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RELIABILITY MODEL OF AIR NAVIGATION SYSTEM OPERATOR

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Abstract—*This paper deals with air navigation system operator reliability. The main goal is to determine the operator's reliability by the means of the chosen model. Peculiarities of reliability models were discovered and the most appropriate one was chosen according to the requirements for restorable system. Method of diffusion nonmonotonic model calculation is preferred. This method can help solve problem of recovery operator efficiency after failure.*

Index Terms—Reliability; air navigation systems operator; reliability model; convolution function; exponential reliability model; diffusion nonmonotonic reliability model; probability of error-free operation.

I. INTRODUCTION

Profession of operator of air navigation systems (ANS) has a high psychological, emotional and intellectual orientation and belongs to the most stressful and emotionally saturated types of professional activity.

From ANS operator's efficiency and his ability to carry out his work accurately and on time depend not only on the capacity of the air traffic control system, but also on flight safety in general [2].

The probability of successful performance of the task in a given operational stage of ergatic system can be used as a quantitative assessment of the ANS operator reliability. During the synthesis of the requirements for an ANS operator the reference estimation of the reliability of his functionality is possible just in case if it is based on an adequate analytical model.

This paper introduces the specifity of an air navigation system, an ergatic one, and emphasizes special functioning aspects of its operators' new definitions.

Some terms of basic reliability theory [5] were developed in order to derive these definitions.

II. ANALYSIS OF RESEARCH

Quantitative evaluation of the operator of air navigation system reliability can be used as a probability of the successful performance of work or task, at a given system operating step, at a given time interval [5].

The air traffic control system is an ergatic control system, which includes both elements: technical equipment and operators that interact with the system.

Therefore, to obtain an objective assessment of reliability of air navigation system we should take into account not only the effect of the air navigation systems, technical equipment quality, but also results of operator of air navigation system activity, that depends on many factors [10].

When we evaluate air navigation system reliability, we can count only technical equipment failures, failures are not related to the operator activities. That means that the operators reliability defaults to the absolute when operator reliability $R = 1.00$.

However, a significant amount of technical equipment failures of air navigation systems, which occur due to the operator fault, indicates a significant impact of operator on the reliability of air navigation systems. Proportion of failures due to the activities of the operator varies from 20 to 95 percent in the reporting documentation [3].

Therefore, the reliability of operator of air navigation systems is not absolute, and it should be taken into account in estimates of its characteristics. Otherwise, the reliability evaluation of air navigation systems becomes too erroneous and exaggerated.

Moreover, if the decrease of the level of technical equipment reliability is connected with the appearance of failures, then the estimated reliability of operator of air navigation system errors that occur in its activities. Error of operator of air navigation systems is an incorrect performing or failure to perform the prescribed action. [7]

Error of operator of air navigation systems can occur in the following cases:

1. Operator aims to achieve some incorrect goals ("substitution of the purpose").
2. An incorrect operator action that enables goal.
3. Operator is idle when his participation is necessary. [5]

Operator errors are due to the following main reasons:

– unsatisfactory training or poor qualification of the operator;

– unsatisfactory performance of operating procedures by the operator;

– poor working conditions, such as poor equipment availability, tightness of workroom or excessive temperature in it;

– lack of incentives for operators;

– high information overload, leading to information stress and information traps;

– poor physical condition that affects the functioning of operator of air navigation systems.

The indicated error causes can be considered independent and classified by the following four types (Fig. 1) [9].

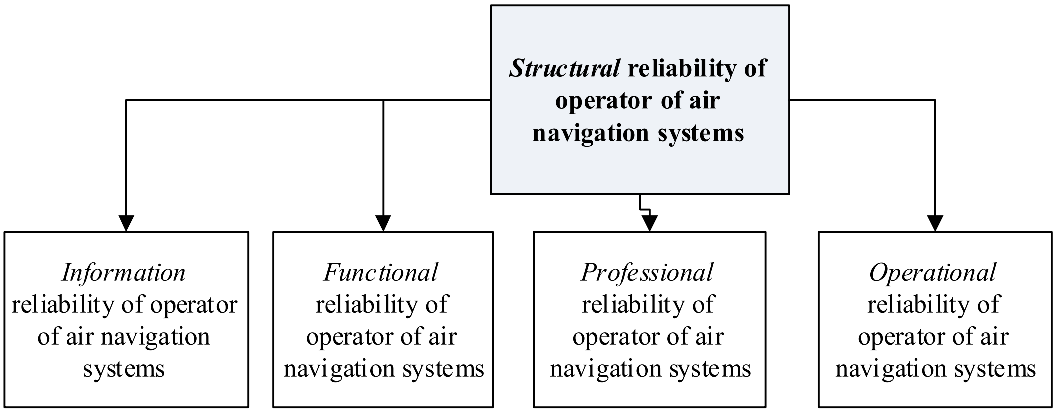


Fig. 1. Structure of operator of air navigation systems reliability

Based on that, the probability of structural error-free operation of operator of air navigation systems can be represented as:

$$R_{str} = R_{prof} \cdot R_{op} \cdot R_{\inf} \cdot R_{func}$$

where $R_{str}, R_{prof}, R_{op}, R_{\inf}, R_{func}$ are probability of error-free operation of operator of air navigation systems: structural, professional, operational, informational, and functional, respectively [6].

In serial systems (Fig. 2) failure of any component of the structure leads to failure of the whole system [2].

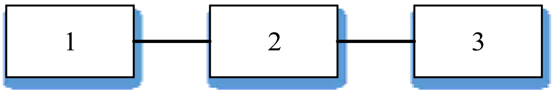


Fig. 2. Serial connected elements

In general, the probability of error-free operation of the system with the serial elements is:

$$R = \prod_{i=1}^{m} R_i,$$

where R is error-free operation; m is the number of serial elements in the system [1].

In a system with parallel structure (Fig.3), system failure generally occurs only at the failure of all elements.

In general, the probability of error-free operation of the system with the parallel elements is:

$$R = 1 - \prod_{i=1}^{m} (1 - R_i),$$

where R is error-free operation; m is the number of parallel elements in the system.

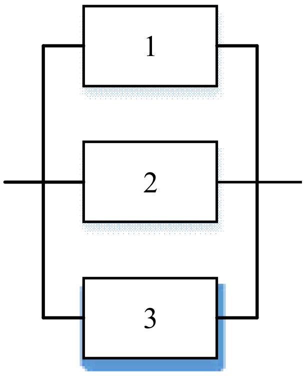


Fig. 3. Parallel connected elements

We can describe any complex structure, such as ANS operator using a combination of serial and parallel connected links.

III. RELIABILITY MODEL OF AIR NAVIGATION SYSTEM OPERATOR

Air navigation systems operator as an element of ergatic system, operates in noisy environments and is eligible for a mistake, when performing functional responsibilities with subsequent restoration of his efficiency. Air navigation system operator’s error is incorrectly performed or a failure to perform the prescribed actions, that leads to an accident or to a situation that may cause an accident [5].

Exhaustive characteristic of any random variable, such as ANS operator’s error, including random duration t of the error-free distribution function $F(t)$, that can be also called distribution model of ANS operator failures or errors. It is associated with the probability of error $Q(t)$ identity, which follows from the definition of the distribution function

$$F(t) \equiv Q(t). \tag{1}$$

A model of an ANS operator's error is the mathematical model in the form of error distribution function or the probability of error occurrence of an ANS operator during the given interval of time [4].

$$R(t) = 1 - Q(t); \tag{2}$$

$$R(t) = 1 - F(t) = 1 - \int_0^t f(t)dt. \tag{3}$$

The error model described by a distribution function *F*(*t*) that is related to the function of error-free operation *R*(*t*), so called reliability model. The relation between *R*(*t*) and *F*(*t*) considering identity (1) can be determined by the ratio (2) from which the obvious dependency between the error-free work of the ANS operator and the model of errors can be seen [1].

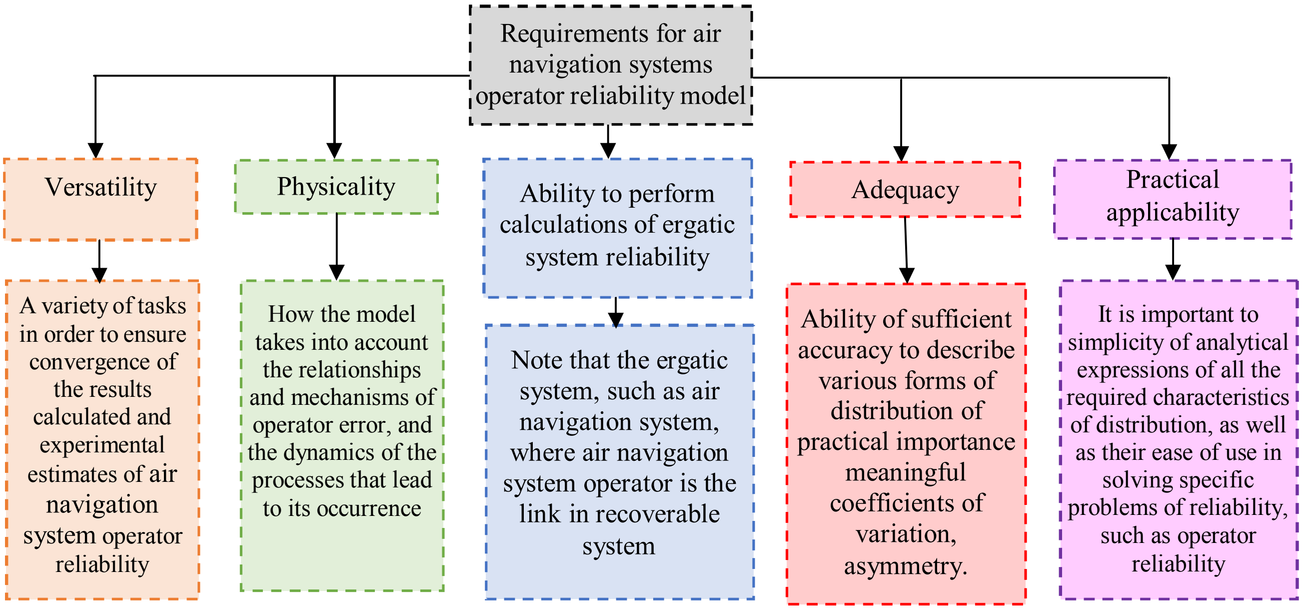
Reliability model of the air navigation systems operator is the mathematical model that establishes a connection between the reliability parameters of the operator, the reliability characteristics of elements of the ANS structure and the parameters of the process of its operation [4].

Hence, creation of reliability model, that provides a calculation of the error-free probability of the ANS operator R (t) as a function of an operating time, involves the determination of the analytical expression of the distribution density of the operating time with the error f (t). In this case, the type of the function f (t) determines the accuracy of calculation of certain quantitative indicators of reliability [8].

IV. AIR NAVIGATION SYSTEMS OPRATOR'S RELIABILITY REQUIREMENTS

However, not all error models used in reliability theory can be applied to ergatic systems because many of them have a range of disadvantages.

Criteria to be complied with the different distribution models of operator error in the time interval due to the peculiarities of its functioning. In accordance with the requirements of regulations such criteria consider: physicality, adequacy, the ability to perform calculations of system reliability, versatility and practical applicability (Fig. 4).



A variety of tasks in order to ensure convergence of the results calculated and experimental estimates of air navigation system operator reliability

How the model takes into account the relationships and mechanisms of operator error, and the dynamics of the processes that lead to its occurrence

Note that the ergatic system, such as air navigation system, where air navigation system operator is the link in recoverable system

Ability of sufficient accuracy to describe various forms of distribution of practical importance meaningful coefficients of variation, asymmetry.

It is important to simplicity of analytical expressions of all the required characteristics of distribution, as well as their ease of use in solving specific problems of reliability, such as operator reliability

Fig. 4. Requirements for air navigation systems operator reliability model

The most important task that can be solved on the basis of the error model is the prediction of reliability of the air navigation system operator can be solved, evaluating its performance and the determination of the impact on fights safety. Therefore, a very important feature of the distribution function, which is used as a model error should be considered as an opportunity to perform the calculation of reliability to be based on it.

Calculation of error-free operation of the air navigation system operator should take into account the fact that the ANS operator as an element of ergatic system, operates in noisy environments and is eligible for a mistake, when performing functional responsibilities with subsequent restoration of his efficiency.

The process of recovery of the ANS operator can be represented as an analytical model in the same way as working capacity and reliability of the system technical components are described.

It is important to note that the calculation of the ANS operator's error-free probability with respect to the necessary recovery may be performed if the model of error distribution has the properties of convolution of the random variable's distribution.

Convolution functions are the operation in functional analysis, shows the "similarity" of one function with the reflected and shifted copy of another. Convolution - a mathematical operation of two functions that generate a third function, which usually can be considered as a modified version of the original one. Essentially, this is a special kind of integral transformation.

Among well-known reliability models, only two match this query: the exponential and diffusion nonmonotonic model.

V. EXPONENTIAL ERROR DISTRIBUTION MODEL

The exponential (EXP) error distribution model [1] is a one-parameter function, in which the density distribution of operating time to failure is expressed by analytic dependence

$$f_{\exp}(t) = \lambda \exp(-\lambda t), \tag{4}$$

where λ is the intensity of air navigation system operator's error.

The intensity of ANS operator's error is the conditional density probability of occurrence of ANS operator's error, which is determined if for the concerned moment of time the error is not occurring [3].

Note that for the exponential model error intensity is constant (5).

$$\lambda = \text{const}. \tag{5}$$

From Fig. 5 we can see that exponential distribution is quite inaccurate model of the error distribution. By using this distribution to create an analytical model of the ANS operator's reliability, it would be necessary to take an omission that ANS operator's errors occur during equal intervals. However, similar condition is not only difficult to implement in practice, but it is also inconsistent with the criteria of fight safety. The ANS operator, working in such a way, would not have been effective and is not safe.

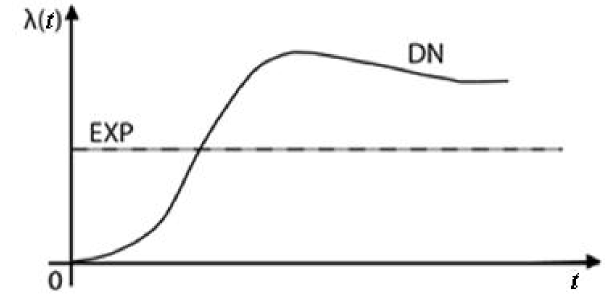


Fig. 5. The intensity of operator error in the exponential model and the diffusion nonmonotonic model

VI. DIFFUSION NONMONOTONE ERROR DISTRIBUTION MODEL

Diffusion nonmonotonic (DN) error distribution model in contrast to the exponential, in which there is only parameter – the scale parameter, is a two-parameter.

Scale parameter μ corresponds to the average operating time of the air navigation system operator till the first error

$$\mu = T_0 = \int_0^{\infty} t\, f(t)dt. \tag{6}$$

Shape parameter υ, equal to the coefficient of variation of operating time till the first error.

$$\upsilon = \frac{\sqrt{D}}{T_0} = \frac{\sigma}{T_0}, \tag{7}$$

where σ is the mean square deviation; *D* is the dispersion, scattering parameter with respect to the central midpoint.

Unlike the exponential model intensity of air navigation system operator error λ will not be constant and can be calculated by the formula

$$\lambda_{DN}(t) = \frac{\sqrt{\mu}}{\upsilon t\sqrt{2\pi t}}\left(\frac{\mu - t}{\nu\sqrt{\mu t}}\right) - \exp\left(\frac{2}{\nu^2}\right) \times \Phi\left(-\frac{\mu + t}{\nu\sqrt{\mu_i t}}\right)\exp\left[\frac{(\mu - t)^2}{2\upsilon^2 \mu t}\right]. \tag{8}$$

VII. CALCULATIONS OF ERROR-FREE OPERATION USING DIFFUSION NONMONOTONIC MODEL AND EXPONENTIAL MODEL OF RELIABILITY

Calculations of error-free operation using diffusion non monotonic model and an exponential model of reliability can be carried out by the "lambda" method for the exponential reliability model and probability-physical methods for nonmonotonic model.

Among the most common arguments, the error distribution model, which has more parameters, is more adequate. Insolvency exponential distribution model as a model of reliability can be inferred by the basis of forward-looking, estimates mean time to error (MTTE) in a wide range of variation, intensity of errors and tasks of varying complexity derived "lambda" and probability-physical methods, and the relationship $\text{MTTE}_{\text{EXP}} / \text{MTTF}_{\text{DN}}$ as elements and systems [8].

Analytical dependences for estimation of mean operating time to the first error of element is based on "lambda" and probability-physical methods and errors of the "lambda" method are shown in Table.

Analysis of the results clearly shows that the estimates of $MTTE_{EXP}$, is obtained on the basis of an exponential distribution model of errors, that is significantly (many times) more than the estimates of $MTTF_{DN}$, obtained by the DN-model of dependability [8].

Mean time to error DN-model achieved only when the failure rate $\lambda > 10^{-5}$ h^{-1}, i. e. low reliability of the air navigation system operator and absence of skills (Fig. 6).

CALCULATED DEPENDENCES FOR ESTIMATION OF MTTF AND ERROR OF "LAMBDA" METHOD

Mean operating time to the first failure		**Error of λ-method**
$MTTF^{exp}$	**$MTTF^{DN} = \mu$**	
$t_o^{exp} = (\lambda)^{-1}$	$\frac{\sqrt{\mu}}{\lambda(t_{op})vt_{op}\sqrt{2\pi t_{op}}}\exp\left(-\frac{(\mu-t_{op})^2}{2v\mu t_{op}}\right)$ $= \Phi\left(\frac{\mu-t_{op}}{\nu\sqrt{\mu t_{op}}}\right) - \exp\left(\frac{2}{\nu^2}\right)\Phi\left(-\frac{\mu+t_{op}}{\nu\sqrt{\mu_i t_{op}}}\right)$	$\delta t_o = \frac{t_o^{exp}}{\mu} - 1$

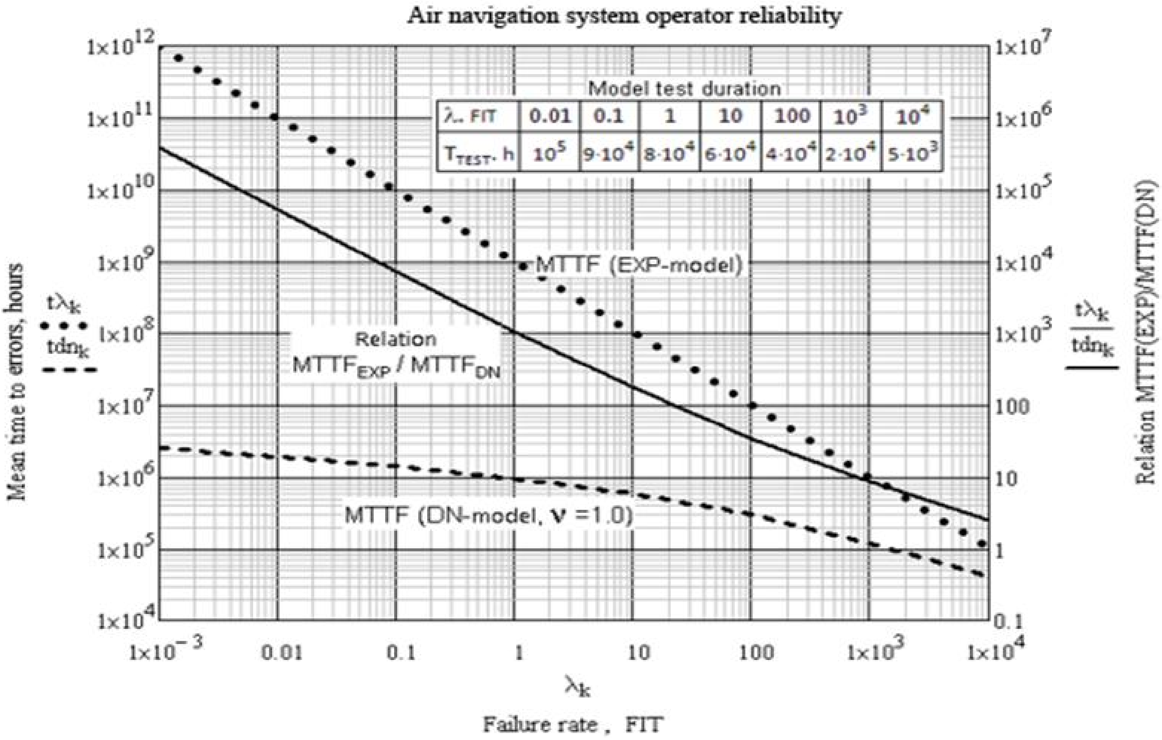


Fig. 6. Predictive estimates $MTTE_{exp}$ and $MTTE_{DN}$ elements and ratio estimates

When the linear model depends on duration timing of the ANS operator's error, intensity count exceeded $MTTE_{EXP}$ at $\lambda \sim 10^3$ FIT is 10 and increases with professional reliability while achieving $\lambda \sim 1{,}0$ 1,0 FIT values $\sim 10^3$ times, while $\lambda \sim 1{,}0$ FIT is $\sim 10^4$ times, or 10^6 %, which demonstrates the level of "rudeness" EXP model reliability. Satisfactory convergence of estimates and $MTTE_{EXP}$

In other words, the worse trained air navigation system operator is, the more exponential distribution model is suitable for describing its dependability [6]. It turns out that the use of the lambda method has no practical sense for safe systems with air navigation system operator with high rate skills.

CONCLUSIONS

It was established that the optimal analytical model of the air navigation system operator's reliability is the diffusion nonmonotonic model of the errors distribution. This model satisfies the requirements for mentioned above model of failures (see Fig. 1).

One of the main advantages of the DN error distribution model can be seen in Fig. 2. Error intensity of DN model close to the real values of the errors of ANS operator.

In addition, scale parameter μ and υ form of DN model are consistent with the peculiarities of functioning of the operator and can be used for the calculations not only in the air navigation system and for all ergatic systems.

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О. В. Кожохіна, В. М. Грібов, С. І. Рудас. Модель надійності оператора аеронавігаційної системи

Розглянуто надійність оператора аеронавігаційних систем та виявлено особливості моделей надійності ергатичних систем. Обрана найбільш відповідна модель згідно з вимогами для відновлюваних систем. Запропонований дифузійний немонотонний метод розрахунку надійності дозволяє вирішити проблему відновлення працездатності оператора після помилки.

Ключові слова: надійність; оператор аеронавігаційної системи; модель надійність; функція згортки; експоненціальна модель надійності; дифузійна немонотонна модель надійності; ймовірність безпомилкової роботи.

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Е. В. Кожохина, В. М. Грибов, С. И. Рудас. Модель надежности оператора аэронавигационной системы

Рассмотрена надежность оператора аэронавигационных систем и выявлены особенности моделей надежности эргатических систем. Выбрана наиболее подходящая модель в соответствии с требованиями для восстанавливаемых систем. Предложенный диффузионный немонотонный метод расчета надежности позволяет решить проблему восстановления работоспособности оператора после ошибки.

Ключевые слова: надежность; оператор аэронавигационной системы; модель надежность; функция свертки; экспоненциальная модель надежности; диффузионная немонотонная модель надежности; вероятность безошибочной работы.

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