always relate to their core business. Moreover, the safety criterion of flight is not perceived by them as the main determining factor.

In a multi-level supply chain, risk compensation occurs. The highest risks affecting efficiency arise for tier-one suppliers. Relatively insignificant risks of the third level may have the most negative impact on maintaining the airworthiness of aircraft or the state of end-user inventory. The "critical points" in the chain "supplier - consumer" should include manufacturers of the most important components and suppliers-monopolists. All processes for the supply of aviation technical equipment should be tied to the level of reliability of the aircraft's readiness for departure, which determines the initial logistics requirements.

When interacting with a multi-level chain of suppliers and airlines, a number of circumstances should be taken into account. First of all, the appearance of failures in the chain causes higher risks for first-tier suppliers, which are most dependent on the reliable functioning of the entire chain. Say, the supply of spare parts of unknown origin at the third level can be a serious problem for suppliers of the first level. Risks associated with maintaining airworthiness and flight safety most affect airframe manufacturers and aircraft engines than the next two levels of suppliers of aviation technical equipment.

Strengthening exclusively administrative control over subsequent links of the supply chain and its levels is not always justified. It requires tremendous efforts and financial resources, which neither government bodies, nor manufacturers, nor transporters, nor shippers possess, and at the same time does not ensure proper efficiency. That is why it is necessary, on the one hand, to expand the risk management area throughout the network, and on the other hand, to concentrate on “critical points”. For this, appropriate tools are needed.

Thus, the need for integration is experienced not only by manufacturers, but also by air transport and infrastructure enterprises. Proper supply chain management tools can provide companies with additional key competitive advantages. Integration allows you to manage the entire logistics complex as a whole.

The presented model indicates the need to create a multi-level logistics system of suppliers of aviation technical equipment. The whole chain of suppliers involved in the process of creating aviation equipment, maintenance and repair should have a common understanding of the tasks, methods of logistic support for the identification and control of spare parts and suppliers.

These tasks of logistic support are successfully solved through the integration of CALS and SCM technologies. CALS (Continuous Acguisition and Lifecycle Support) tools provide continuous development and product life cycle support, and SCM (supply chain management). Information support covers the processes of design, production, operation and disposal. The goal of integrating CALS into a single logistics system is to increase the efficiency of all participants in the chain by reducing the time from product development to operation, reducing costs and increasing the level of customer service.

The aviation industry enterprises form product data management systems on the basis of electronic catalogs of components and spare parts integrated with the electronic documentation preparation unit. Through the collection and analysis of information about aviation resources, the system of objective control of aircraft, life cycle processes about products “enter” the operational zone. Airlines, in fact, are the ultimate consumers of CALS solutions and, along with the aviation industry, are interested in their effective application. The business processes of industrial enterprises are integrated with the processes of airlines through the most important channel for the movement of resources and spare parts - an integrated supply chain.

1.3.3 Integrated logistic support

Until now, in our country, despite the development of market relations, insufficient attention has been paid to issues related to the logistics of after-sales stages of the product life cycle. At these stages, the purchase and delivery of products, commissioning and operation, after-sales service and repair, and the supply of spare parts are carried out. In Western terminology, this block of questions is united by the concept of Integrated Logistic Support, which is an essential component of the CALS concept.

The objectives of integrated logistics support include:

- impact on design to ensure future optimal operation of equipment;
- definition and clarification of resources for ensuring the product life cycle;
- the supply of necessary resources at the lowest cost throughout the life of the equipment.

According to experts, the market for maintenance and repair of aircraft will grow from about $ 31 billion in 2000 to $ 44 billion by 2010. The prospects and problems of maintenance and repair are the same as in air transport: consolidation of airlines, competition and the use of advanced technologies. According to Van der Stigele, Vice President of Transport and Logistics at Credit Suisse First Boston, airlines will join forces for joint aircraft maintenance and forcing all suppliers to lower prices for parts and services.

The ILP for the operation of aviation equipment is aimed at solving such problems as the engineering support for the technical operation of aircraft, the operational restoration of aircraft, the provision of spare parts for the airline fleet, the study of the technical condition of aircraft, monitoring the level of reliability of equipment, reducing operating and repair costs, etc.

The creation of an intersectoral system of interaction between industrial and transport enterprises on the basis of integrated logistic support will help coordinate the efforts of various departments and enterprises, as well as business communities, one way or another involved in this area. These include the Ministry of Defense, the Ministry of Economic Development, the Ministry of Industry and Science, the Ministry of Transport, Rosaviakosmos, the Interstate Aviation Committee, the State Standard, associations of manufacturers and suppliers of equipment and components, an association of operators of aviation equipment, etc.

It is proposed to use information systems as the base ones, which include modules of expanding logistic interaction. Self-regulatory logistics centers of competence are seen as the main tool for intersectoral coordination of resource supply and the provision of electronic services. Among the main functions that should be provided:

- coordination at the information level of all participants in the logistics process;
- electronic processing and analysis of logistics data based on standards;
- identification of unauthorized and non-certified deliveries of aircraft equipment;
- organization of the exchange of necessary information between manufacturers, suppliers, operators.

Within the framework of the system under consideration, an electronic platform for trading in spare parts using international aviation standards can play a significant role in structuring the aviation market and translating it into logistics methods of self-regulation.

Its key tasks are to minimize duplication of the processes of production and delivery of aviation technical equipment in the field of operation, reduce costs and improve the quality of service. The use of electronic bidding followed by the inclusion of a logistic control system will significantly reduce the resources consumed and the risks of improper execution of contracts, and create an information infrastructure for supply support services.

Conclusion to chapter

The open architecture of the information system can ensure high efficiency and effectiveness of the supply of aviation technical equipment, implements logistics functions in the field of order formation, logistics, operation and repair of aircraft. Appropriate organizational and technological solutions will contribute to improving the reliability of operation, regularity and safety of flights, significantly reducing the costs of aviation enterprises and civil aviation. The creation and development of a model of an intersectoral system of supplying resources based on integrated logistic support will allow: ousting uncertified parts and unscrupulous suppliers from the market; reduce the costs of airlines and other market entities for maintaining airworthiness, the purchase of aviation technical equipment, maintenance; increase flight safety; tighten control over the critical parameters of aviation equipment.

Logistic functional diversification provides the following tasks:

- cataloging and accounting of the implementation of supplies for state needs;
- determination of the resource component of enterprises based on the creation and maintenance of a single electronic database;
- implementation of quality systems;
- the creation and maintenance of an intersectoral supply system of aviation resources.

As part of the solution to the problem of ensuring logistic functional diversification by the GOST R / TK 355 / PK 6 standardization subcommittee and the State Center for System Research, the program "A system platform for creating an industry of supply chains of resources and electronic logistics services in the Russian Federation based on harmonized international standards" has been developed. Among the objects of aviation activity requiring logistic support, the program highlights: information technology; maintenance and repair; aviation services and quality systems; freight and passenger transportation; licensing and certification system; aviation leasing; supply of resources and spare parts; flight safety.

The creation of an intersectoral supply system of aviation resources is primarily aimed at improving the efficiency and reliability of aviation leasing, maintenance and repair of aviation equipment, and flight safety.

CHAPTER 2

POSSIBILITIES OF A PROBABILISTIC-PHYSICAL METHOD FOR ASSESSING THE RELIABILITY OF AIRCRAFT COMPONENTS

The adequacy of theoretical solutions and correctly processed experimental data allowed the authors of these studies to propose a method for calculating the reliability of various technical products, devices and systems taking into account degradation processes that cause aging, wear, fatigue, etc., when failure rate is a function of operating time. In contrast to the well-known and discussed above lambda method, which assumes the independence of the intensity of failures from operation, this method is called probabilistic-physical.

Probabilistic-physical method of reliability calculation takes into account the dependence of the probability of reaching the limit value by the physical determining parameter on the operating time, ie connects the probability of failure with the physical parameter that causes failure. As a result, the parameters of the obtained probability distribution of failures have a certain physical meaning. In particular, in the considered two-parameter probability-physical DN- and DM-models of failures the parameter of scale of distributions of failures coincides with average speed of change of defining parameter, and the parameter, forms of distribution - with coefficient of variation of this speed.

The application of the probabilistic-physical method for the calculation of indicators of reliability, durability and safety of non-renewable and renewable technical systems assumes the availability of initial information about the average values and coefficients of variation of operating time to failure of the elements forming the system under study. Therefore, consideration of the probabilistic-physical method should begin with the definition of these characteristics of the elements.

2.1 Evaluation of the durability of systems by the criterion of limit state

Durability of technical systems is defined as the ability to maintain a working condition until the onset of the limit state with the established strategy of maintenance and repair. An indicator of the durability of renewable systems is the average service life, which is defined as the mathematical expectation of service life. Service life, as well as other indicators of reliability (operating time before failure, operating time between failures) reveals a significant statistical variance. This scatter can be a characteristic of the achieved level of technology, as well as technological culture and discipline. Until recently, due to the use of the exponential failure model, there was no method of analytical calculation of the durability of technical systems.

Technical and operational characteristics of durability (assigned service life and assigned resource) were established at the design stage for general reasons of obsolescence of equipment, information of economic nature or on the basis of data on durability of analogues obtained as a result of long operation. Note that these characteristics, strictly speaking, are not indicators of the durability of the equipment. The mathematical apparatus of reliability research on the basis of DN-distribution of operating time to failure allows to make the analytical forecast of indicators of durability of the equipment of the aircraft at a design stage by criterion of a limiting condition.

The calculation of the durability (average service life) of renewable components of avionics (Pic. 3) on the basis of the probabilistic physical method is reduced to the solution of the transcendental relative T equation for a given criterion of the limit state ω:

$$\omega_{\text{доп}} = \sum_{i=1}^{N} n_i \sum_{m=1}^{\infty} \frac{m \cdot \sqrt{\mu_i}}{\nu_i \cdot T_{\text{сл}} \cdot \sqrt{2\pi \cdot T_{\text{сл}}}} \cdot \exp\left[-\frac{\left(T_{\text{сл}} - m \cdot \mu_i\right)^2}{2\nu_i^2 \cdot \mu_i \cdot T_{\text{сл}}} \right]$$

Figure 3. The calculation of the durability of renewable components of avionics

2.1.2 Gamma-percent service life

Gamma percentage service life is a frequently used indicator of the durability of electronic on-board and ground equipment. Thus, in the technical characteristics of the modular MS system, which is a set of universal means of measuring electrical parameters for equipment of various purposes, and registered in the register of special measuring instruments for civil aviation, the following reliability indicators are given:

- average operating time before failure - not less than 8560 hours;
- gamma-percent resource - not less than 10000 h at γ = 95%;
- gamma-percent service life - not less than 15 years at γ = 95%;
- average calendar service life (before writing off) - not less than 20 years;
- gamma-percent shelf life - not less than 10 years at γ = 95%.

The initial data for calculating the gamma-percent service life are:

- N - the number of typonominal (differing in intensity-failure of elements) of the system;
- the number of elements of each type ni, i∈, 1 N;
- failure indicators of elements μi, νi;
- criterion of the limit state of the system.

The figure (Fig. 4) shows the result of the study of the influence of the level of failure to reach the limit state γ on the value of the gamma-percent service life of the system. The values of gamma-percent service life Tγ and quantile X are summarized in a matrix on which graphical dependences are constructed.

$$T\gamma := \begin{array}{l} \left(\begin{array}{ccccccccccc} 90 & 91 & 92 & 93 & 94 & 95 & 96 & 97 & 98 & 99 & 99.9 \\ 0.366 & 0.354 & 0.341 & 0.327 & 0.313 & 0.298 & 0.281 & 0.262 & 0.239 & 0.208 & 0.145 \\ 7661 & 7403 & 7134 & 6852 & 6553 & 6232 & 5879 & 5480 & 5000 & 4349 & 3032 \end{array}\right) \end{array} \begin{array}{l} -\gamma \\ -X \\ -T_{\gamma.\text{сл}} \end{array}$$

Figure 4. Influence of the level of failure to reach the limit state

2.1.3 Forecasting the residual life of operated systems

Estimates of residual life, as well as residual life, are needed to determine the residual cost of operating the avionics and, accordingly, the cost of spare components (within the cost approach). When implementing the revenue approach, residual resources and service life determine the period during which cash flows should be expected, and therefore their values significantly affect the efficiency of the airline.

The methodology for estimating residual resources and service life is based on the notion that the residual service life (resource) of equipment is a random variable that can be described by probabilistic-physical models. With this approach, you can understand and take into account in the calculation of the cost of equipment the fact that the actual service life may significantly exceed the norm. In this case, the resource (service life) set in the documentation has the meaning of the minimum service life (resource), during which the manufacturer guarantees normal operation with a high probability.

The individual characteristics of the avionics component (residual life and residual service life) can be accurately determined only after its limit state has occurred. Until these events occur, we can only talk about predicting these values with greater or lesser probability. Therefore, the residual service life is the predicted value of the expected time after which the facility will reach the limit state and will be decommissioned. It is worth emphasizing that the residual term in the general case is not equal to the remaining time before reaching the normative term. The same applies to the residual resource.

2.2 Diagnostic software for fail-safety of avionics

A segmented complex system (Fig. 5) can ensure fault tolerance at the level of airworthiness and flight regularity requirements only if there are diagnostic tools (monitoring) of the platform’s operating condition with sufficiently high characteristics of control completeness, diagnostic depth, and reliability of proper functioning. Therefore, the health monitoring system must perform the following functions:

- detection of malfunctions in the platforms;
- elimination of errors and other discrepancies;
- automated recovery of the platform in case of hardware failures and segmentation violations, including group-type failures and cascaded flight failures;
- restoration (repair) of platforms with failed redundant hardware components during routine maintenance.

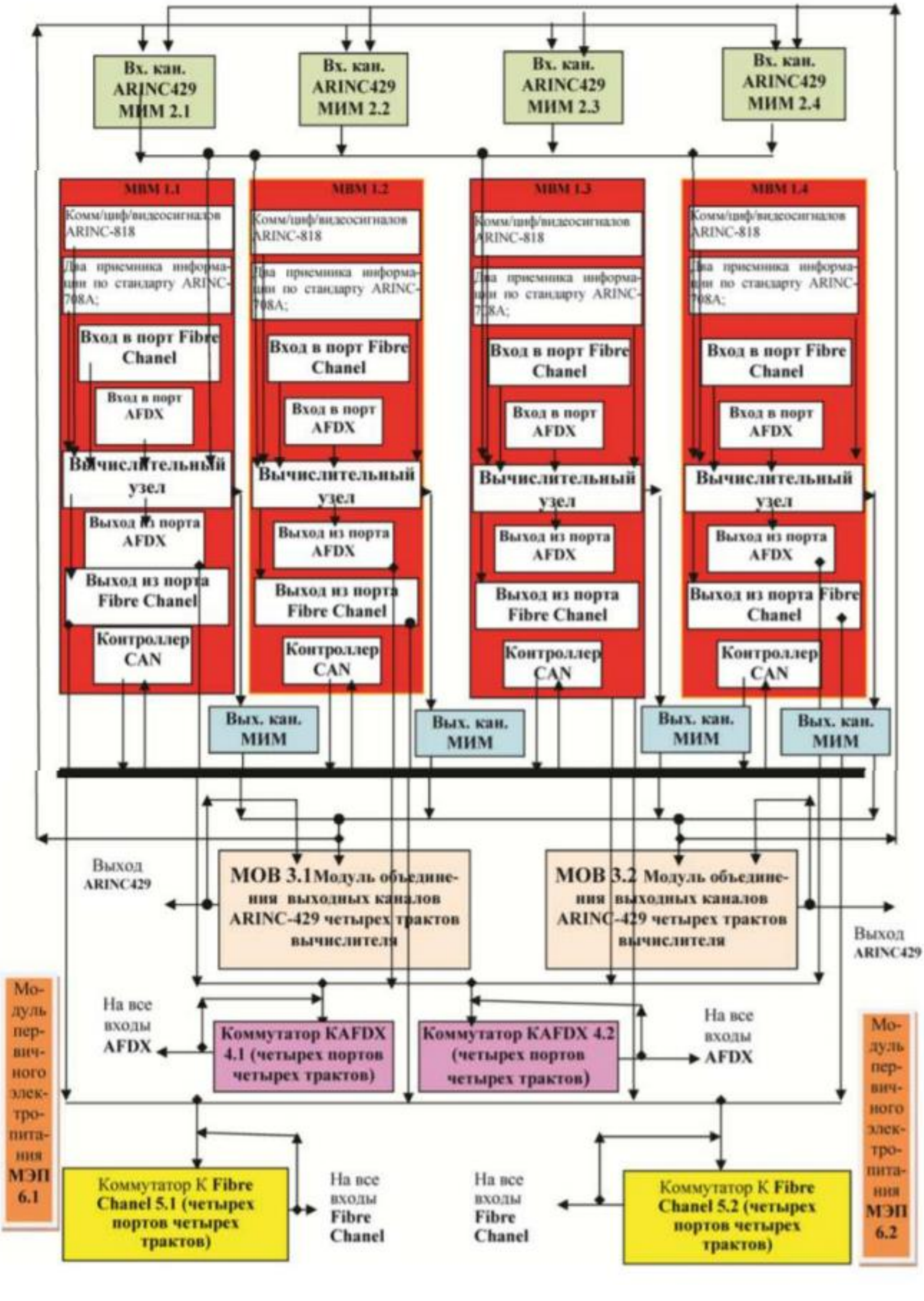


Figure 5. A segmented complex system

The methods used to detect and resolve the consequences of platform failures should not depend on the supported applications. The elimination of failures also includes the detection of failures and the errors caused by them, their exact identification when they occur and the adoption of adequate responses. The interface-computing process in the platform is organized in such a way that in each cycle of Real Time (Fig. 6), the following two hardware-software systems operate independently but interconnected:

- monitoring of the operating state, which includes an analysis of the state of the platform components and its reconfiguration in the event of failures and failures;
- solving functional problems on a workable interface-computing resource.

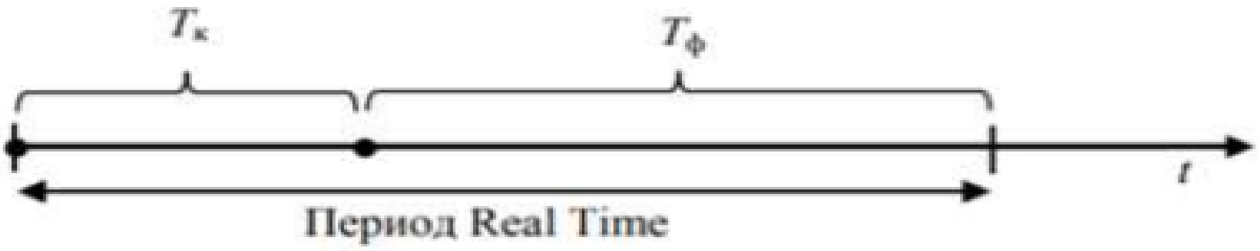


Figure 6. Cycle of Real Time

For platform components on which critical functions are implemented, the failure parry time should be less than one second, since a catastrophic situation can develop in no more than one second.

Failures of non-critical functions can be detected and countered on the interval of many cycles of the Real Time period. The period of monitoring the operational status of non-critical functions can be several minutes. We introduce a restriction on all types of monitoring of the operating state for ten minutes. Then it can be argued that by the end of each ten-minute interval of the aircraft’s flight, before a new failure occurs, the system for which the operational status was monitored will be operational. We define the above values of the parameters of the diagnostic tools, based on compliance with the requirements of airworthiness and regularity of flights.

The reliability of the correct functioning depends on the implemented control errors when the diagnostic tools generate a false signal of failure or miss violations in the structure or information. The presence of control errors reduces the significance of the correct functioning of the interface-computing path. The reliability of diagnostic information depends on a number of factors, both technical, due to the specific implementation of digital structures and the strategy for their maintenance, as well as semantic, associated with the adopted laws of the presentation and processing of information, as well as software. If we do not take into account the semantic value of the information itself, but consider only the reliability determined by the reliability of the equipment, the parameters of the selected monitoring methods and diagnostic tools, then we can talk about the reliability of the IV platform. The reliability of the correct functioning of the platform is defined as the truth of the output and characterizes:

- quality of flight functions performed by the platform structure
- the ability of the applied diagnostic tools to fix the correctness or fallacy of the result of the platform.

2.3 Probability-physical forecasting of reliability of operated components of avionics

The probabilistic-physical approach is based on the use of the laws of failure distribution (reliability models) arising from the analysis of physical degradation processes in the elements of technical systems and leading to their failure. In this case, the physical processes of degradation are considered as random processes. This approach to the study of reliability is called probabilistic-physical, since it directly establishes a connection between the probability of reaching the limit level by a physical determining parameter, i.e. binds the values of the probability of failure and the physical parameter that causes the failure.

As a result, the parameters of the obtained probability distribution of failures have a specific physical meaning. In particular, in the considered two-parameter probabilistic physical failure models, the scale parameter coincides with the average rate of change of the determining parameter, and the shape parameter with the coefficient of variation of this speed. It is advisable to use the possibilities of probabilistic-physical prediction of the reliability of the operated components of on-board equipment (BO) in the interests of integrated support for maintenance and repair (MRO) of aircraft.

The development and implementation of an information system in the structure and operation of airports will ensure the efficient operation of complex high-tech products, which undoubtedly are the BO and aircraft systems in general, and the operation of which, as you know, often costs the owner much more than acquiring. According to international statistics in the field of information technology, the use of the latter in the creation and operation of complex high-tech systems is the guarantor of a continuous increase in productivity and quality without changing the time spent. Possibilities of probabilistic-physical prediction of reliability.

The mathematical apparatus for solving reliability problems based on diffusion distributions leads not only to more accurate predictive estimates than the traditional one based on an exponential model, but also to solving a significantly larger number of typical reliability problems. If 25 typical reliability problems are solved on the basis of non-monotonic (DN) distribution, then only 13 of the 25 mentioned problems are solved on the basis of the exponential distribution. The high universality of two-parameter diffusion distributions allows us to solve the necessary problem of unifying the methods of measuring the reliability of the element base and BO aircraft systems (both electronic and and mechanical). It turned out that the probabilistic-physical methods for assessing reliability indicators are very effective under the conditions of observation (during operation) of highly reliable objects, in particular, avionics as part of the aircraft BC, when there are small statistics of failures. In such a situation, due to the use of additional a priori information about the physical processes of degradation of the observed objects, it seems possible to obtain predictive estimates of reliability indicators.

The probability-physical technology of reliability research makes it possible to supplement the electronic systems of information support of aircraft maintenance and repair with computer algorithms implemented, in particular, in the Mathcad package and providing forecasting: the average operating time to failure of the components of the aircraft during flight operation in the presence of single failures; average operating time to failure of the components of the BO in the absence of failures in the process of flight operation; residual resources after the failure-free operation of the BO system for a fixed time; the average service life (and calendar duration of operation) of the BO components for a given criterion of the limiting state; gamma-percent life of the components of the BO at a given value of the probability of not reaching the limit state; distribution of the number of failures of components and systems at the stage of long-term operation of BO (throughout the entire service life); the probability distribution of exactly m failures, m 1

M, during the long-term operation of BO; quantitative assessment of spare components in the airline’s exchange fund for a given value of the sufficiency indicator.

The indicated possibilities of probabilistic-physical forecasting of reliability are a very significant addition to the information support of aircraft maintenance and repair, which includes the interaction of the operator with the enterprises of the developer, supplier, and government safety management and control bodies in terms of ensuring and maintaining the airworthiness of the aircraft. In support of the foregoing, we present some of the indicated realizations of the probabilistic-physical forecast of quantitative estimates of reliability indicators. The initial data for the implementation of the forecast capabilities are the average value of T0 and the coefficient of variation of the time between failure of the studied avionics components. In some cases, these characteristics are known to the operator. If a priori reliability estimates are not available, then they can be obtained after the start of operation when the first failures appear.

Consider the algorithms for predicting the reliability of avionics components, including for the case when the initial data on the reliability of the operator are unknown. Prediction of mean time between failures in the presence of single failures. Let N = 50 of the same type of computing units be operated as part of the aircraft's onboard equipment. During 3000 flight hours after the start of their operation, the loss of flight functions (operability) was recorded by the built-in monitoring tools and confirmed during ground inspections of three units (K = 3). The operating time of the blocks to failure amounted to 2010, 2780 and 3000 hours.

We will find the MTBF (MTTF) by the quantile method (Fig. 7), assuming that the MTBF distribution of the operated units is described by the DN-model of reliability. Then the expression for the probability of the jth failure is defined as:

$$\Phi\left(\frac{t_j - T_o}{\nu \cdot \sqrt{t_j \cdot T_o}}\right) + \exp\left(\frac{2}{\nu^2}\right) \cdot \Phi\left(-\frac{t_j + T_o}{\nu \cdot \sqrt{t_j \cdot T_o}}\right) = \frac{j}{N}$$

Figure 7. Quantile method

The point estimate of mean time to failure is calculated according to (Fig. 8):

$$T_{\text{o}} = \frac{1}{K} \cdot \sum_{j=1}^{K} \frac{t_j}{X(j/N, \nu)}$$

Figure 8. The point estimate of mean time to failure

In which the operating time is determined by the values of the operational probability of failure and the coefficient of variation of the time between failures by solving the transcendental equation.

2.3.1 Prediction of m failure distribution

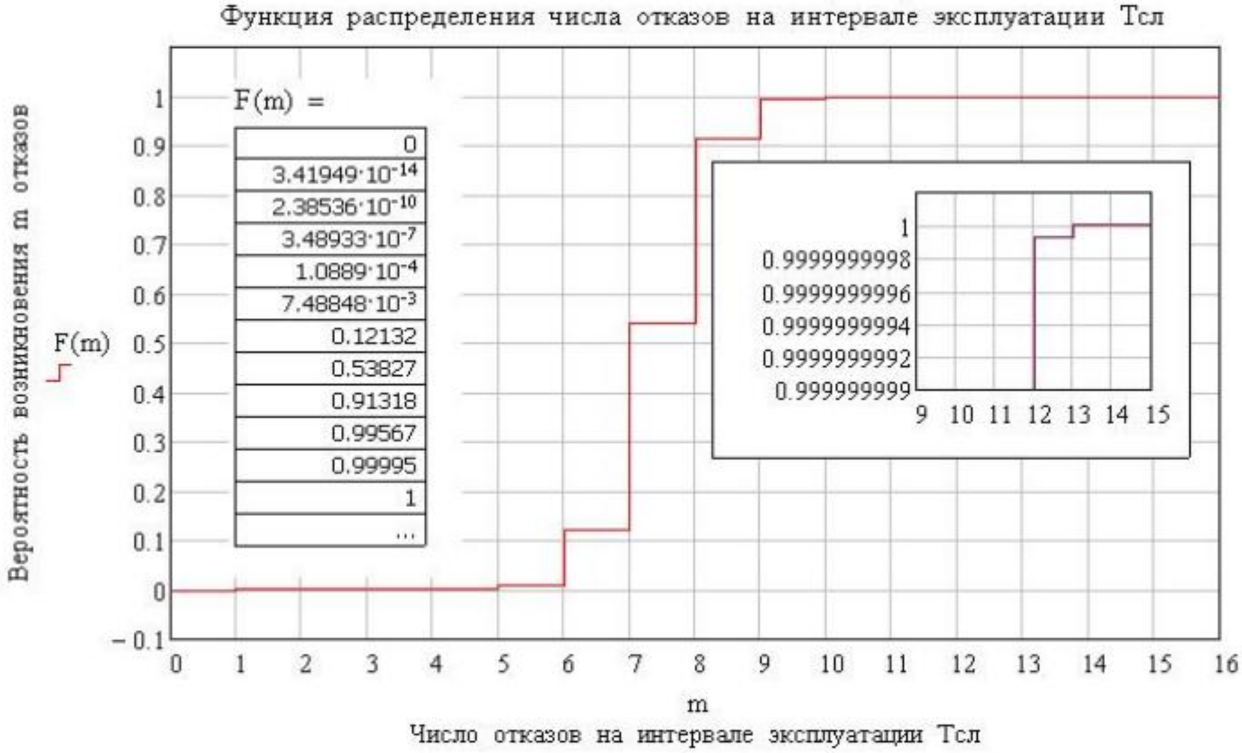
Performed by the example of a multilayer printed circuit board (MPP), which is a replaceable assembly unit (CCE) as part of the avionics quick-detachable unit (BSB). The composition of the board's electrical components includes: 20 discrete ICs, 86 resistors (MLT), 72 capacitors (ceramic), 24 SR contacts, 2260 soldered joints and 1 MPP.

Prediction of the distribution of m (Fig. 9) is made on the basis of the recovery model of the form:

$$F(m) = \Phi\left(\frac{m - X_{\text{сл}}}{\nu_{\text{сл}} \cdot \sqrt{X_{\text{сл}}}}\right) + \exp\left(\frac{2 \cdot m}{\nu_{\text{сл}}^{2}}\right) \cdot \Phi\left(-\frac{m + X_{\text{сл}}}{\nu_{\text{сл}} \cdot \sqrt{X_{\text{сл}}}}\right)$$

Figure 9. Prediction of the distribution of m

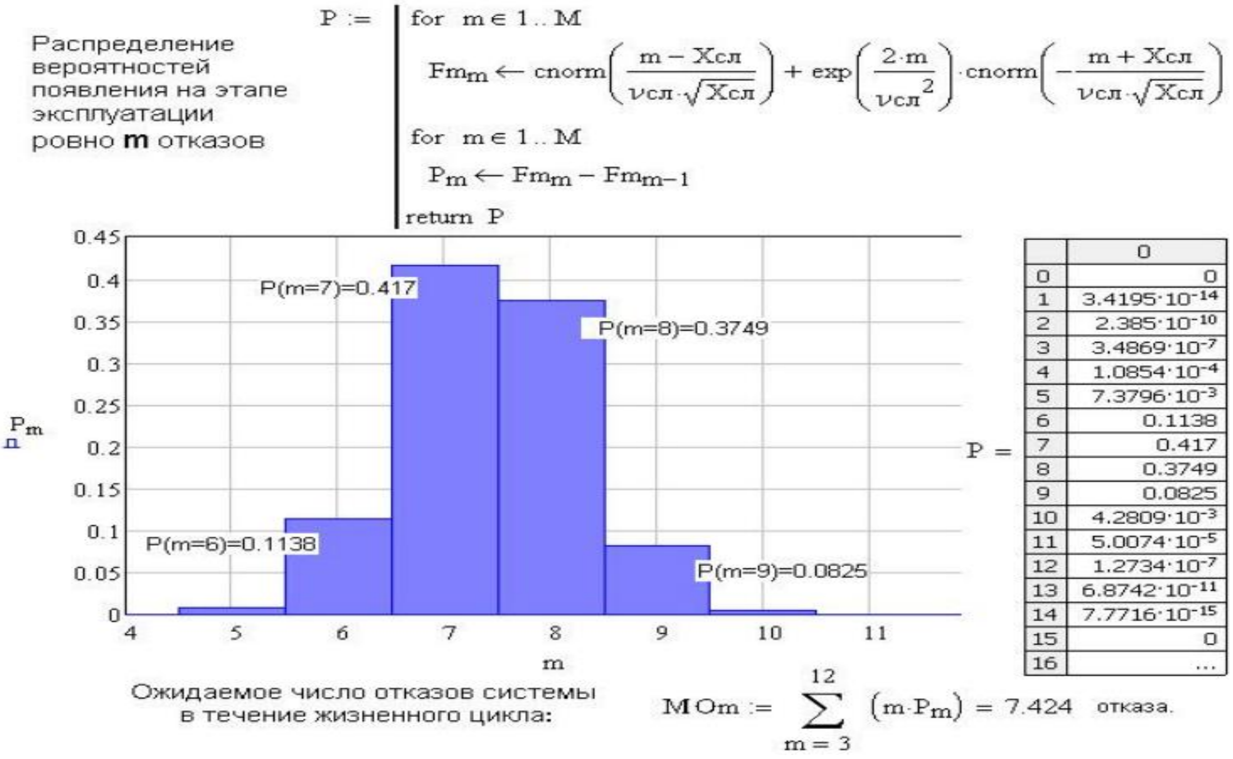
The results of predicting (Fig. 10) the distribution (Fig. 11) of the number m of board failures:



F(m) =

0
$3.41949\cdot10^{-14}$
$2.38536\cdot10^{-10}$
$3.48933\cdot10^{-7}$
$1.0889\cdot10^{-4}$
$7.48848\cdot10^{-3}$
0.12132
0.53827
0.91318
0.99567
0.99995
1
...

Figure 10. PCB failure m distribution (CCE)



```
P :=  | for  m ∈ 1..M
      |   $Fm_m \leftarrow \mathrm{cnorm}\left(\frac{m - X_{сл}}{\nu_{сл}\cdot\sqrt{X_{сл}}}\right) + \exp\left(\frac{2\cdot m}{\nu_{сл}^2}\right)\cdot\mathrm{cnorm}\left(-\frac{m + X_{сл}}{\nu_{сл}\cdot\sqrt{X_{сл}}}\right)$
      | for  m ∈ 1..M
      |   $P_m \leftarrow Fm_m - Fm_{m-1}$
      | return  P
```

P =

	0
0	0
1	$3.4195\cdot10^{-14}$
2	$2.385\cdot10^{-10}$
3	$3.4869\cdot10^{-7}$
4	$1.0854\cdot10^{-4}$
5	$7.3796\cdot10^{-3}$
6	0.1138
7	0.417
8	0.3749
9	0.0825
10	$4.2809\cdot10^{-3}$
11	$5.0074\cdot10^{-5}$
12	$1.2734\cdot10^{-7}$
13	$6.8742\cdot10^{-11}$
14	$7.7716\cdot10^{-15}$
15	0
16	...

$$MOm := \sum_{m=3}^{12} (m\cdot P_m) = 7.424$$ отказа.

Figure 11. Probability distribution of exactly m failures

Conclusion to chapter

The stated approach and the obtained results of the reliability study during long-term operation create the prerequisites for ensuring both flight safety and effective maintenance, which excludes the situation “aircraft on the ground due to the lack of spare elements”.

Reliability of a product is defined as the probability that the product will not fail throughout a prescribed operating period. The reliability of each component and the configuration of the system consisting of these components determines the system reliability (i.e., the reliability of the product).

Reliability importance is a measure of how much effect each component has on the overall reliability of the system. ... In other words, Component 1 has a higher reliability importance. In simple systems such as this series system configuration, it is easy to identify the weak components.

Availability, Testability, maintainability and maintenance are often defined as a part of "reliability engineering" in reliability programs. Reliability plays a key role in the cost-effectiveness of systems; for example, cars have a higher resale value when they fail less often.

An assessment is reliable if it measures the same thing consistently and reproducibly. If you were to deliver an assessment with high reliability to the same participant on two occasions, you would be very likely to reach the same conclusions about the participant’s knowledge or skills. A test with poor reliability might result in very different scores across the two instances.

It’s useful to think of a kitchen scale. If the scale is reliable, then when you put a bag of flour on the scale today and the same bag of flour on tomorrow, then it will show the same weight. But if the scale is not working properly and is not reliable, it could give you a different weight each time.

Just like a kitchen scale that doesn’t work, an unreliable assessment does not measure anything consistently and cannot be used for any trustable measure of competency. As well as reliability, it’s also important that an assessment is valid, i.e. measures what it is supposed to. Continuing the kitchen scale metaphor, a scale might consistently show the wrong weight; in such a case, the scale is reliable but not valid.

CHAPTER 3

ANALYTICAL ANALYSIS OF THE PROCESS FOR PREDICTING THE RELIABILITY OF AIRCRAFT COMPONENTS

The most pressing issue for civilian aircraft is flight safety. Loss of flight-critical functions by critical avionics applications directly affects flight safety, which depends, in particular, both on the level of reliability of aircraft and on the reliability of information on the technical condition of aircraft components. A decrease in the required levels of reliability and reliability leads to special situations during the flight, which are described in the Normative documents and must be taken into account when assessing the airworthiness of the aircraft. In this case, a special situation is recognized as a situation that arose as a result of exposure to adverse factors or their combinations, and leading to a decrease in flight safety. According to special situations, according to the degree of danger due to the technical condition of the aircraft components, they are divided into:

- the complication of flight conditions, characterized by a slight deterioration in the characteristics of stability and controllability or flight characteristics of the aircraft. The increasing complexity of flight conditions does not necessitate an immediate change in the flight plan and does not prevent its successful completion;
- difficult situations, characterized by a noticeable deterioration in the characteristics of stability, controllability, flight characteristics, or when one or more flight parameters go beyond operational limitations, but without reaching the limit restrictions / design conditions;
- emergency situations characterized by a significant deterioration in the characteristics of stability and controllability or flight characteristics or leading to the achievement (exceeding) of limit restrictions / design conditions;
- catastrophic situations, in the event of which the prevention of death is almost impossible.

According to the frequency of occurrence of the event (failures, failure states, special situations, external influences) are divided into five groups. For a quantitative assessment of the occurrence of events, the following probability values are assigned, related to one flight:

- repeated - more than 10 –3;
- moderately likely - in the range of 10 –3 - 10 –5;
- unlikely - in the range of 10 –5 - 10 –7;
- extremely unlikely - in the range of 10 –7–10 –9;
- almost unbelievable - less than 10 –9 (almost impossible).

Prediction of performance is one of the tasks of technical diagnostics and a necessary condition for effective monitoring of the state of aircraft components in flight. However, to assess the performance of aircraft components in the upcoming flight, it is not enough to calculate the value of the failure-free indicator, for example, the probability of failure-free operation R (t) for a certain predetermined time t using an adequate reliability model, and to verify that the airworthiness standards are met according to the schedule at which the point the line R (t) corresponding to the total operating time t completed by flights will indicate the probability value of a possible special situation on the ordinate axis.

This approach is acceptable only for continuous and long-term use systems, for example, on-board control complex for spacecraft for various purposes, the active life of which can be 15 - 20 years. However, it seems to us that such an approach to predicting the reliability of aircraft components in upcoming flights is unlawful for the following reasons. The duration of operation of a modern aircraft can reach 80,000 or more flight hours, which are realized in successive flights for 30 to 40 years. The alternation of takeoffs and landings sets the cyclical operation of all aircraft components, is a feature of air transport and amounts to tens of thousands of cycles over the life of the aircraft. Transients that occur when you turn on the aircraft systems before takeoff and turn them off after landing, significantly affect the reliability, in particular, on-board microprocessors and other electronic products.

The cyclic nature of the work and the periodic effect on operational factors, especially temperature fluctuations, lead to repeated changes in mechanical stresses in materials caused by differences in temperature expansion coefficients. This creates the prerequisites for the appearance of residual defects in the structure of materials and deformation of structural elements. As a result, residual changes in the failure-free parameters occur, which are sometimes called cyclic changes.

Since the flight consumes the resource of any component of the aircraft, the cyclical nature of their functioning leads to the fact that in each subsequent flight of the aircraft its components are sent with failure-free parameters, reduced compared with the parameters in the previous flight, and this fact is not taken into account in linear forecasting. In our opinion, when assessing reliability, in particular, when predicting the operability of avionics modules in upcoming flights, it seems advisable to take into account changes in their reliability parameters.

The proposed approach to assessing failure-free operation in flight is based on taking into account the residual resources of the aircraft components after each flight and we called it cyclical forecasting of failure-free operation. The article presents an algorithm for predicting the health of digital avionics modules, implemented in a computer Mathcad program that simulates the cyclicity of work and the gradual (from flight to flight) loss of the original resource by the avionics module.

A comparative analysis of the two approaches to forecasting (linear and cyclical) is based on a universal probabilistic-physical model of reliability with the given reliability parameters of a digital module. The errors of the linear method for predicting the reliability of on-board aviation systems operating in a cyclic mode are obtained, and the boundaries of the allowable number of aircraft flights are shown without violating the established classification of failure states.

3.1 Reliability prediction model features

The appearance in the theory of reliability and the recognition in state standards of diffusion distributions that implement a probabilistic-physical approach to the study of the reliability of technology, provided researchers with a mathematical apparatus that provides solutions to previously unsolvable problems. Diffusion distributions of the operating time to failure of technical products are the only among all known reliability models that allow obtaining analytical dependencies for quantifying the residual resources of operated products after the product has been functioning smoothly for a certain time, determined by the number of flights completed.

For the analysis of cyclic prediction of the failure-free operation of the aircraft electronic components, a universal diffusion nonmonotonic (DN) distribution of the mean time to failure was selected that most adequately reflects the resource consumption processes in the IET with a distribution function (it is the probability of failure) of the form (Fig. 12):

$$Q(\mu, \nu, t) = \Phi\left(\frac{t-\mu}{\nu \cdot \sqrt{\mu \cdot t}}\right) + \exp\left(\frac{2}{\nu^2}\right) \cdot \Phi\left(-\frac{t+\mu}{\nu \cdot \sqrt{\mu \cdot t}}\right)$$

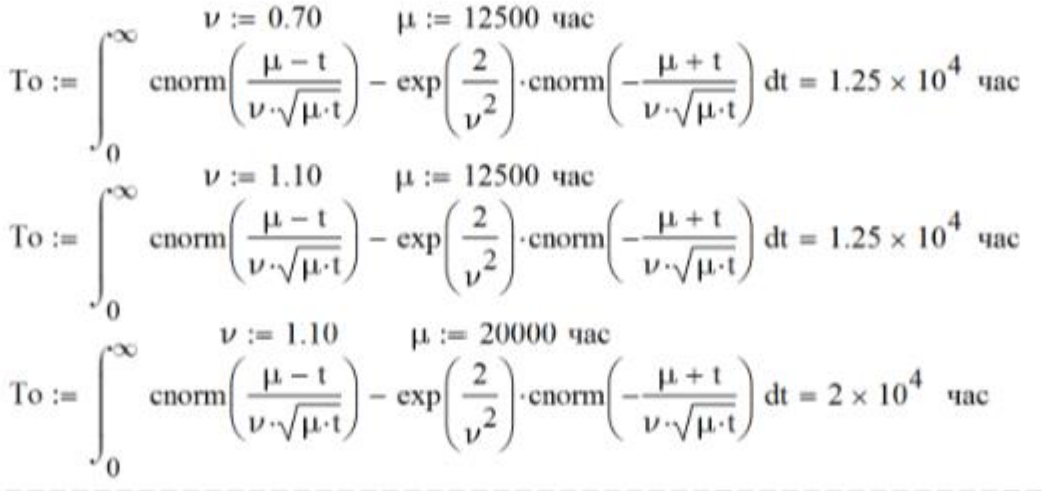
Figure 12. Analysis of cyclic prediction of the failure-free operation

The reliability model is the analytical representation of the probability of uptime, which in the DN distribution of failures has the form (Fig. 13):

$$R(\mu, \nu, t) = \Phi\left(\frac{\mu - t}{\nu \cdot \sqrt{\mu \cdot t}}\right) - \exp\left(\frac{2}{\nu^2}\right) \cdot \Phi\left(-\frac{\mu + t}{\nu \cdot \sqrt{\mu \cdot t}}\right)$$

Figure 13. The reliability model

The scale parameter is the reciprocal of the average rate of degradation, coincides with the average time the determining parameter reaches the limit value and determines the mean time between the investigated component of the aircraft to failure, i.e. is, according to Standart, a measure of reliability (Fig. 14):



$$\nu := 0.70 \qquad \mu := 12500 \text{ час}$$

$$To := \int_0^{\infty} \mathrm{cnorm}\left(\frac{\mu - t}{\nu\cdot\sqrt{\mu\cdot t}}\right) - \exp\left(\frac{2}{\nu^2}\right)\cdot\mathrm{cnorm}\left(-\frac{\mu + t}{\nu\cdot\sqrt{\mu\cdot t}}\right) dt = 1.25 \times 10^4 \text{ час}$$

$$\nu := 1.10 \qquad \mu := 12500 \text{ час}$$

$$To := \int_0^{\infty} \mathrm{cnorm}\left(\frac{\mu - t}{\nu\cdot\sqrt{\mu\cdot t}}\right) - \exp\left(\frac{2}{\nu^2}\right)\cdot\mathrm{cnorm}\left(-\frac{\mu + t}{\nu\cdot\sqrt{\mu\cdot t}}\right) dt = 1.25 \times 10^4 \text{ час}$$

$$\nu := 1.10 \qquad \mu := 20000 \text{ час}$$

$$To := \int_0^{\infty} \mathrm{cnorm}\left(\frac{\mu - t}{\nu\cdot\sqrt{\mu\cdot t}}\right) - \exp\left(\frac{2}{\nu^2}\right)\cdot\mathrm{cnorm}\left(-\frac{\mu + t}{\nu\cdot\sqrt{\mu\cdot t}}\right) dt = 2 \times 10^4 \text{ час}$$

Figure 14. The scale parameter is the reciprocal of the average rate of degradation

The shape parameter n is the coefficient of variation of the mean time between failures, coincides with the coefficient of variation n of the rate a of the change in the value of the parameter that determines the technical condition, and does not affect the value of failure-free operation - where parameter m preserves the initial value of To = 12,500 hours when changing the value of the coefficient of variation with n = 0.70 on n = 1.10). In this study, in order to take into account the resource consumption in flight, one of the indicators of this process is used - the average residual resource of the avionics module, determined for the IET by the DN distribution of the time between failures by the following dependence obtained in the work (Fig. 15):

$$\rho(\tau) = \frac{(\mu-\tau)\cdot\Phi\left(\dfrac{\mu-\tau}{\nu\sqrt{\mu\,\tau}}\right) + (\mu+\tau)\cdot\exp\left(2\nu^{-2}\right)\cdot\Phi\left(-\dfrac{\mu+\tau}{\nu\sqrt{\mu\,\tau}}\right)}{\Phi\left(\dfrac{\mu-\tau}{\nu\sqrt{\mu\,\tau}}\right) - \exp\left(2\nu^{-2}\right)\cdot\Phi\left(-\dfrac{\mu+\tau}{\nu\sqrt{\mu\,\tau}}\right)};$$

Figure 15. DN-distribution of the time between failures

For aircraft components with prevailing failures of electromechanical and mechanical elements, the probability of failures and the reliability model are described by a monotonic diffusion (DM) distribution (Fig. 16):

$$Q(\mu,\nu,t)=\Phi\left(\frac{t-\mu}{\nu\cdot\sqrt{\mu\cdot t}}\right)\qquad R(\mu,\nu,t)=\Phi\left(\frac{\mu-t}{\nu\sqrt{\mu t}}\right)$$

Figure 16. The probability of failures and the reliability model

The average residual resource is calculated by the formula obtained in (Fig. 17):

$$\rho(\tau)=\left[\Phi\left(\frac{\mu-\tau}{\nu\sqrt{\mu\tau}}\right)\right]^{-1}\left\{\left[\mu\left(1+\frac{\nu^2}{2}\right)-\tau\right]\Phi\left(\frac{\mu-\tau}{\nu\sqrt{\mu\tau}}\right)+\right.$$
$$\left.+\frac{\mu\nu^2}{2}\exp\left(\frac{2}{\nu^2}\right)\Phi\left(-\frac{\mu+\tau}{\nu\sqrt{\mu\tau}}\right)+\frac{\nu\sqrt{\mu\tau}}{\sqrt{2\pi}}\exp\left[-\frac{(\tau-\mu)^2}{2\nu^2\mu\tau}\right]\right\}$$

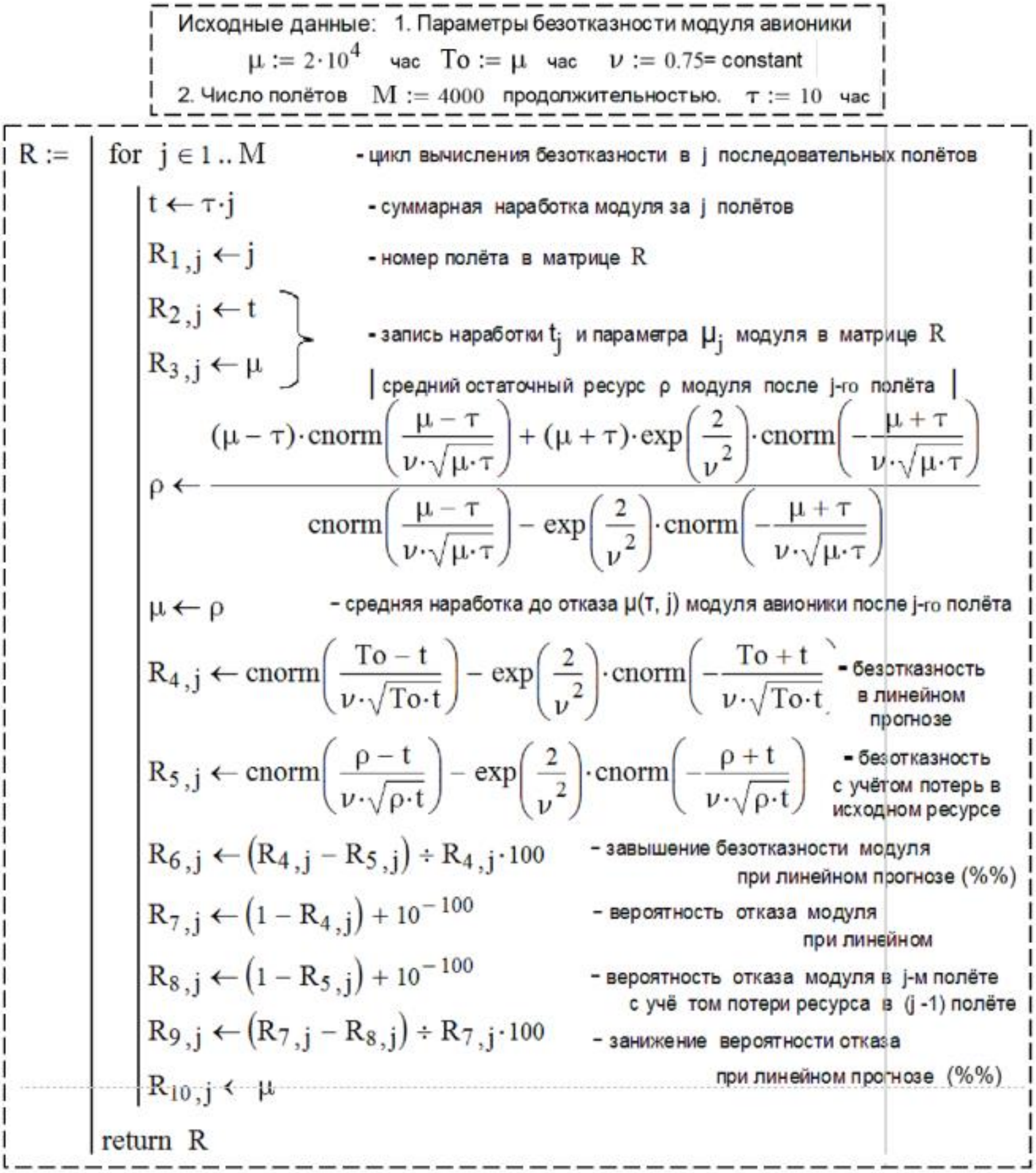
Figure 17. The average residual resource

The residual resources of the aircraft components are used not only to solve the problem posed here. It is known that residual resources are used in assessing the minimum possible quantitative composition of spare components based on the sufficiency index when determining the permissible upper limit for the duration of restoration (repair) of dismantled components due to a violation of their functioning and other tasks.

3.1.2 Avionics module reliability prediction program

A computer Mathcad program that simulates the processes of cyclic and linear reliability prediction, as well as generates information for a comparative analysis of the forecasting methods under consideration, is built on the basis of dependencies and contains comments on operators (Fig. 18).

The program provides step-by-step, i.e. from flight to flight, starting from flight number 1, the calculation of the probabilities of failure-free operation and the probabilities of failure of the investigated component of the aircraft (digital module), taking into account the loss of life in each flight, as well as the discrepancy in the linear and cyclic forecast estimates. The initial data to the program are the parameters of the failure distribution of the component under study, the duration of a typical flight and the number of flights M. The result of the program is the matrix R.



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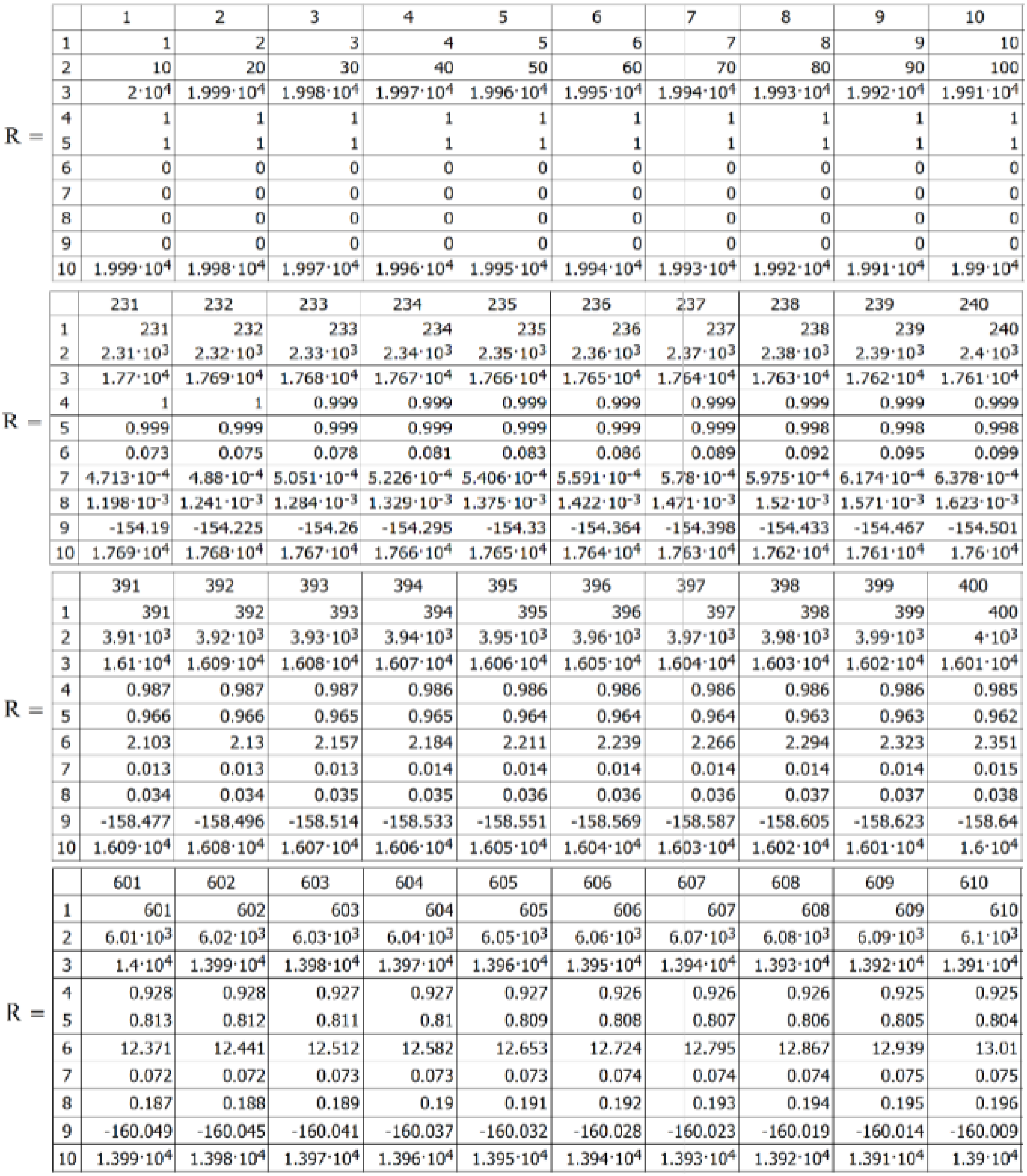
Исходные данные:   1. Параметры безотказности модуля авионики
    $\mu := 2\cdot 10^4$ час   $To := \mu$ час   $\nu := 0.75$= constant
2. Число полётов   $M := 4000$   продолжительностью.   $\tau := 10$ час

$R :=$ | for $j \in 1..M$                        - цикл вычисления безотказности в j последовательных полётов
       |     $t \leftarrow \tau \cdot j$                     - суммарная наработка модуля за j полётов
       |     $R_{1,j} \leftarrow j$                    - номер полёта в матрице R
       |     $R_{2,j} \leftarrow t$  }
       |     $R_{3,j} \leftarrow \mu$  }                - запись наработки $t_j$ и параметра $\mu_j$ модуля в матрице R
       |                                   | средний остаточный ресурс ρ модуля после j-го полёта |
       |     $\rho \leftarrow \dfrac{(\mu-\tau)\cdot \mathrm{cnorm}\left(\dfrac{\mu-\tau}{\nu\cdot\sqrt{\mu\cdot\tau}}\right)+(\mu+\tau)\cdot\exp\left(\dfrac{2}{\nu^2}\right)\cdot\mathrm{cnorm}\left(-\dfrac{\mu+\tau}{\nu\cdot\sqrt{\mu\cdot\tau}}\right)}{\mathrm{cnorm}\left(\dfrac{\mu-\tau}{\nu\cdot\sqrt{\mu\cdot\tau}}\right)-\exp\left(\dfrac{2}{\nu^2}\right)\cdot\mathrm{cnorm}\left(-\dfrac{\mu+\tau}{\nu\cdot\sqrt{\mu\cdot\tau}}\right)}$
       |     $\mu \leftarrow \rho$                    - средняя наработка до отказа μ(τ, j) модуля авионики после j-го полёта
       |     $R_{4,j} \leftarrow \mathrm{cnorm}\left(\dfrac{To-t}{\nu\cdot\sqrt{To\cdot t}}\right)-\exp\left(\dfrac{2}{\nu^2}\right)\cdot\mathrm{cnorm}\left(-\dfrac{To+t}{\nu\cdot\sqrt{To\cdot t}}\right)$   - безотказность в линейном прогнозе
       |     $R_{5,j} \leftarrow \mathrm{cnorm}\left(\dfrac{\rho-t}{\nu\cdot\sqrt{\rho\cdot t}}\right)-\exp\left(\dfrac{2}{\nu^2}\right)\cdot\mathrm{cnorm}\left(-\dfrac{\rho+t}{\nu\cdot\sqrt{\rho\cdot t}}\right)$   - безотказность с учётом потерь в исходном ресурсе
       |     $R_{6,j} \leftarrow (R_{4,j}-R_{5,j}) \div R_{4,j}\cdot 100$     - завышение безотказности модуля
       |                                         при линейном прогнозе (%%)
       |     $R_{7,j} \leftarrow (1-R_{4,j})+10^{-100}$      - вероятность отказа модуля
       |                                         при линейном
       |     $R_{8,j} \leftarrow (1-R_{5,j})+10^{-100}$      - вероятность отказа модуля в j-м полёте
       |                                         с учё том потери ресурса в (j -1) полёте
       |     $R_{9,j} \leftarrow (R_{7,j}-R_{8,j}) \div R_{7,j}\cdot 100$     - занижение вероятности отказа
       |                                         при линейном прогнозе (%%)
       |     $R_{10,j} \leftarrow \mu$
       | return R
```

Figure 18. Module failure prediction program

When forecasting the failure-free operation of aircraft components that are not electronic products (Table 2), it is enough for the three program operators to assign analytical expressions corresponding to the DM distribution of operating time to failure (Table 3):



R =

	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9	10
2	10	20	30	40	50	60	70	80	90	100
3	$2\cdot10^{4}$	$1.999\cdot10^{4}$	$1.998\cdot10^{4}$	$1.997\cdot10^{4}$	$1.996\cdot10^{4}$	$1.995\cdot10^{4}$	$1.994\cdot10^{4}$	$1.993\cdot10^{4}$	$1.992\cdot10^{4}$	$1.991\cdot10^{4}$
4	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	$1.999\cdot10^{4}$	$1.998\cdot10^{4}$	$1.997\cdot10^{4}$	$1.996\cdot10^{4}$	$1.995\cdot10^{4}$	$1.994\cdot10^{4}$	$1.993\cdot10^{4}$	$1.992\cdot10^{4}$	$1.991\cdot10^{4}$	$1.99\cdot10^{4}$

R =

	231	232	233	234	235	236	237	238	239	240
1	231	232	233	234	235	236	237	238	239	240
2	$2.31\cdot10^{3}$	$2.32\cdot10^{3}$	$2.33\cdot10^{3}$	$2.34\cdot10^{3}$	$2.35\cdot10^{3}$	$2.36\cdot10^{3}$	$2.37\cdot10^{3}$	$2.38\cdot10^{3}$	$2.39\cdot10^{3}$	$2.4\cdot10^{3}$
3	$1.77\cdot10^{4}$	$1.769\cdot10^{4}$	$1.768\cdot10^{4}$	$1.767\cdot10^{4}$	$1.766\cdot10^{4}$	$1.765\cdot10^{4}$	$1.764\cdot10^{4}$	$1.763\cdot10^{4}$	$1.762\cdot10^{4}$	$1.761\cdot10^{4}$
4	1	1	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
5	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.998	0.998	0.998
6	0.073	0.075	0.078	0.081	0.083	0.086	0.089	0.092	0.095	0.099
7	$4.713\cdot10^{-4}$	$4.88\cdot10^{-4}$	$5.051\cdot10^{-4}$	$5.226\cdot10^{-4}$	$5.406\cdot10^{-4}$	$5.591\cdot10^{-4}$	$5.78\cdot10^{-4}$	$5.975\cdot10^{-4}$	$6.174\cdot10^{-4}$	$6.378\cdot10^{-4}$
8	$1.198\cdot10^{-3}$	$1.241\cdot10^{-3}$	$1.284\cdot10^{-3}$	$1.329\cdot10^{-3}$	$1.375\cdot10^{-3}$	$1.422\cdot10^{-3}$	$1.471\cdot10^{-3}$	$1.52\cdot10^{-3}$	$1.571\cdot10^{-3}$	$1.623\cdot10^{-3}$
9	-154.19	-154.225	-154.26	-154.295	-154.33	-154.364	-154.398	-154.433	-154.467	-154.501
10	$1.769\cdot10^{4}$	$1.768\cdot10^{4}$	$1.767\cdot10^{4}$	$1.766\cdot10^{4}$	$1.765\cdot10^{4}$	$1.764\cdot10^{4}$	$1.763\cdot10^{4}$	$1.762\cdot10^{4}$	$1.761\cdot10^{4}$	$1.76\cdot10^{4}$

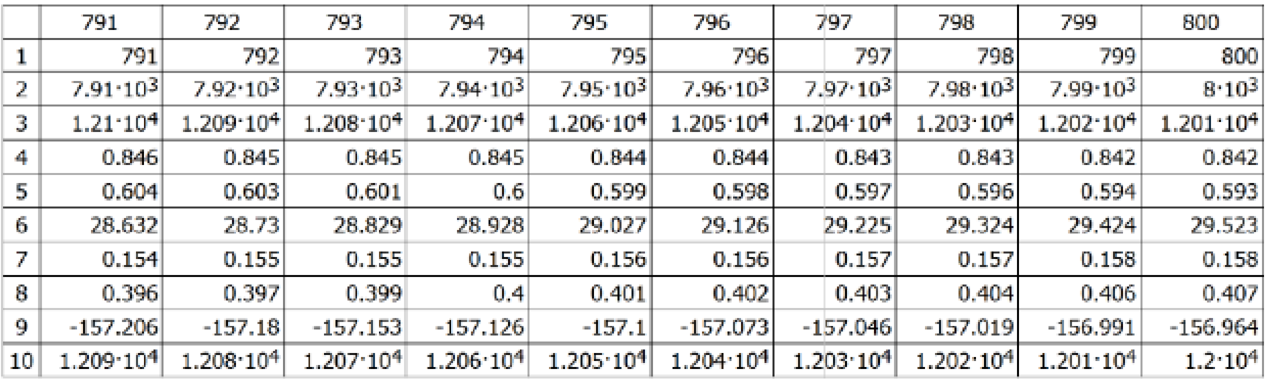
R =

	391	392	393	394	395	396	397	398	399	400
1	391	392	393	394	395	396	397	398	399	400
2	$3.91\cdot10^{3}$	$3.92\cdot10^{3}$	$3.93\cdot10^{3}$	$3.94\cdot10^{3}$	$3.95\cdot10^{3}$	$3.96\cdot10^{3}$	$3.97\cdot10^{3}$	$3.98\cdot10^{3}$	$3.99\cdot10^{3}$	$4\cdot10^{3}$
3	$1.61\cdot10^{4}$	$1.609\cdot10^{4}$	$1.608\cdot10^{4}$	$1.607\cdot10^{4}$	$1.606\cdot10^{4}$	$1.605\cdot10^{4}$	$1.604\cdot10^{4}$	$1.603\cdot10^{4}$	$1.602\cdot10^{4}$	$1.601\cdot10^{4}$
4	0.987	0.987	0.987	0.986	0.986	0.986	0.986	0.986	0.986	0.985
5	0.966	0.966	0.965	0.965	0.964	0.964	0.964	0.963	0.963	0.962
6	2.103	2.13	2.157	2.184	2.211	2.239	2.266	2.294	2.323	2.351
7	0.013	0.013	0.013	0.014	0.014	0.014	0.014	0.014	0.014	0.015
8	0.034	0.034	0.035	0.035	0.036	0.036	0.036	0.037	0.037	0.038
9	-158.477	-158.496	-158.514	-158.533	-158.551	-158.569	-158.587	-158.605	-158.623	-158.64
10	$1.609\cdot10^{4}$	$1.608\cdot10^{4}$	$1.607\cdot10^{4}$	$1.606\cdot10^{4}$	$1.605\cdot10^{4}$	$1.604\cdot10^{4}$	$1.603\cdot10^{4}$	$1.602\cdot10^{4}$	$1.601\cdot10^{4}$	$1.6\cdot10^{4}$

R =

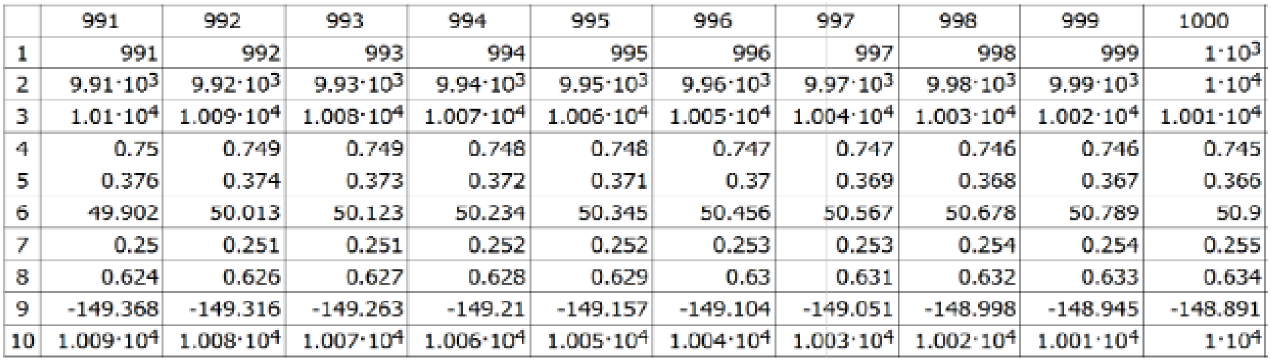
	601	602	603	604	605	606	607	608	609	610
1	601	602	603	604	605	606	607	608	609	610
2	$6.01\cdot10^{3}$	$6.02\cdot10^{3}$	$6.03\cdot10^{3}$	$6.04\cdot10^{3}$	$6.05\cdot10^{3}$	$6.06\cdot10^{3}$	$6.07\cdot10^{3}$	$6.08\cdot10^{3}$	$6.09\cdot10^{3}$	$6.1\cdot10^{3}$
3	$1.4\cdot10^{4}$	$1.399\cdot10^{4}$	$1.398\cdot10^{4}$	$1.397\cdot10^{4}$	$1.396\cdot10^{4}$	$1.395\cdot10^{4}$	$1.394\cdot10^{4}$	$1.393\cdot10^{4}$	$1.392\cdot10^{4}$	$1.391\cdot10^{4}$
4	0.928	0.928	0.927	0.927	0.927	0.926	0.926	0.926	0.925	0.925
5	0.813	0.812	0.811	0.81	0.809	0.808	0.807	0.806	0.805	0.804
6	12.371	12.441	12.512	12.582	12.653	12.724	12.795	12.867	12.939	13.01
7	0.072	0.072	0.073	0.073	0.073	0.074	0.074	0.074	0.075	0.075
8	0.187	0.188	0.189	0.19	0.191	0.192	0.193	0.194	0.195	0.196
9	-160.049	-160.045	-160.041	-160.037	-160.032	-160.028	-160.023	-160.019	-160.014	-160.009
10	$1.399\cdot10^{4}$	$1.398\cdot10^{4}$	$1.397\cdot10^{4}$	$1.396\cdot10^{4}$	$1.395\cdot10^{4}$	$1.394\cdot10^{4}$	$1.393\cdot10^{4}$	$1.392\cdot10^{4}$	$1.391\cdot10^{4}$	$1.39\cdot10^{4}$

Table 2. Avionics module failsafe prediction results



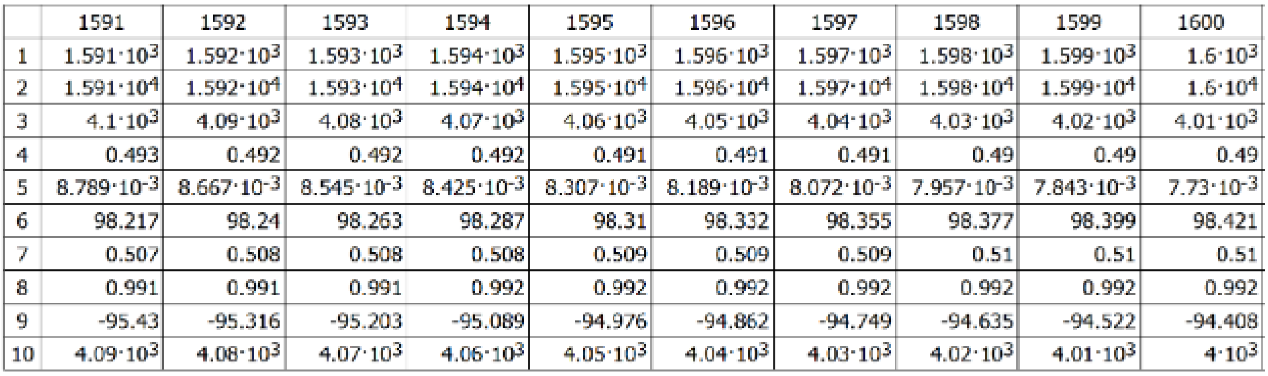
R =

	791	792	793	794	795	796	797	798	799	800
1	791	792	793	794	795	796	797	798	799	800
2	$7.91\cdot10^{3}$	$7.92\cdot10^{3}$	$7.93\cdot10^{3}$	$7.94\cdot10^{3}$	$7.95\cdot10^{3}$	$7.96\cdot10^{3}$	$7.97\cdot10^{3}$	$7.98\cdot10^{3}$	$7.99\cdot10^{3}$	$8\cdot10^{3}$
3	$1.21\cdot10^{4}$	$1.209\cdot10^{4}$	$1.208\cdot10^{4}$	$1.207\cdot10^{4}$	$1.206\cdot10^{4}$	$1.205\cdot10^{4}$	$1.204\cdot10^{4}$	$1.203\cdot10^{4}$	$1.202\cdot10^{4}$	$1.201\cdot10^{4}$
4	0.846	0.845	0.845	0.845	0.844	0.844	0.843	0.843	0.842	0.842
5	0.604	0.603	0.601	0.6	0.599	0.598	0.597	0.596	0.594	0.593
6	28.632	28.73	28.829	28.928	29.027	29.126	29.225	29.324	29.424	29.523
7	0.154	0.155	0.155	0.155	0.156	0.156	0.157	0.157	0.158	0.158
8	0.396	0.397	0.399	0.4	0.401	0.402	0.403	0.404	0.406	0.407
9	-157.206	-157.18	-157.153	-157.126	-157.1	-157.073	-157.046	-157.019	-156.991	-156.964
10	$1.209\cdot10^{4}$	$1.208\cdot10^{4}$	$1.207\cdot10^{4}$	$1.206\cdot10^{4}$	$1.205\cdot10^{4}$	$1.204\cdot10^{4}$	$1.203\cdot10^{4}$	$1.202\cdot10^{4}$	$1.201\cdot10^{4}$	$1.2\cdot10^{4}$



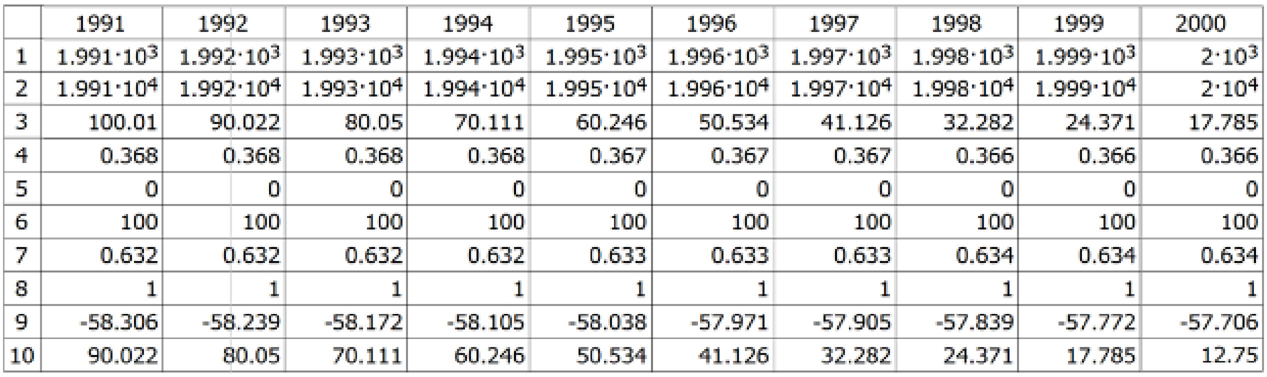
R =

	991	992	993	994	995	996	997	998	999	1000
1	991	992	993	994	995	996	997	998	999	$1\cdot10^{3}$
2	$9.91\cdot10^{3}$	$9.92\cdot10^{3}$	$9.93\cdot10^{3}$	$9.94\cdot10^{3}$	$9.95\cdot10^{3}$	$9.96\cdot10^{3}$	$9.97\cdot10^{3}$	$9.98\cdot10^{3}$	$9.99\cdot10^{3}$	$1\cdot10^{4}$
3	$1.01\cdot10^{4}$	$1.009\cdot10^{4}$	$1.008\cdot10^{4}$	$1.007\cdot10^{4}$	$1.006\cdot10^{4}$	$1.005\cdot10^{4}$	$1.004\cdot10^{4}$	$1.003\cdot10^{4}$	$1.002\cdot10^{4}$	$1.001\cdot10^{4}$
4	0.75	0.749	0.749	0.748	0.748	0.747	0.747	0.746	0.746	0.745
5	0.376	0.374	0.373	0.372	0.371	0.37	0.369	0.368	0.367	0.366
6	49.902	50.013	50.123	50.234	50.345	50.456	50.567	50.678	50.789	50.9
7	0.25	0.251	0.251	0.252	0.252	0.253	0.253	0.254	0.254	0.255
8	0.624	0.626	0.627	0.628	0.629	0.63	0.631	0.632	0.633	0.634
9	-149.368	-149.316	-149.263	-149.21	-149.157	-149.104	-149.051	-148.998	-148.945	-148.891
10	$1.009\cdot10^{4}$	$1.008\cdot10^{4}$	$1.007\cdot10^{4}$	$1.006\cdot10^{4}$	$1.005\cdot10^{4}$	$1.004\cdot10^{4}$	$1.003\cdot10^{4}$	$1.002\cdot10^{4}$	$1.001\cdot10^{4}$	$1\cdot10^{4}$



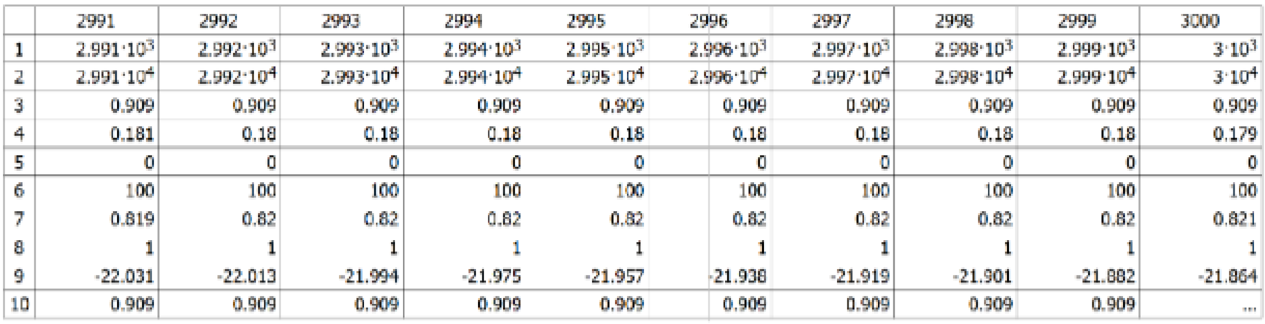
R =

	1591	1592	1593	1594	1595	1596	1597	1598	1599	1600
1	$1.591\cdot10^{3}$	$1.592\cdot10^{3}$	$1.593\cdot10^{3}$	$1.594\cdot10^{3}$	$1.595\cdot10^{3}$	$1.596\cdot10^{3}$	$1.597\cdot10^{3}$	$1.598\cdot10^{3}$	$1.599\cdot10^{3}$	$1.6\cdot10^{3}$
2	$1.591\cdot10^{4}$	$1.592\cdot10^{4}$	$1.593\cdot10^{4}$	$1.594\cdot10^{4}$	$1.595\cdot10^{4}$	$1.596\cdot10^{4}$	$1.597\cdot10^{4}$	$1.598\cdot10^{4}$	$1.599\cdot10^{4}$	$1.6\cdot10^{4}$
3	$4.1\cdot10^{3}$	$4.09\cdot10^{3}$	$4.08\cdot10^{3}$	$4.07\cdot10^{3}$	$4.06\cdot10^{3}$	$4.05\cdot10^{3}$	$4.04\cdot10^{3}$	$4.03\cdot10^{3}$	$4.02\cdot10^{3}$	$4.01\cdot10^{3}$
4	0.493	0.492	0.492	0.492	0.491	0.491	0.491	0.49	0.49	0.49
5	$8.789\cdot10^{-3}$	$8.667\cdot10^{-3}$	$8.545\cdot10^{-3}$	$8.425\cdot10^{-3}$	$8.307\cdot10^{-3}$	$8.189\cdot10^{-3}$	$8.072\cdot10^{-3}$	$7.957\cdot10^{-3}$	$7.843\cdot10^{-3}$	$7.73\cdot10^{-3}$
6	98.217	98.24	98.263	98.287	98.31	98.332	98.355	98.377	98.399	98.421
7	0.507	0.508	0.508	0.508	0.509	0.509	0.509	0.51	0.51	0.51
8	0.991	0.991	0.991	0.992	0.992	0.992	0.992	0.992	0.992	0.992
9	-95.43	-95.316	-95.203	-95.089	-94.976	-94.862	-94.749	-94.635	-94.522	-94.408
10	$4.09\cdot10^{3}$	$4.08\cdot10^{3}$	$4.07\cdot10^{3}$	$4.06\cdot10^{3}$	$4.05\cdot10^{3}$	$4.04\cdot10^{3}$	$4.03\cdot10^{3}$	$4.02\cdot10^{3}$	$4.01\cdot10^{3}$	$4\cdot10^{3}$



R =

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	$1.991\cdot10^{3}$	$1.992\cdot10^{3}$	$1.993\cdot10^{3}$	$1.994\cdot10^{3}$	$1.995\cdot10^{3}$	$1.996\cdot10^{3}$	$1.997\cdot10^{3}$	$1.998\cdot10^{3}$	$1.999\cdot10^{3}$	$2\cdot10^{3}$
2	$1.991\cdot10^{4}$	$1.992\cdot10^{4}$	$1.993\cdot10^{4}$	$1.994\cdot10^{4}$	$1.995\cdot10^{4}$	$1.996\cdot10^{4}$	$1.997\cdot10^{4}$	$1.998\cdot10^{4}$	$1.999\cdot10^{4}$	$2\cdot10^{4}$
3	100.01	90.022	80.05	70.111	60.246	50.534	41.126	32.282	24.371	17.785
4	0.368	0.368	0.368	0.368	0.367	0.367	0.367	0.366	0.366	0.366
5	0	0	0	0	0	0	0	0	0	0
6	100	100	100	100	100	100	100	100	100	100
7	0.632	0.632	0.632	0.632	0.633	0.633	0.633	0.634	0.634	0.634
8	1	1	1	1	1	1	1	1	1	1
9	-58.306	-58.239	-58.172	-58.105	-58.038	-57.971	-57.905	-57.839	-57.772	-57.706
10	90.022	80.05	70.111	60.246	50.534	41.126	32.282	24.371	17.785	12.75



R =

	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000
1	$2.991\cdot10^{3}$	$2.992\cdot10^{3}$	$2.993\cdot10^{3}$	$2.994\cdot10^{3}$	$2.995\cdot10^{3}$	$2.996\cdot10^{3}$	$2.997\cdot10^{3}$	$2.998\cdot10^{3}$	$2.999\cdot10^{3}$	$3\cdot10^{3}$
2	$2.991\cdot10^{4}$	$2.992\cdot10^{4}$	$2.993\cdot10^{4}$	$2.994\cdot10^{4}$	$2.995\cdot10^{4}$	$2.996\cdot10^{4}$	$2.997\cdot10^{4}$	$2.998\cdot10^{4}$	$2.999\cdot10^{4}$	$3\cdot10^{4}$
3	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909
4	0.181	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.179
5	0	0	0	0	0	0	0	0	0	0
6	100	100	100	100	100	100	100	100	100	100
7	0.819	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.821
8	1	1	1	1	1	1	1	1	1	1
9	-22.031	-22.013	-21.994	-21.975	-21.957	-21.938	-21.919	-21.901	-21.882	-21.864
10	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	0.909	...

Table 3. Avionics module failsafe prediction results

3.2 Analysis of the results of cyclic and linear forecasting of failure free avionics module in flight

For a comparative analysis, we present the results of the calculations with graphs of the dependencies of the residual resource (Figure 19), the probability of module failure (distribution function of the time between failures), the probability of its failure-free operation and the errors that we attribute to the linear forecasting method, objectively believing that the cyclic performance assessment method more adequately reflects the loss process resource components in flight.

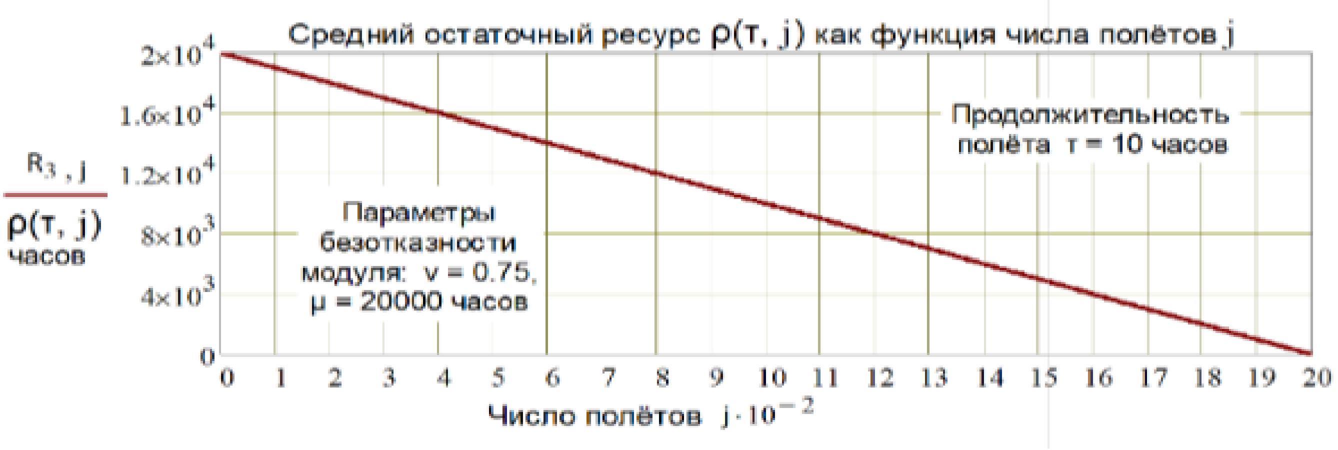


Figure 19. Dependence of the average residual resource of the module on the number of flights performed

In linear forecasting, estimates of the probability of failure in upcoming flights are underestimated, which is illustrated by the behavior of the distribution function of failures (probability of failure) for the considered methods for predicting the failure-freeness of the module. Underestimating the probability of failure is a methodological error in linear forecasting and amounts to tens and hundreds of percent (Fig. 20).

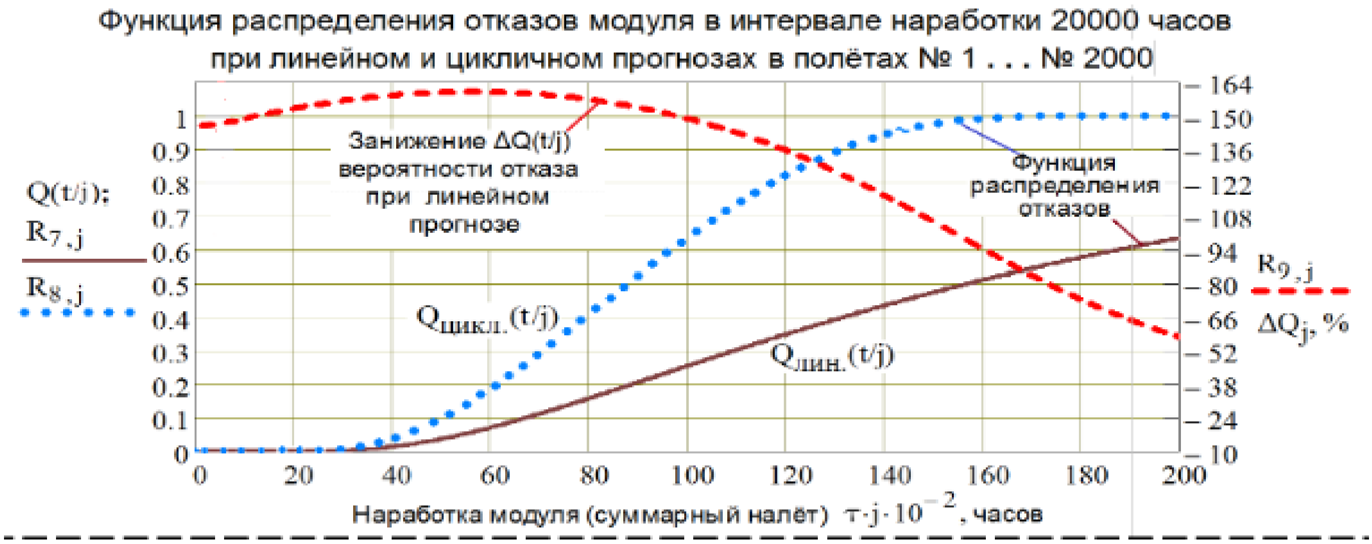


Figure 20. The probability of module failure with two methods for predicting reliability in the operating time interval of 0. . . 20,000 flight hours with no cracks

The indicated errors of underestimating the probability of failure in a linear forecast appear (Fig. 21) already at the beginning of operation (at the first flight), i.e. in the zone of almost unbelievable (almost impossible) events, the upper boundary of which corresponds to a probability of Q = 10 –9.

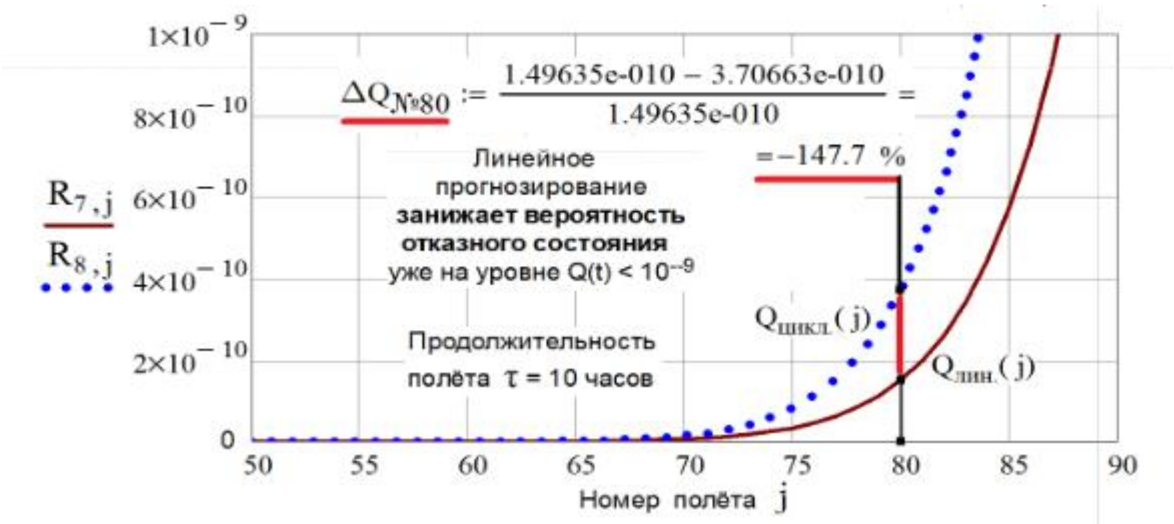


Figure 21. Avionics module failure distribution function for Q = 10 –9

However, during the long-term operation of the aircraft, as the initial resource is lost (Fig. 22) in successive flights, the probability of a special situation increases and may exceed the safety level specified by the Airworthiness Standards.

At the same time, the number of flights operated with underestimated airworthiness standards increases to several tens or more (Fig. 23).

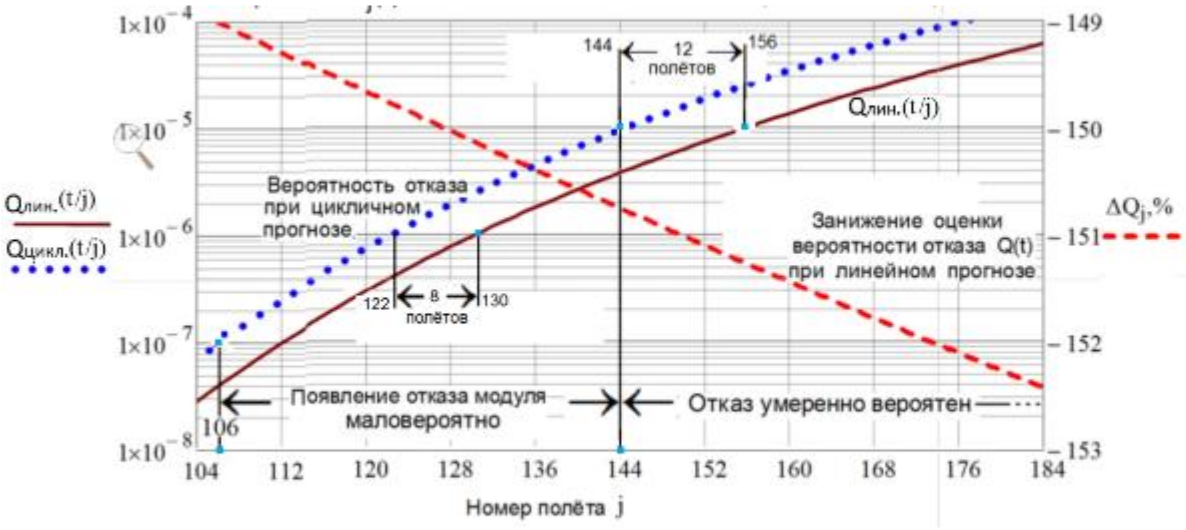


Figure 22. Methodological errors of linear reliability prediction in areas of unlikely and moderately probable failure of the avionics module

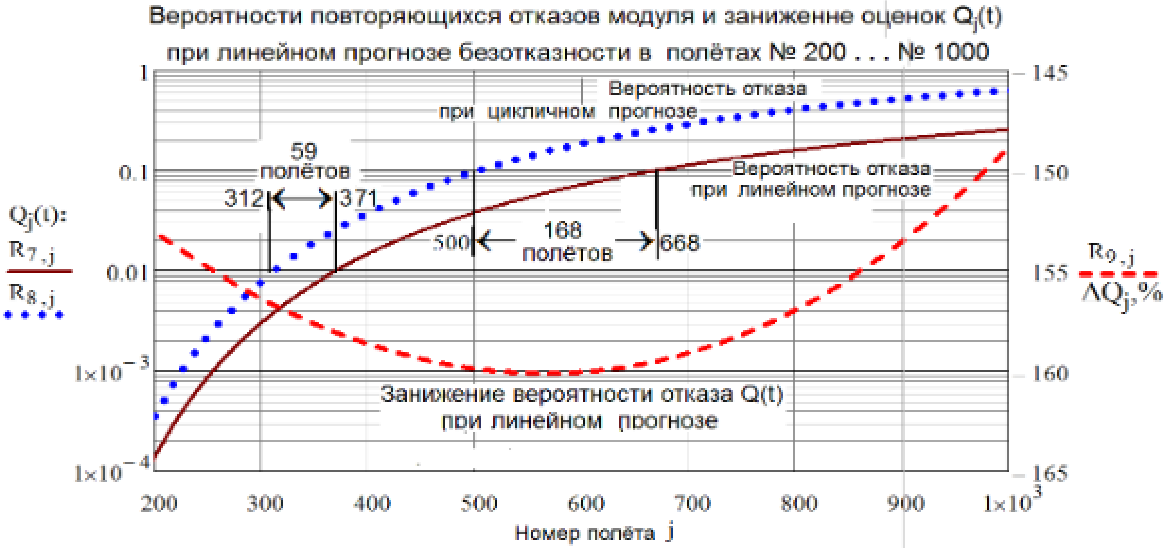


Figure 23. Methodological errors of linear reliability prediction

Quantitative estimates of linear forecasting errors can be obtained on the basis of the analysis of the reliability function (reliability models), which describe the processes for implementing linear and cyclical forecasting of the avionics module operability in flight (Fig. 24).

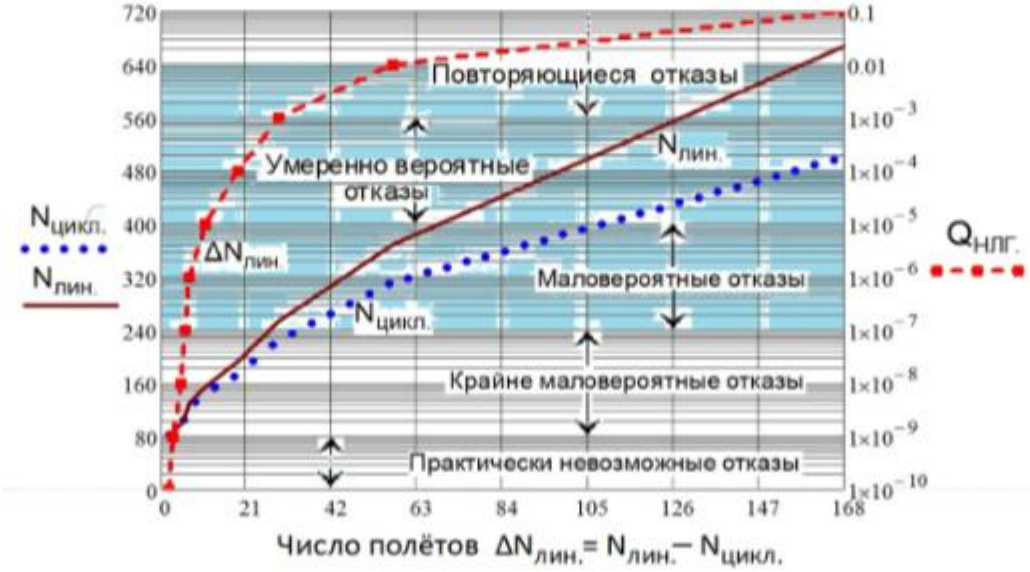


Figure 24. Methodological errors of the 2nd kind in the linear prediction of the failure-free avionics module during aircraft operation

In the synthesis of ultra-high reliability systems, in particular, switching and computing platforms for on-board electronics of the IMA class, the smallest possible probabilities of special situations and the identification of rare failures are provided on the basis of the principle of independent but interconnected functioning of state monitoring systems, which includes an analysis of the state of the platform components and its reconfiguration in the event of failures and malfunctions. Moreover, the probability of failure-free operation of such IMA components, as well as the reliability levels of estimates of their technical conditions (Fig. 25), can reach values of 0.9999999 and more (Fig. 26).

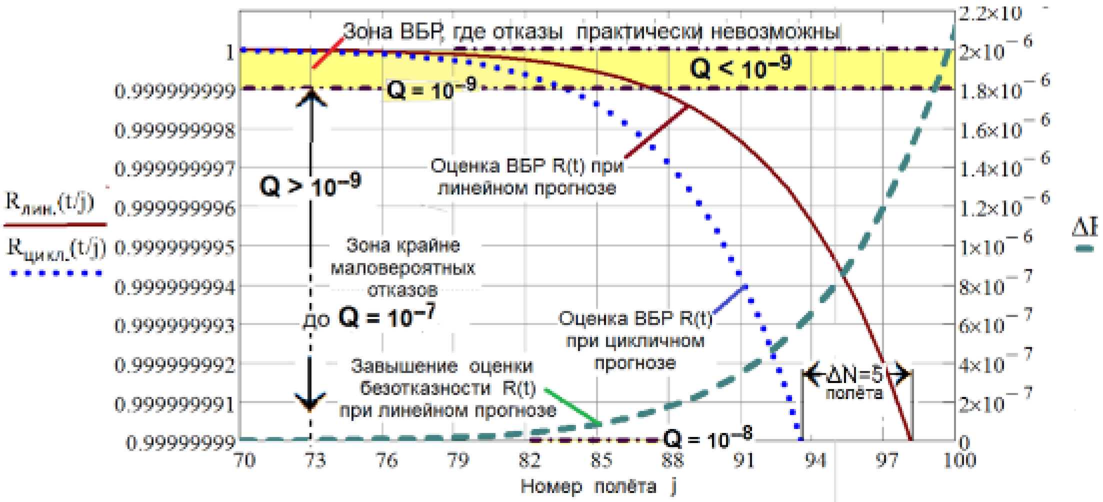


Figure 25. The reliability model of the module with two methods for predicting health and methodological errors of the linear method in areas of practically impossible and extremely unlikely special situations

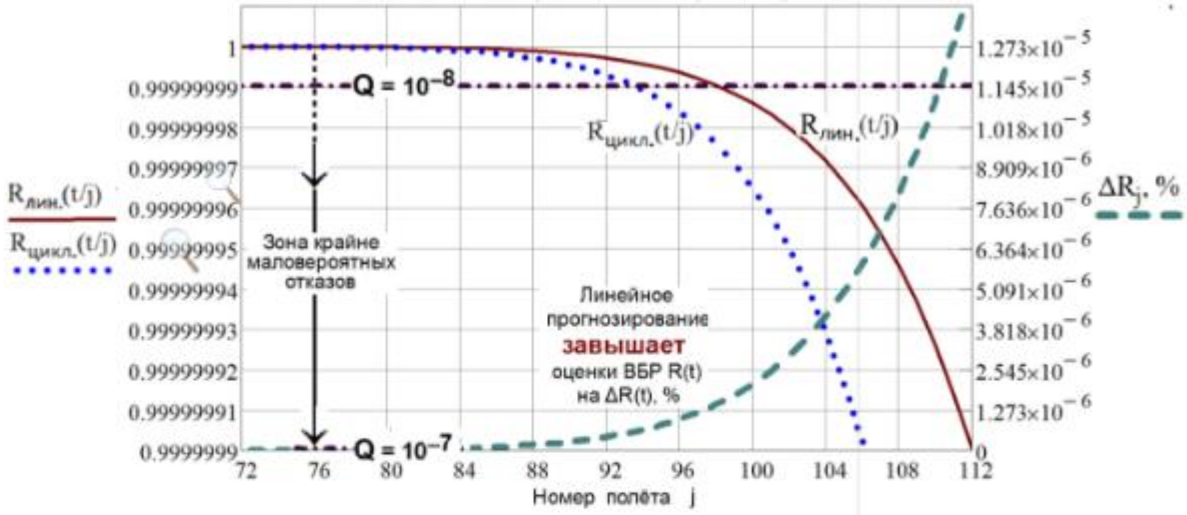


Figure 26. Module reliability model and methodological errors of the linear method in the zone of extremely unlikely special situations

As expected, a methodical error of the second kind, which overestimates the probability of failure-free operation, coincides with a error of the second kind, calculated by the distribution function of failures and underestimates the probability of failure in the same flight interval (Fig. 27).

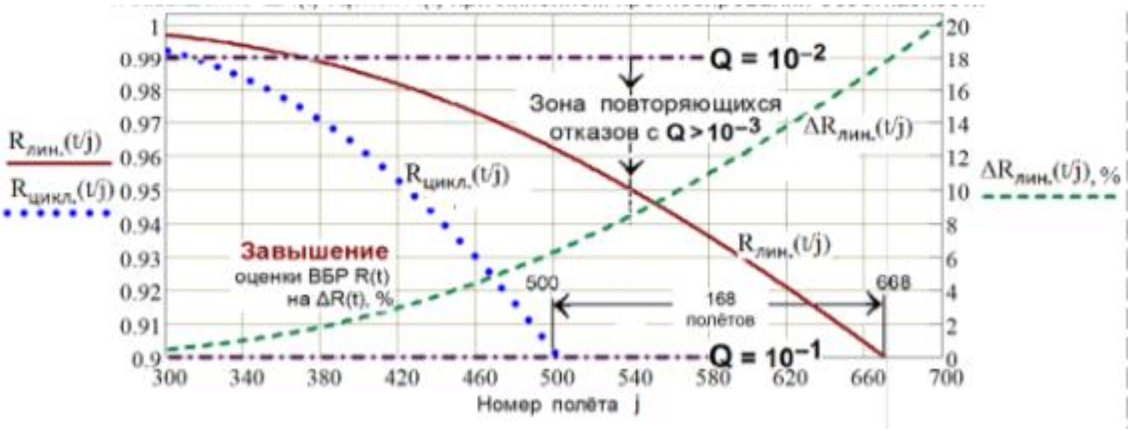


Figure 27. The reliability model of the module with two methods for predicting operability and methodological errors of the linear method in the zone of repeated special situations

On the operation interval of up to 20,000 flight hours, the error in underestimating the probability of failure significantly exceeds the error in overestimating the probability of failure-free operation, which is explained by different ranges of variation in the values of the functions under study (Fig. 28).

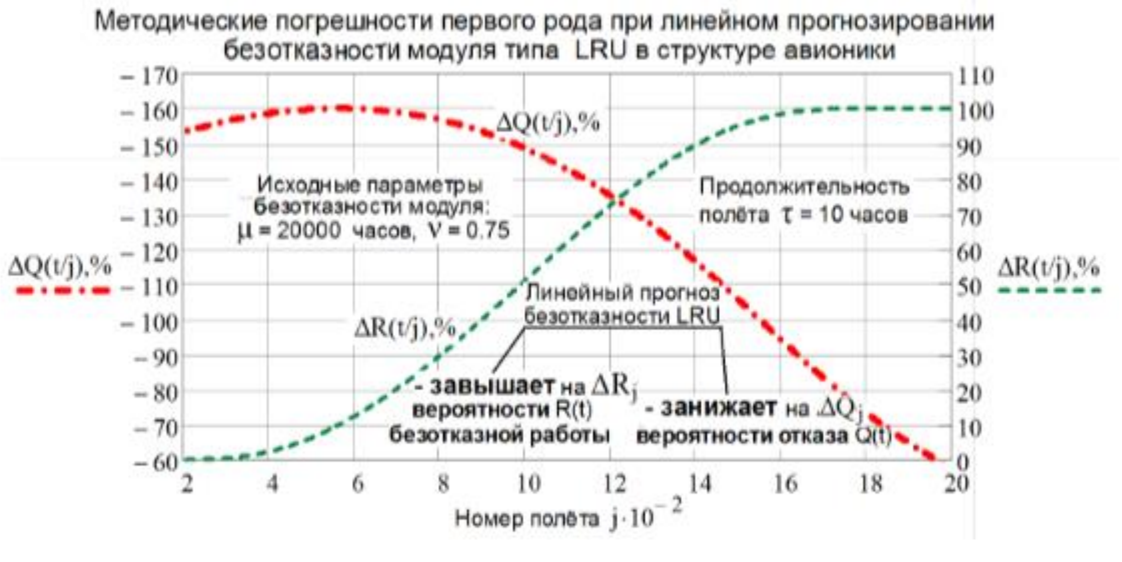


Figure 28. Methodological errors of the first kind in the linear forecasting of failure-free avionics module during aircraft operation

Dependences of the number of flights performed with an increase in risk (with an increase in the probability of failure-free operation relative to the values specified on the abscissa axis in accordance with the classification, and a methodological error of the second kind (Fig. 29), where the background indicates the range of practically attainable probability of failure-free operation from 0 ,9999999 to 0.999 aircraft in flight (unlikely and moderately probable special situations).

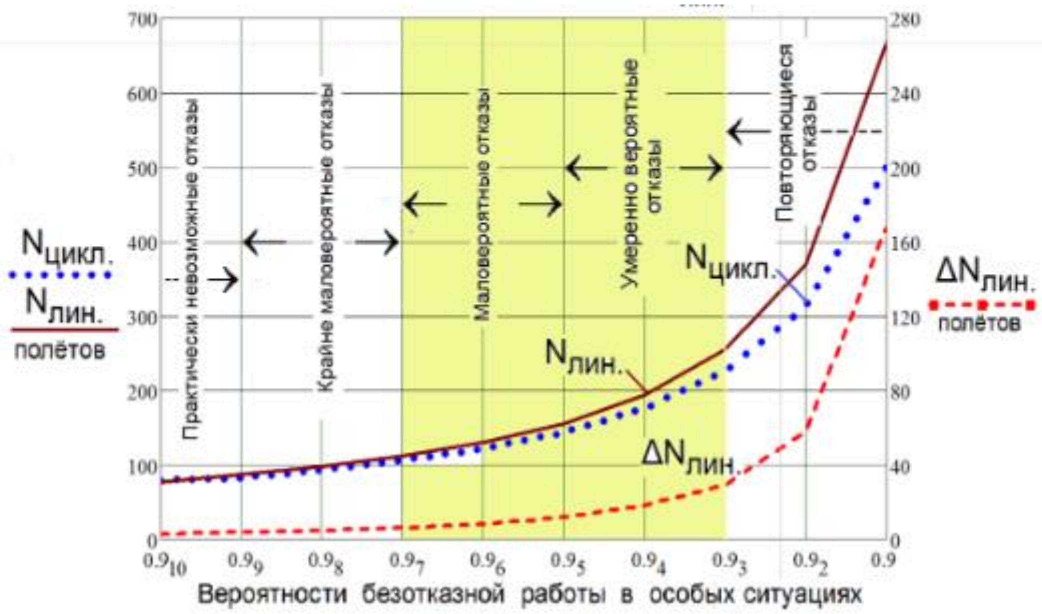


Figure 29. Error of the 2nd kind of linear prediction of module health

Concluding the comparative analysis of methods for predicting the failure-free performance of aircraft components in flight, we note that currently, in the face of increasing competition in the global air transportation market, the efficiency of airline companies largely depends on information support for the operation of aircraft. The authors of the study believe that the results obtained are a further development of information support for aircraft operation and analytical monitoring of risk levels for predictive safety of aviation activities.

Conclusion to chapter

The data obtained during cyclical forecasting of failure-free operation should be used in modern information-analytical systems for monitoring the airworthiness of aircraft components, in which real-time monitoring of the life cycle of aircraft and their components is the most important system-forming mechanism.

Accounting for residual resources significantly supplements the data on the technical condition of aircraft components. The program for obtaining residual resources can be implemented in the language used in IAS, included in the functional module for monitoring the life cycle of the aircraft and its components.

The introduction into the structure of the cyclic reliability prediction method based on modern probabilistic physical DN- and DM-reliability models eliminates the violation of the airworthiness standards during flights, specifically (up to the figure in the classification of special situations) ensures flight safety and increases the efficiency of airlines.

CONCLUSION

The diploma robot offers a new method for assessing the reliability of aircraft components in the upcoming flight, taking into account the loss of resources in the previous flight. called cyclic forecasting of failure-free operation and adequately describing the process of component degradation during flight operation of the aircraft. The result of the implementation of the Mathcad-program sequential (from flight to flight) control of residual resources allows you to see; the degradation process for a given number of flights (from the first to the flight with the number M).

The peculiarities and possibilities of modern avionics and its role in ensuring the safety of civil aircraft are considered. The most important characteristics of avionics are the reliability of all its components and the probability of monitoring their technical condition.

The technique of synthesis of requirements to accuracy of analog of digital measuring instruments of parameters of components of avionics in the conditions of obstacles operating in flight at the set probability of an estimation of a technical condition is developed. The technique is based on the calculation of errors in the control of parameters for tolerance and provides a choice of the minimum possible accuracy class from the standard range.

The advantages of the technique are:

- the adequacy of the model of the process of one-time measurements of the values of the parameters of performance and proper functioning in the event of possible failures of avionics components,
- the use of normalization of the characteristics of the diagnostic process in the monitoring of avionics components in flight,
- the ability to obtain the required accuracy class of meters in the entire range of characteristics of the diagnostic process.

The efficiency of the technique is illustrated by a clear example of obtaining the required accuracy classes of meters with a given characteristic of the controlled parameters and the required reliability of information in the monitoring system

The proposed approach to obtaining classes of accuracy of meters in the design creates an opportunity to improve the efficiency of the airline.

LIST OF REFERNCES: