ISSN 2229-5518

# SPACE MEASUREMENTS OF RELIABILITY AND THE HOPE FOR IT

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**Abstract**— Research of the reliability problem is related to the choice of methods that can provide rational solutions, both in the technical and technological field, as well as within the scope of the socio-economic, public and environmental-space dimensions. The choice of a research depends on the nature of the subject of our knowledge as well as on the level of development of the theoretical and social thinking that is characteristic of the age we live in.

In the contemporary natural science, starting with the development of atomistic ideas in physics and the theory of chemical structure of the substances, and leading to the creation of cybernetics, bionics and the general systems theory, the structural approach of exploring the objects of reality is used and developed. With this approach, every subject of knowledge is viewed as an organized system of material elements, to which one or another degree of sustainability is inherent.

Furthermore, the property of **system reliability** is determined by the nature of the source components, their quality and quantity as well as by the type and topology of the relationships and interactions between them. This also defines the spiritual component of scientists' research, i.e. the search for **hope (expectation) for the reliability of existence of technical-economic and social systems as well as on our planet Earth.**

**Index Terms**— deterministic and probabilistic systems; reliability research; space measurements, hope for reliability

## 1 Introduction

When exploring cybernetic complex dynamic systems, we should first be interested in the nature and topology of their internal structure. By using this approach, we can differentiate between *deterministic and probabilistic systems* [1, 2].

The existence of probabilistic systems is related to "operational" thinking and adaptive behavior, involving an element of random search and, of course, hope for a successful outcome from it.

Deterministic systems have been predominantly studied in the 19th century in the technical sciences and in the first half of the 20th century. These systems are characterized by "invariance" throughout their existence and the permanency of their functioning in an immutable environment. This allows for the studied processes to be accurately predicted at any interval of time [3].

Unequivocally deterministic processes have been historically investigated on the basis of quantitative methods. In this connection, the term "dynamic laws" has been formulated, defining the so-called "**principles of dialectics**" [1].

The study of deterministic systems is related to dynamic regularity. It represents such a form of causal relationship in which each preceding state unambiguously defines all of the following states, and of course the hope for their existence (or extinction). In this way, by knowing the past of a given system, one can predict its future.

Determinism in nature is linked to the views of many scholars such as Democritus, Hobbes, and especially the French - Diderot, Goldbach, d'Alembert and Pierre Laplace, with a significant contribution to the development of the mechanistic science concept of the world. In this sense, substantial is the contribution of the Russian scientist - encyclopedist Dmitri Mendeleev - *chemist, physicist, economist, technologist, geologist, meteorologist, pedagogue and aviator* [24]. He is the inventor of the Periodic Law of Chemical Elements in year 1869. Based on this law, he summarizes the basic principles of inorganic chemistry, creating the "Periodic table of elements" and first in the history of science, predicts the existence and properties of the elements that have not yet been discovered. Mendeleev improves the predictions of the state of chemical compounds on the basis of the system reliability of the elements in them.

Mechanistic determinism, as it is known, rejects the objective nature of chance and probability. [1, 2, 3].

With the emergence of cybernetics, the synthesis of various cybernetic systems has demonstrated the limitation of mechanistic determinism. The theoretical unsoundness of the concept for the uniqueness of deterministic development has been established. The efforts of designers and engineers, involved in the development of deterministic systems and adopting a variety of measures to ensure such behaviour, prove to be untenable. In connection with technical systems becoming more and more complex, especially risk systems, the requirement to accept certain assumptions as true, proved to be in contradiction with reality and its systematic assessment [6, 20]. The catastrophic reduction of reliability of the deterministic systems is a decisive causal prerequisite for an interest to arise in the second half of the 20th century in systems, whose functioning is subject to probability laws [4, 5, 6, 18, 19, 20].

Computers with a rigid (fixed) program are essentially unambiguous deterministic systems. This defines the high reliability of their operation. The amazing success achieved in the field of information processing is also based on that. Of course, the building and maintenance in an operational condition of such systems is becoming more and more difficult. It is no accident that David Smith and Samuel Davidson as early as 1985 state the following: "In the computer's logic circuits, it is necessary to know where exactly passes each one of the $10^7$ or even more connections. If one of these connections is incorrect or lacking, it is possible to get complete nonsense. In addition, the deviation from normal operation of one functional element of the computer or the interruption of one connection between its units and systems will render the entire machine useless" [9].

Numerous data show that "nature does not fully trust" the universal determinism. As an example, it is possible to point out the logical elements that it (nature) has used to create the human central nervous system (they are considerably less resistant than their electronic analogues in computers).

**Formulation of the research problem**

The nature of reliability research is determined by the work of the human brain as a biological object in nature that manages the interaction of machines and people.

Two contemporary points of view exist regarding the nature of neuronal mechanisms of the brain. Some scientists claim that the brain works by following algorithms set earlier, similar to the operation of computers. According to other scientists, the brain functions not only on the basis of deterministic principles and functions, i.e. its work differs from the operation of computers [7, 8, 9, 10].

The American psychologist Frank Rosenblatt states the following: ***"The brain is more or less a computational device in which stochastic processes and adaptation play a casual and insignificant role. It relies to a great extent on these processes, and therefore, the pattern in which they are being implemented proves to be unable to explain its psychological peculiarities"*** [11].

The probabilistic approach to reliability research is based on the existence of statistical regularity in the behavior of systems (technical, biological, economic, public, etc.). Statistical regularity represents such an ordered causal relationship, in which the previous state of the investigated system determines the next state ambiguously and with some probability is an objective measure of the possibility for this state to be accomplished. Statistical laws act in non-autonomous systems, the properties of which depend on constantly changing external influences.

If the dynamic regularity represents a specific form of manifestation of unambiguously deterministic laws, then statistical regularity is a form of manifestation of probability laws. The two types of laws are closely interlinked and manifest themselves simultaneously in different areas of planetary reality. This idea coincides with the statement of Sergey Melyuhin and Stephen Hawking: "*In the majority of cases in the macroworld, dynamic laws are realized as a major trend against the background of statistical processes in which the causal relationship needs to break through a large number of coincidences"* [4, 12].

Between deterministic and probabilistic processes cannot be established a clear boundary. Dynamic laws operate in relatively simple autonomous systems, but the concepts of great and small complexity and autonomy are relative. What under certain conditions appears to be simple, under other circumstances, can be complicated. Statistical laws act where there is a large number of objects (elements of them) and a connection exists between them. Of course, it must be taken into consideration that a law that is dynamic for a system of arbitrary order may be statistical for a system of lesser order. The following can be concluded:

**Dynamic regularity is, in essence, a statistical regularity with a proba-bility of event realization close to one.**

Therefore, probability laws are inherent to multiple events, but for a single event they are inapplicable. Modern theory of reliability uses the methods of probability theory and mathematical statistics. It should be known that there are realizable and non-realizable opportunities and trends in every phenomenon. In order to determine the correlation between them and their respective probability, practical experience and experiments (observation) are necessary by utilizing a large number of items (objects, phenomena, biological individuals) [13].

It must be taken into account, that Igor Kuzmintsev claims something interesting but yet unproven:*" **Statistical laws apply not only to mass phenomena. In a certain aspect, they also refer to individual events originating under their action as a form of their realization in the respective system"*** [14].

**Solution of the research problem**

The theory of reliability is based on the probabilistic nature of the **Reliability phenomenon**. With this approach, for all states in which a system is in, are released a number of $G=\{x\}$ from such states that differ in terms of reliability (**the hope for normal functioning**). This ensemble is called a ***phase space of the system***. The Reliability phenomenon is inextricably bound to the event of ***"system failure" ("diseases in humans and animals ")*** [19, 20, 21, 22, 25].

Over time, in the constituent elements of the observed system, various alterations arise, related to their "aging". Therefore, if at any moment $t$ the state of the observed system is described by a point $x_1$, then at a point of time $t_2 > t_1$ the state of the systems corresponds to a point $x_2$. At that, it may be that $x_2 \neq x_1$. If we designate with $x(t) \in G$ the state of the system at a given moment in time, then the sequence of states $x(t)$ will depend on the current time $t$ and can be considered as a process happening at the current time. Since the changes in system states have a random nature, the assessments of $x(t)$ can be defined as a trajectory of a random process, taking place in the phase space of the states of the observed system $G$.

As a second step in the building of the observed mathematical model, the respective random process is determined depending on the specific conditions of the task assignment. During the determination of the phase system $G=\{x\}$, when in it is assigned the random process $x(t)$, describing the evolution of the system over time, then the next stage is the choice of different numerical characteristics of system reliability.

Generally, the characteristics of reliability can be considered as a mathematical expectation by some functional $\Phi$, determined on the trajectory of the process $x(t)$. The functional $\Phi$ is used to determine the process $x(t)$, if each trajectory $x(t)$ corresponds to some number $\Phi\{x(t)\}$. The reliability indicator $\varphi$ is defined as the mathematical expectation of this functional $\Phi$, i.e. the equation is in effect:

ISSN 2229-5518

$$\varphi = M\left[\Phi\left\{x\left(t\right)\right\}\right] \quad (1)$$

Let us examine the main characteristics of reliable operation of the functional element (FE) from the observed system until the first failure. It is considered that FE starts working at a moment in time $t = 0$, and at the point $t = \tau$ a state of failure occurs. As "functional element" is denoted not only an indispensable part of the system, but also any other device, the reliability of which is investigated regardless of the reliability of the other constituent FE. It is assumed that with the letter $\tau$ is designated the lifetime of the FE. Thereof is derived the following equation for the function $Q_F(t)$ representing the probability of failure of the FE up to the current point in time $t$, i.e. $P\left\{\tau < t\right\}$:

$$Q_F(t) = P\left\{\tau < t\right\} \quad (2)$$

The function $Q_F(t)$ completely defines the reliability of FE of the system. Together with it, the other widely distributed function in the theory of reliability is also used – the probability of non-failure (PNF) work in time $t$. It is denoted by $P_{NF}(t)$. The relationship between the probability of failure of one FE and its probability of faultless operation at one and the same point in time $t$ or time interval $\Delta t$ is determined by

$$P_{NF}(t) = 1 - Q_F(t) = P\left\{\tau > t\right\} \quad (3)$$

The function $P_{NF}(t)$ describes the probability of non-failure work (faultless operation) of FE for the current time $t$. The example of this function is a monoto-nically decreasing exponential function, as at the moment $t = 0$ the value of $P_{NF}(t) = 1$, and at the moment in time $t = +\infty$ the value is $P_{NF}(t) = 0$.

As a result of (3) follows the basic equation of reliability of natural systems:

$$P_{NF}(t) + Q_F(t) = 0 \quad (4)$$

The graphical representation of the function $P_{NF}(t)$ is shown in a number of books, dedicated to the problems of reliability [5, 7, 8, 13, 15].

Another characteristic of the reliability of a system is the so-called intensity of failure flow (or risk of failure).

It is denoted by $\omega\left(t\right)$ for renewable systems and by $\lambda\left(t\right)$- for non-renewable. The subject of this research is above all the renewable systems, although the difference between the two types of systems is too blurry. Moreover, for a stationary, ordinary flow of failures of an observed technical system in the absence of event consequences in it, is valid the equation $\hat{\omega}\left(\Delta t\right) = \hat{\lambda}\left(\Delta t\right)$ [8, 18, 19, 20].

The intensity of failure flow for renewable systems is determined according to the following formula:

$$\omega(t) = f(t) / P_{NF}(t) \quad (5)$$

where $f\left(t\right)$ is the probability density of failures of the observed renewable natural system [7, 8].

From equations (3) to (5) after the respective mathematical transformations for a stationary observer on planet Earth, results the definition of the following equation, determining the probability of faultless operation (non-failure work) $P_{NF}(t)$ of the sy-stem within the observation interval $\Delta t = t_2 - t_1$ [18, 19, 20, 25].

$$P_{NF}\left(t_1, t_2\right) = e^{-\int_{t_1}^{t_2}\omega(t)dt} = exp\left[-\int_{t_1}^{t_2}\omega\left(t\right)dt\right] \quad (6)$$

where $\omega\left(t\right)$ is the intensity of failure flow within the observed time interval $\Delta t = t_2 - t_1$.

From equation (6) it is evident that exponential law is much more useable in the theory of reliability. Almost all problems, originating in relation with reliability issues are resolved with the use of exponential distribution. The main reason for this is that the exponential law of reliability has one extremely important property.

Under this law of distribution, the probability of faultless operation within an observed time interval $\left(t, t+\tau\right)$ depends not on the time of a priori work $t$, but on the length of the observation interval $\tau$ in the study of the respective object and the reliability (as well as the hope for it).

In other words, if we are certain that at a given point in time the FE is in good working order, then its future behavior will not be dependent on the past (see the fundamental works of B. Gnedenko, Y. Belyaev, A. Solovyev, Mathematical methods of reliability theory. Moscow 1965 and Barlow R., Proschan F. Mathematical Theory of Reliability. N.Y., 1969).

Under the conditions stated above and a constant value of the intensity of failure flow $\hat{\omega}\left(\Delta t\right) = \hat{\lambda}\left(\Delta t\right)$ within the observation interval $\Delta t$, the probability of faultless operation within the operating interval $\left(t, t+\tau\right)$ shall be determined by:

$$P_{NF}\left(t, t+\tau\right) = P_{NF}\left(t+\tau\right) / P_{NF}\left(t\right) = e^{-\lambda\left(t+\tau\right)} / e^{-\lambda t} = e^{-\lambda\tau} \quad (7)$$

Formula (7) is proof of the exponential distribution of the probability of faultless operation within the observation interval $\tau$ in the performed study.

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ISSN 2229-5518

The thus proven property of exponential distribution is characteristic, i.e. if it is executed for an arbitrary law on the probability of faultless operation, then this law is necessarily exponential.

As an example, the reliability of faultless operation of a spacecraft, that has encountered a cloud of meteorites, is examined. The assumption is accepted, that a failure in the spaceship can occur only if a sufficiently large meteorite damages its hull.

If we assume that the meteorites are evenly distributed in space and time, it is clear that the probability of a meteorite hitting the spaceship, during the relevant flight time interval, will not be dependent on whether meteorites have hit the ship's hull in the a priori past.

Consequently, the law of distribution of reliability, i.e. the probability of faultless operation (normal flight) of the spacecraft is exponential.

Following the example shown, let us determine the assessment of the intensity of failure flow $\hat{\omega}(t)$ for a technical system (TS) on the ground within the observation interval $\Delta t$ [8, 17, 18, 19, 20]

$$\hat{\omega}(t) = \frac{\sum_{i=1}^{n} r_i(t_1,t_2)}{n(t_1,t_2)\sum_{i=1}^{n}\tau_i(t_1,t_2)} \tag{8}$$

where: $r_i(t_1,t_2)$ is the number of failures of the $i$-sequential TS within the interval $\Delta t = t_2 - t_1$; $n(t_1,t_2)$ - the number of observed TS of the same type within the interval $\Delta t$; $\tau_i(t_1,t_2)$ - time for interrupted operation of the of the $i$-sequential TS within the interval $\Delta t$.

From the standpoint of Albert Einstein's special theory of relativity, if we assume that the time interval $\Delta t$ for a stationary observer on the planet Earth is determined by [15, 16], then follows:

$$\Delta t = \Delta t_{MS} / \sqrt{1 - V_{MS}^2 / c^2} \tag{9}$$

where: $\Delta t_{MS}$ is the time interval for a moving system (aircraft, moving at the speed $V_{MS}$; c – speed of light in a vacuum, established by Einstein to be a constant with value of $300000\ km/s$.

Under these conditions, a mathematical analysis of the problem is performed in the context of the relativity theory by the genius physicist Albert Einstein.

From equation (9) follows the formula for the speed $V_{MS}$ of the observed moving system:

$$V_{MS} = c\sqrt{1 - (\Delta t_{MS} / \Delta t)^2} \tag{10}$$

In equation (10) for the speed $V_{MS}$ of the observed moving system (aircraft) relative to the planet Earth is introduced the concept of relativistic (relative) indicator of reliability $R(V_{MS})$ determined by:

$$R(V_{MS}) = \Delta t_{MS} / \Delta t \tag{11}$$

As a result of equation (10) follows, that the time interval $(t_1, t_2)$ of the moving system, within which is determined the intensity of failure flow $\omega_{MS}(t)$ and the pro-bability of faultless operation $P_{NEMS}(t)$, is:

$$\Delta t_{MS} = t_2 - t_1 = R(V_{MS})\Delta t \tag{12}$$

From (12) and under the assumption of stationarity, ordinariness and lack of consequences of the failure flow of the moving system (analogously for the stationary system – in particular the planet Earth), for its intensity $\omega_{MS}(t)$ follow the equa-tions:

$$\omega_{MS}(t) / \omega(t) = \Delta t_{MS} / \Delta t, \tag{13}$$

$$\omega_{MS}(t) = R(V_{MS})\omega(t), \tag{14}$$

Therefore, for the moving system (aircraft moving at high speed relative to the planet Earth), the basic law of reliability for $P_{NEMS}(t)$, will look like the following (from the point of view of an observer on Earth)

$$P_{NFMS}(t_1,t_2) = e^{-\int_{t_1}^{t_2}\omega_{MS}(t)dt} \tag{15}$$

The analysis of equation (15) shows that for a studied moving material system, observed from the planet Earth and moving at a velocity $V_{MS} \geq c.10^{-3} = 300\,km/s$ [21, 22] (the missiles of the anti- missile defense system of the USA have an approximate speed of 6,6 $km/s$; small meteorites can reach speed relative to the Earth in the range of 30 to 300 km/s and much, much higher is the speed of space particles colliding with the Earth), the basic law of reliability will be as follows:

$$P_{NFMS}(t_1,t_2) = e^{-R(V_{MS})\int_{t_1}^{t_2}\omega(t)dt} \tag{16}$$

where $V_{MS}$ is the speed of the moving material system (meteorite or space particles), moving relative to the planet Earth, on which the reliability is assessed.

On the other hand, the relativistic indicator of reliability $R(V_{MS})$ is determined by (8) as:

ISSN 2229-5518

$$R(V_{MS}) = \omega_{MS}(t)/\omega(t) = \Delta t_{MS} / \Delta t = f(V_{MS}) = a_n V_{MS}^n + a_{n-1} V_{MS}^{n-1} + \ldots + a_1 V_{MS} + a_0 \quad (17)$$

where $f(V_{MS})$ is a function, describing the change in speed $V_{MS}$ of the moving system relative to the planet Earth, approximated by a power series with coefficients $\{a_i\}_{i=0}^{n}$ in the sense of the smallest squares [13]. Formula (17) is used for the purpose of deve-lopment of the theoretical and applied knowledge of reliability.

Provided that the aircraft has been launched in the cosmic space around the planet Earth (for example, the space shuttle "Atlantis") and a technological investigation has been performed of the intensity of failure flow of the communication system in terrestrial conditions /on Earth/ (stationary system) and space conditions (moving system), formula (16) will look like this:

$$P_{NFMS}(t_1,t_2) = \left\{ e^{-\int_{t_1}^{t_2} \omega(t)dt} \right\}^{R(V_{MS})} = \left\{ P_{NFSEC}(t_1,t_2) \right\}^{R(V_{MS})} \quad (18)$$

where $P_{NFMS}(t_1,t_2)$ is the reliability (probability of non-failure work) of the studied communication System at Earth Conditions (SEC).

As a result of formula (18) comes the important conclusion that in space conditions the reliability of the monitored communication system will be increased (similarly for other types of technological systems). As confirmation of this, we can mention well-known examples of accidents and crashes of space shuttles and rockets. These happen exclusively during lift off from the planet's surface or when passing through the Earth's atmosphere, which is very risky for society.

Analogous is also the conclusion that follows from Albert Einstein's theory regarding the shortening of the length $L$ of the objects: "The dimensions of all moving bodies from a single moving system (MS) appear shortened in the direction of mo-vement, in comparison with their dimensions in earth conditions (EC), i.e. this again substantiates the validity of the following formula [16]:

$$L_{MS} = L_{EC}\sqrt{1-(V_{MS}/c)^2} \quad (19)$$

As a result of formula (19) follows the important conclusion regarding inc-reasing of the reliability of objects, representing elements of a moving system and whose movement is taking place in space.

It is no coincidence that scientific and technological experiments (technical, biological, social, etc.) can be carried out in outer space, whose realization would be impossible in terrestrial conditions.

**Example study of reliability**

It is assumed, that we are monitoring 10 communication systems of the same type of the space shuttle "Atlantis" during 1000 hours of continuous operation (initially in terrestrial conditions and then in space). The total number of failures under conditions on Earth is 3 and in space conditions is 1 [22]. By using formulas (7) and (17) we make the following calculations for the intensity of failure flow in system at earth conditions (SEC) and in system in space conditions (SSC):

$$\hat{\omega}_{SEC}(t_1,t_2) = \frac{3}{10.1000} = 0,3.10^{-3}\ fit$$
$$\hat{\omega}_{SSC}(t_1,t_2) = \frac{1}{10.1000} = 0,1.10^{-3}\ fit \quad (20)$$
$$R(V_{MS}) = \frac{\hat{\omega}_{SSC}(t_1,t_2)}{\hat{\omega}_{SEC}(t_1,t_2)} = 0,33$$

where fit is the measurement unit of the intensity of failure flow, equivalent to 1 failure/h.

The following are the calculations of the probability of non-failure work (faul-tless operation) in earth condition (EC) according to the approximate formula for stationary, ordinary and without consequences failure flow [21, 22]:

$$P_{NFEC}(t_1,t_2) = e^{-\omega_{EC}(t_1,t_2)}.\tau = e^{-0,3.10^{-3}}.10^3 = 0,742. \quad (20)$$

In accordance with the deduced above formula (18) the probability of faultless operation in space conditions (SC) will have the following value:

$$P_{NFSC}(t_1,t_2) = \left\{ P_{NFEC}(t_1,t_2) \right\}^{R(V_{MS})} = 0,742^{0,33} = 0,906 \quad (21)$$

After verification of the uncertainty of the calculations (the derived formula) by using the classical calculation from (5) for the reliability of the communication system of Atlantis in space conditions, we obtain the result:

$$P_{NFSC,1}(t_1,t_2) = e^{-\omega_{SC}(t_1,t_2)} e^{-0,1.10^{-3}}.10^3 = 0,905 \quad (22)$$

Therefore, the absolute uncertainty of the calculations of the probability of faultless operation of the communication system in question in space conditions is:

$$\Delta P_{NFSC}(t_1,t_2) = 0,906 - 0,905 = 0,001 \quad (23)$$

The formulated reasoning is made on the condition that the speed of light in vacuum is a constant, i.e. the aircraft is moving outside the earth's atmosphere.

The reasoning and conducted research are a symbiosis between the deterministic and probabilistic approaches for in-

ISSN 2229-5518

vestigating reliability of natural objects of natural and artificial origin in space. They show that the exponential law as well as many other laws of reliability distribution (normal, Erlang, Weibull, etc.) testify to the probabilistic nature of reliability.

## 4 Conclusion

As a result of the performed reliability analysis based on deterministic and probabilistic approaches to research and in the context of the measurements of nature in space, the following conclusions have been made:

1. The probabilistic nature of reliability is inherent not only in technical systems, but also in the natural, biological, social and global space systems.
2. It is necessary to introduce a relativistic probability indicator in order to assess the reliability of a system consisting of a planet and moving around it high-speed material object. This also applies to the hope for the survival of mankind.
3. The relativistic indicator of reliability is universal for any conditions, to which the observed object is subjected, as these conditions originate as a result of the different types of interactions with the objective reality.

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