316. Possibilities of Assessment of Reliability of an Anthropotechnical System

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Abstract. Reliability and safety characteristics [7] of an anthropotechnical system are the basic information about the correctness of relation between a man (e.g. pilot) and a helicopter (machine). Methods of defining them are still an open problem. The article presents an innovative way of definition of reliability characteristics of a pilot and a helicopter engine as well as an entire anthropotechnical system. Described are theoretical bases of this method, which are various configurations of the "equation of state" describing relations pilot – helicopter and helicopter – pilot [8, 9].

Defined was the set of "numbers of limit state violations" of the parameter of pilot's physical condition a_P and technical state of the helicopter a_S, which as "premises of damage" were used for calculation of estimators of reliability characteristics. It is noteworthy that these characteristics could be particularly useful in the process of comparing different pilots and helicopters in various situations appearing in the course of utilisation.

Keywords: diagnostics, adjustment, safety, reliability, signals, pilot, helicopter.

Introduction

The reality around us consists of cybernetic control systems, amongst which it is possible to enumerate technical, production, social systems etc. [1, 10] Thus, we have a system of utilisation of a technical object (e.g. the system pilot - helicopter), a system of production of market products (e.g. an enterprise), an education system (e.g. school) etc. In all systems a man is acting according to strictly determined principles. For instance, in the system of utilisation of the helicopter active is the pilot (helicopter, maintenance), in the system of production - technical inspection (machines, workers), in the system of education - teacher (pupils, study aids, administration). The human being appearing in these systems with his special senses and with possibilities of inductive generalising very often (what is demonstrated by above-mentioned examples) performs very difficult role of an inspector of a system (the man is a peculiar evaluation system not to say a special measuring system) examining its state and state of its components, as well as evaluating the ability of the system for fulfilling of assumed, usually very complex objectives. Thus, the pilot should at any time evaluate the applicability of the helicopter (his conditions of flying - environment and technical condition) with help of the six-stage di Franco or the ten-stage Cooper scale [5].

A technical inspector usually evaluates product value with help of the three-class quality scale, and a teacher evaluates quality of pupil's work with help of the six-stage mark scale of progress of study. The process of fulfilling of the "system inspector" role by the man is difficult and requiring high qualifications. In most cases he notices the real state of the system at any time and transforms it into the abstract multidimensional image according to acquired knowledge of observations and impressions. In-depth analysis of this image is the base for carrying out of necessary generalisations, and next for elaboration of sought quality evaluation and applicability of the entire system, where the man is acting as its constituent element. [2, 3, 5] It is worth to notice that the assessment of the entire system consists at least of two partial assessments – the first is the self-assessment of man's activity in the system and the second is the assessment of technical parts of the system. These assessments depend on current predispositions of the man. Thus, the man can assess his malfunctions as good, and the good technical object as bad. Hence in such demonstrative, often met systems like pilot - helicopter irregularities of this type always lead to appearance of premises of flying accidents. Therefore examination of quality of action of the man, the operator of the machine, the pilot, is so important and necessary. It has been discerned, that the good tool for assessment of the role of the biological element are its reliability factors.

Theoretical premises for determination of reliability factor of the pilot – helicopter system

A pilot and a helicopter in their environment form an interdependent anthropotechnical control system. The reliability of this system in even's measure depends on reliability of the pilot and the helicopter. The reliability of the pilot is defined with probability of the event of his ability i.e. the ability of correct performing of required navigation and control actions - R_P. The reliability of the aeroplane is determined with the probability of events that while making the task it will not lose its technical and functional efficiency - R_S. The reliability of the anthropotechnical system pilot - helicopter in the environment is defined as its ability for proper fulfilling of an assumed task - R_A.

The reliability of the system R_A can be calculated from the formula (1). [7]

$$R_A = R_P R_S \quad (1)$$

Tentatively on the base of (1) it is possible to determine:
system unreliability

$$F_A = 1 - R_A \quad (2)$$

function of density of causes of unreliability

$$\psi_A = \frac{dF_A}{dt} \quad (3)$$

function of intensity of causes of the applicability

$$\lambda_A = \frac{\psi_A}{F_A} \quad (4)$$

expected time of applicability until the first cause of unreliability appears

$$F(T) = \int_0^\infty R(t)dt \quad (5)$$

where: T – random variable of the time of utilisation t.

On the base of formulas (1 - 5) it is possible to state, that all used factors of reliability of an anthropotechnical system can be calculated after previous determination of pilot's reliability function $R_P(t)$ and helicopter's reliability function R_S. These functions can be determined through examination of events, which result in unreliability. They are the base for determination of estimators of reliabilities of pilot R_P* and helicopter R_S*:

$$R_P^* = \frac{n(t)_P}{n_P} \quad (6)$$

$$R_S^* = \frac{n(t)_S}{n_S} \quad (7)$$

where: $n(t)_P$ - event of pilot's malfunction, n_P - sum of events of incorrect and correct actions of the pilot, $n(t)_S$ - catastrophic events of helicopter's action, n_S - sum of events of catastrophic and correct actions of the helicopter.

Process of determination of the reliability function of the anthropotechnical system R_A amounts to calculation of estimators R_P* and R_S*, then of reliability functions $R_P(t)$ and $R_S(t)$ (which should be described with dependent functions: Weibull, exponential, power, logarithmic - power). [7] However, the serious problem remains the identification of correct and incorrect events concerning the helicopter and the pilot, particularly when it has been assumed that the user and the ground crew with their action have assured such situation that there is complete lack of incorrect events. Hence the verification of reliability characteristics of the anthropotechnical system during its utilisation becomes difficult, and often impossible - however it has been discerned, that e.g. incorrect events necessary for formulas (6) and (7) can be replaced with "forecast events" identified in the process of diagnosing of constitutive elements and entire anthropotechnical system. [4, 5]

Prediction of incorrect events in the system pilot – helicopter

With his influence on the helicopter the pilot changes its environment. This influence is effective when the technical state of the helicopter is right. Thus, it is possible to write:

$$\frac{dU}{dt} = a_P U + b_P D \quad (8)$$

where: U – control signal of the helicopter manoeuvring program, D - signal of the technical condition of the helicopter, a_P - parameter of the correctness of pilot's action, b_P - parameter of influence intensity of technical condition on correctness of manoeuvring.

The a_P parameter characterises the psychophysical condition of the pilot. It is being set by the pilot within strictly determined limits. A "trip" of the a_P parameter beyond these borders will be then an undesirable event of pilot's malfunction, which can be treated as the incorrect event $n(t)_P$.

The helicopter performing every utilitarian work wears unconditionally. Intensity of this wear depends obviously on the program of flight. Thus, it is possible to write:

$$\frac{dD}{dt} = a_S D + b_S U \quad (9)$$

where: a_S - parameter of technical condition of the helicopter, b_S - parameter of intensity of pilot's influence on the change of technical condition.

Thus, it will be enough to determine graphs of a_P and a_S parameters within the utilisation time "t", and then incorrect events, when a_P and a_S are not located within determined limits resulting from assumed level of carried out examinations (this can be σ, 2σ, 3σ - σ standard deviation).

Prediction of reliability characteristics of the system pilot – helicopter engine

Examined were relations between signals resulting from the utilisation quality of the helicopter and diagnostic signals (vibroacoustic signals resulting from their technical condition). Results of examinations are shown in the table 1.

Basing on principles of static and dynamic identification from the equation (8) it is possible to determine the global parameter of pilot's physical condition a_P:

$$\hat{a}_P = \left(-\frac{b_P}{a_P}\right) = \frac{\sum U_i D_i}{\sum D_i^2} \quad (10)$$

$$a_P = \frac{\Delta U}{\Delta\Theta\left(U + \hat{a}_P D\right)} \quad (11)$$

Tentatively using data from the research in the table 1 and the relations (10) and (11) we can obtain graphs of the a_P parameter characterising the physical condition of the pilot. This state is incorrect, when a_P exceeds the limit determined with the range $\pm\sigma$ (what is equal to the level of 1%). These graphs are shown on the fig. 1.

The number of exceeded pilot's condition parameters is the base for calculation (from the relations (6)) of pilot's reliability estimators $R_P{*}(t)$, which in turn are the base for calculation of the reliability factor function $R_P(t)$. The reliability estimators and functions are shown on the figs. 2a and 2b.

In the similar way it is possible to determine the global parameter of the technical condition a_S of the engine of the KANIA helicopter:

$$\hat{a}_S = \left(-\frac{b_S}{a_S}\right) = \frac{\sum D_i U_i}{\sum U_i^2} \quad (12)$$

$$a_S = \frac{\Delta D}{\Delta\Theta\left(D + \hat{a}_S U\right)} \quad (13)$$

The graphs of the a_S parameter and its incorrect states are shown on the fig. 3.

Table 1.

Flight hours	**Hours**	**Flights**	**Flights/ hrs**	ΔA	ΔA	$\frac{\Delta A}{\Delta\Theta}$	$\frac{\Delta A}{\Delta\Theta}$
Θ				**right engine**	**left engine**	**right engine**	**left engine**
191	1.61	9	5.59				
203	6	29	4.83				
292	15	64	4.27				
348	6	46	7.67				
483	7	62	8.86				
549	16	88	5.50				
554	3	16	5.33				
560	6	28	4.67				
713	8	26	3.25				
720	2	11	5.50				
879	21	126	6.00				
912	3	30	10.00				
931	15	78	5.20				
1012	4	30	7.50				
1020	8	83	10.38				
1024	3	16	5.33				
1027	3	16	5.33				
1042	15	137	9.13				
1063	2	10	5.00				
1120	18	237	13.17	-1	1		
1146	22	290	13.18	-1	2		
1148	2	23	11.50	0	-3		
1189	9	59	6.56	0	-1		
1230	5	10	2.00	3	-1		
1304	4	27	6.75	-3	0		
1308	4	15	3.75	3	0		
1327	2	14	7.00	-2	-3		
1333	2	11	5.50	-3	-3		
1364	5	16	3.20	1	-3	0.08	-0.23
1645	3	22	7.33	2	-3	0.09	-0.09
1648	6	50	8.33	-3	-3	0.09	-0.09
1654	5	37	7.40	-1	-3	0.09	-0.09
1659	4	43	10.75	-1	-3	-0.07	-0.07
1662	3	23	7.67	0	-3	-0.07	-0.07

The number of exceeded engine condition parameters in the course of its utilisation is the base for calculation (from the relations (7)) of engine reliability estimators $R_S{*}(t)$, which in turn are the base for calculation of the reliability factor function $R_S(t)$. The reliability estimators and functions are shown on the figs. 4a and 4b.

From the analysis of figs. 2a and 2b results that it is possible to observe the influence of object's technical condition on the reliability of pilot's action. Next, the state of pilot's action influences the reliability of helicopter engines – figs. 4a and 4b. The reliability functions (figs. 2a, 2b and figs. 4a, 4b) of the anthropotechnical system allow prediction (1) of trends of a flying accident with fixed utilisation conditions.

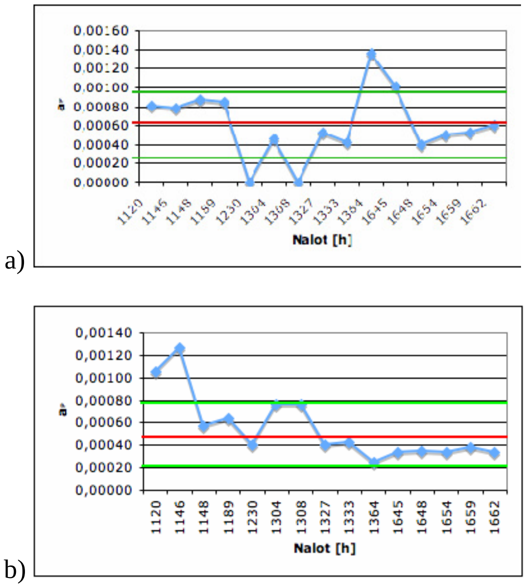


Fig. 1. Number of exceeded limits of the a_P parameter characterising pilot's physical condition (blue) for the right (fig. a) and left engine (fig. b), where for the right engine the average violation value (green) amounts to 0.00061 (red) and standard deviation to +/- 0.00036 and for the left engine 0.00055 and +/- 0.00028 respectively

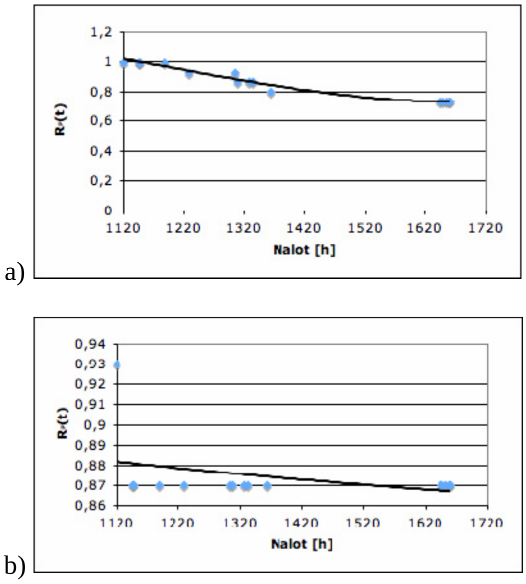
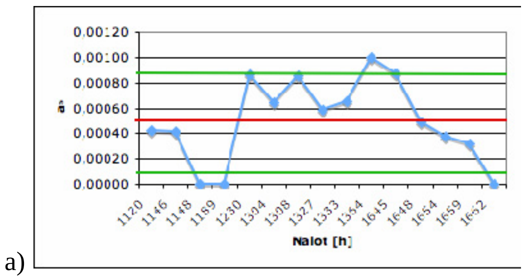


Fig. 2. Reliability estimators and functions of pilot's condition



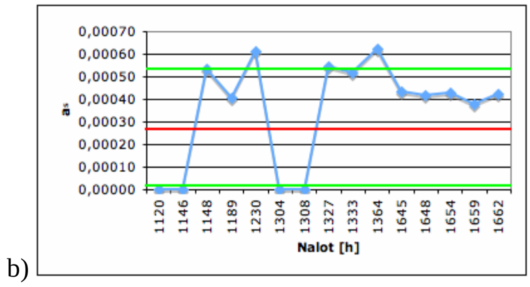


Fig. 3. Graphs of the parameter a_S and its incorrect states (blue) for the right (fig. a) and left engine (fig. b), where for the right engine the average violation value amounts to 0.00050 (red) and standard deviation +/- 0.00028 and for the left engine 0.00023 and +/-0.00023 respectively

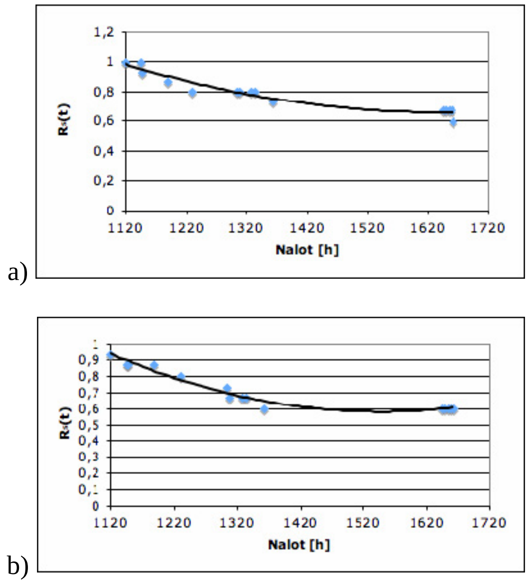


Fig. 4. Reliability estimators and functions for engines

Summary

The meaning of characteristics in the process of utilisation of anthropotechnical systems is unquestioned to this extent that the problem of their determination is strictly regulated by norms (BS 5760, IEC 605, GOST 19460, NFX 06 - 501, PN - 79/N - 04031), domestic, foreign and international. The characteristics are determined on the base of the number of failures appearing in the process of utilisation, which are always dangerous for the object and the user. Therefore the method of prediction of reliability characteristics presented here can be very useful, since it is calculated from facts less dangerous than damage, i.e. from violations of limit values of parameters of pilot's action quality a_P and helicopter's technical condition a_S.

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