

## THE METHOD OF CHECKS DETERMINING PERIODS OF TECHNICAL STATE FOR UNMANNED AIR VEHICLE ONBOARD EQUIPMENT

*In the article is considered the influence of Unmanned Air Vehicle's onboard equipment (its dependability) upon the overall performance of the whole complex. The method formulated for determining periods between the checks of technical state of Unmanned Air Vehicle of the onboard equipment. The algorithms are improved for evaluating statistical consequences of Unmanned Air Vehicle technical state during its operation. The drift influence of the measurement parameters and the control unit at time of technical state inspection for Unmanned Air Vehicle onboard equipment was showing. Suggestions for using of the proposed method were offered.*

**Keywords:** technical state, onboard equipment, unmanned air vehicle, characteristics of check, method.

### Introduction

**Problem statement.** Components of Unmanned Air Vehicle (UAV) – terrestrial, airborne navigation and flight control and targeting equipment – are complex electromechanical and radio systems, therefore, despite all the pre-control measures, their use may arise failures both at the start and in flight [1–3]. Analysis of UAV results in recent armed conflicts has shown that some machines did not fulfill the task, have been lost or suffered an accident due to malfunction of onboard equipment (OE) [2]. Fail-safety of UAV OE acquires an important value. At the same time, we note that in terms of financial constraints and a lack of procurement of new UAV study have an urgent task of extending terms of resources used by the machine (especially OE). In these circumstances, the importance of acquiring OE account UAV reliability and its failure-time specified in the evaluation of its technical condition (which depends on the frequency of the timing of the test) while preparing them for combat use.

Investigation of the effect of time on the operation  $t$  availability  $K_g(t)$  of UAV and the accuracy of the serviceable condition  $D(t)$  of UAV OE yielded relationship

$$F(t) = a_1 K_g(t) + a_2 D(t), \quad (1)$$

where  $a_1, a_2$  is coefficients of coordination (see fig. 1).

Adequacy in depending confirmed physical meaning flowing process. Thus, an increase in the frequency of checking  $t_k$  the value  $K_g(t)$  of the time interval  $[t_1, t_k]$  is increased (by reducing the idle time during the audit). But it reduces the value of  $D(t)$  in the time interval  $[t_k, t_2]$  (without a monitor can not be said about the serviceability or malfunction of UAV OE). Therefore, the optimal period  $t_k$  of maintenance checks

of UAV OE, at which the maximum value of the function  $F(t)$ .

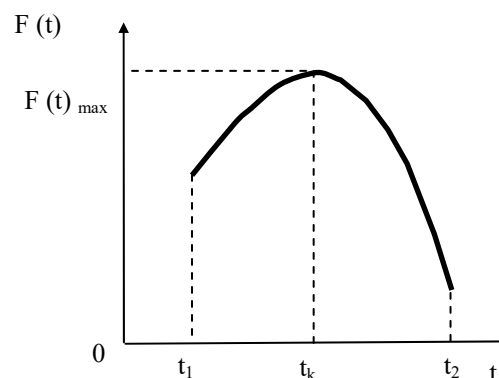


Fig. 1. The dependence factoring of the availability  $K_g(t)$  and serviceable condition  $D(t)$  for determining the operating time

In addition, during the transition to a system of exploitation is arms, including drones, on-condition, pressing is the problem of determining the timing of maintenance checks of UAV OE.

**Literature analysis.** The analysis of works [1–3], aimed at addressing the use of drones has shown that most of the work focused on the study objectives and the technical state of vehicles. Questions of the organization of pre-determining the technical condition of UAV neglected, although, as indicated above, from the technical condition of UAV depends on the result of its intended use.

Therefore, **the article task** is to do methods for determining the timing of the technical state of UAV OE for for the timely finding of eventual failures in OE.

### Main body

Structural organization and BO features determined by the requirements of each specific mission of UAV and

therefore a great variety of options. When considering OE advisable not to talk about specific implementations, and the basic concepts of their construction [1; 3]:

- multi-level structure organization corresponding to the hierarchical nature of the decided functional tasks;
- programmability of architecture the possibility of organizing a dynamic reallocation of tasks to system resources;
- unify of information exchange channels between the levels of the hierarchy;
- modularity of constructions and structure of as the elements of OE and the whole system, the availability of time-twisted controls, and diagnosing operation of recovery.

Multi-level hierarchical organization of UAV OE is determined by the necessity of separation of tasks across levels of information processing, each is characterized by its generalization degree. So the problem can be divided in such levels [4]:

- problems solved on the basis of the information of only one sensor;
- information processing tasks of sensors (functionally similar);
- tasks of general complex kind which summarizing information from a few functional subsystems of UAV OE f (in the process of acceptance of information);
- control tasks, display and control to be solved on the basis of summarizing all the information received.

The hierarchy of these problems classes, determines the feasibility of establishing a multi-level information processing of typical OE structure.

The current and future for UAV used (assuming the application), after following basic types of OE for an information-processing unit on board:

- remote sensing;
- data retransmitting;
- protection of information;
- navigation, orientation, guidance.

OE problems analysis shows that their decision comes down to the implementation of processing and analyses signals and images [1].

Depending on the application of OE performance indicator may be a vector  $\vec{K}_S(t)$  [6]:

$$\vec{K}_S(t) = \langle K_S^I(t), K_S^{II}(t) \rangle$$

or scalar  $K_S(t)$ :

$$K_S(t) = K_S^I(t) \mid K_S^{II}(t) \geq K_S^I(t),$$

$$K_S(t) = K_S^{II}(t) \mid K_S^I(t) \geq K_S^{II}(t),$$

$$K_S(t) = \alpha K_S^I(t) + (1 - \alpha) K_S^{II}(t),$$

where  $K_S^I(t)$  is coefficient of the probability of finding of OE in an operable condition;  $K_S^{II}(t)$  is a coefficient of the probability of finding a control unit (CU) of OE

in operable condition;  $\alpha$  is significance level of coefficients  $K_S^I(t), K_S^{II}(t)$  in assessment  $K_S(t)$ ,  $\alpha \in (0, 1)$ .

Alternate finding of OE in active time slots  $t_a$  and duration  $t_p$  of a passive time intervals of duration requires clarification of the concept of bug. The bug (refusal) comes in next cases offer:

- during the time interval  $\Delta t_a$  (active time interval) in CU program can not be eliminated the consequences of bug (bugs)  $V_a$ , of the total number of refusals (bugs)  $V_i$ , thus  $V_i \in V_a(t_a) \cup V_p(t_p)$ ;
- in active interval operation CU does not provide a value  $K_S(t)$  satisfies the inequality:

$$K_S(t) \geq K_{S_T}(t), \forall t \in (t_{a0}, t_{p0}),$$

where  $t_{a0}, t_{p0}$  is the beginning of active and passive variables intervals production activities of UAV OE;

- at time intervals passive operation of UAV OE for is not ensured value  $K_S^I(t)$  satisfying the inequality:

$$K_S^I(t) \geq K_{S_T}(t);$$

- at time intervals active  $\forall t \in (t_{a0}, t_{p0})$  is not provided equality:  $K_S(t) = \text{const}$ .

Let  $P_{OE}(t)$  there is the probability of no bug of OE during work at time  $t$ ;  $P_{OE}^S(t)$  is required (set) the probability value of failure-free operation of the OE at time  $t$ ;  $L(t_a)$  is the number of refusals (bugs) in the active time interval;  $\tau_p$  is the average time spent on self-healing software refusal (bug).

Conditions trouble-free operation of OE define a system of inequalities:

$$\begin{cases} L(t_a)\tau_p \leq \Delta t_a; \\ K_S(t_a) \rightarrow \max; \\ P_{OE}(t) \geq P_{OE}^S(t), t \in (t_{a0}, t_{p0}), \end{cases} \quad (2)$$

$$\begin{cases} L(t_a)\tau_p \leq \Delta t_a; \\ K_S(t_a) \geq K_S^S; \\ P_{OE}(t) \rightarrow \max, t \in (t_{a0}, t_{p0}). \end{cases} \quad (3)$$

The solution of system (2) defines the conditions to maximize the finding probability of UAV OE for operable at a predetermined level to the fastness to the refusals (bugs). On the contrary, the solution of system (3) determines the conditions for maximizing to the fastness to the refusals (bugs) of UAV OE with a given probability of finding of UAV OE for in working condition.

Let is assumed that the system (2) and (3) replace the software (masking) the absents (bugs) channel modules of UAV OE is held for a time not exceeding  $\Delta t_a$ .

Application of UAV OE uses characteristic [4; 5]:  
 – exceeding of density of current of bugs  $\lambda_c$   
 above density  $\lambda_o$  current of refusals  
 ( $\lambda_c = \beta\lambda_o$ ,  $\beta = 10 \div 100$ );  
 – clustering (grouping) of refusals and bugs;  
 – parallel operation of CU and other elements on  
 UAV OE for active intervals time and dearth of work on  
 the passive intervals time.

Structure of UAV OE has components, characteristics values (autonomous power supply voltage, electric resistance, capacitance, inductance, etc.) of which at the effect of factors physical factors (aging, periodical of heat, electromagnetic radiation and other) change and can substantially influence on an operational capability of UAV. On leaving of values of these parameters for the bound of allowance there can be random failures and bugs [5].

For the timeliness definition of failings (bugs) components of OE method is offered of dates definition of technical state check of UAV OE. This method is provided by the set level of fail-safe behavior (2) on consequences previous and current determinations by the assistance of the values special facilities of characteristics by their evaluation statistical.

**A method** contains briefing evaluation statistical information and evaluation algorithm statistical for values definition of feasibility coefficients.

1. Problem statement of check dates of UAV OE technical state.

Basic data for a calculation:

– N devices of OE are subject to periodic inspection; of the  $y(t)$  is the results of control parameter of UAV OE. Each of control parameter is determined at the time t operating time (according to the specifications and technical documentation).

Every cast from N devices certified i number of times,  $i = 1, \dots, M$ , during the operation (operational data of the document).

Each parameter is given a two-way flanks:  $y_b \leq y(t) \leq y_o$ , where  $y_b$ ,  $y_o$  there is the lower and upper limits of acceptable change parameter values, respectively.

The test results of each parameter on-time series form a realization:

$$\hat{Y} = \{y_{ij}(t_{ij}), i = 1, \dots, M; j = 1, \dots, N\}, \quad (4)$$

where N, M is the number of this type of equipment and the measurements number for this parameter i of each unit respectively.

In the particular case it may be  $M = 1$ . Then, for the use of a single method implementation is divided into parameter S implementations over a time interval and formed the model and the permissible limits  $y_b^M(t)$

and  $y_o^M(t)$ , within which the values the controlled parameter of UAV OE with a given confidence level.

Extrapolation of the model parameters is carried out to violation of clause:

$$y_b \leq y_b^M(t); y_o^M(t) \leq y_M. \quad (5)$$

The point in time  $t_k$  at which the violation of the condition (5), to set a date of the next maintenance checks of UAV OE for this type.

Determining the subsequent timing of regular checks of UAV OE performed by repeating the procedure definition of calculations designs  $y_b^M(t)$  and  $y_o^M(t)$ , their analysis and solution of the problem (5) to reach the set limit values of controlled drift parameters of UAV OE.

2. Statistical evaluation algorithm of UAV OE technical state.

2.1. Moments  $\nu_1, \mu_2, \beta_1, \beta_2$  design density characterizing drift distributions of of determination  $Y^r(t)$ ,  $r = 1, \dots, Q$  characteristic, the total number of control parameters of UAV OE technical state of the Q for all devices N this class j-th number of times is in the sections of time  $t, \nu_1, \mu_2, \beta_1, \beta_2$ , where  $\nu_1, \mu_2$  is first and second central moment respectively;  $\beta_1, \beta_2$  is third and fourth central resulted moment respectively.

2.2. The moments static assessments are settled accounts following relations:

$$\nu_1 = \sum_{j=1}^N Y_j / M; \mu_2 = \frac{1}{N-1} \sum_{j=1}^N (Y_j - \nu_1)^2, \quad (6)$$

$$\beta_1 = \mu_3 / \mu_2^{3/2}; \beta_2 = \mu_4 / \mu_2^2 - 3,$$

where 
$$\mu_3 = \frac{1}{N-1} \sum_{j=1}^N (Y_j - \nu_1)^3,$$

$$\mu_4 = \frac{1}{N-1} \sum_{j=1}^N (Y_j - \nu_1)^4.$$

2.3. Casual process design of UAV OE drift characteristic gets out S polynomials of class:

$$m^S(t) = \varphi(k) \sum_{k=1}^{qS} C_k^{(S)}; \quad S = 1, \dots, 4, \quad (7)$$

where  $\varphi(k)$  is Chebyshev polynomials, which satisfying orthogonality condition;  $C_k^{(s)}$  is coefficients of s-th moment function; q is degree polynomial in; s is number of moment functions ( $s = \overline{1 \dots 4}$ ).

2.4. The base of Chebyshev polynomials is formed [4]:

$$\Phi = \begin{pmatrix} \varphi_1(t_1), \varphi_2(t_2), \dots, \varphi_q(t_1) \\ \dots \\ \varphi_1(t_{np}), \varphi_2(t_{np}), \dots, \varphi_q(t_{np}) \end{pmatrix} \quad (8)$$

at initial conditions:

$$\varphi_1(t) = 1; \varphi_2(t) = t - C_{21}\varphi_1(t); \quad (9)$$

where  $C_{21} = \frac{\sum_{i=1}^M t_i}{M}$ .

Function  $\varphi_3(t)$  formed:

$$\varphi_3(t) = t^2 - C_{32}\varphi_2(t) - C_{31}, \quad (10)$$

where  $C_{31} = \frac{\sum_{i=1}^M t_i^2}{M}$ ,  $C_{32} = \frac{\sum_{i=1}^M t_i^2 \varphi_2(t_i)}{\sum_{i=1}^M \varphi_2(t_i)^2}$ .

Function  $\varphi_4(t)$  formed:

$$\varphi_4(t) = t^3 - C_{43}\varphi_3(t) - C_{42}\varphi_2(t) - C_{41}; \quad (11)$$

where  $C_{41} = \frac{\sum_{i=1}^M t_i^3}{M}$ ,  $C_{42} = \frac{\sum_{i=1}^M t_i^3 \varphi_2(t_i)}{\sum_{i=1}^M \varphi_2(t_i)^2}$ ;

$$C_{43} = \frac{\sum_{i=1}^M t_i^3 \varphi_3(t_i)}{\sum_{i=1}^M \varphi_3(t_i)^2}.$$

2.5. Polynomials functions  $m_1^1(t), m_2^1(t), m_3^1(t), m_4^1(t)$  formed for the first initial moment of density of distribution of UAV OE drift characteristic  $v_1(t)$ :

$$\begin{aligned} m_1^1(t) &= C_1; \quad m_2^1(t) = C_1 + C_2\varphi_2(t); \\ m_3^1(t) &= C_1 + C_2\varphi_2(t) + C_3\varphi_3(t); \\ m_4^1(t) &= C_1 + C_2\varphi_2(t) + C_3\varphi_3(t) + C_4\varphi_4(t), \end{aligned} \quad (12)$$

where  $C_1 = \frac{\sum_{i=1}^M v_1(t_i)}{M}$ ;  $C_2 = \frac{\sum_{i=1}^M \varphi_2(t_i) v_1(t_i)}{\sum_{i=1}^M \varphi_2(t_i)^2}$ ;

$$C_3 = \frac{\sum_{i=1}^M \varphi_3(t_i) v_1(t_i)}{\sum_{i=1}^M \varphi_3(t_i)^2}; \quad C_4 = \frac{\sum_{i=1}^M \varphi_4(t_i) v_1(t_i)}{\sum_{i=1}^M \varphi_4(t_i)^2}.$$

Polynomials functions  $m_1^2(t), m_2^2(t), m_3^2(t), m_4^2(t)$  formed for the second central moment  $\mu_2(t)$ .

Polynomials functions  $m_1^3(t), m_2^3(t), m_3^3(t), m_4^3(t)$  formed for the third central moment  $\beta_1(t)$ .

Polynomials functions  $m_1^4(t), m_2^4(t), m_3^4(t), m_4^4(t)$  formed for the fourth central moment  $\beta_2(t)$ .

2.6. Analyzing the formed polynomial functions built model stochastic process drift controlled parameter of UAV OE has the best predictive properties.

The study sample consisting of M variables sections is divided into two sub-samples: even  $J_2$  and odd  $J_1$ .

The moment functions  $v_1, \mu_2, \beta_1, \beta_2$  respectively odd-sample  $J_1$  are approximated by polynomial functions according to algorithms (4–12).

A function settles  $\sigma_{j_1 j_2}^2$  accounts:

$$\sigma_{j_1 j_2}^2 = \frac{1}{M_j} \sum_{i=1}^{M_j} \left[ m_1^{(j)}(t_i) - m^{(j)}(t_i) \right]^2, \quad j = 1, 2,$$

where  $m^{(j)}(t_i)$  is the average value of the polynomial function is calculated by formula (7).

Plotted from any dependences  $\sigma_{j_1 j_2}^2$  built from a degree q polynomial function of approach.

2.7. To build a model of a random process pro-drift parameter of UAV OE for chosen in polynomial function with a degree q built on the functions of polynomials  $m^{(l)}(t)$  with a q, which provide  $\min \sigma_{j_1 j_2}^2$ .

Values  $v_1, \mu_2, \beta_1, \beta_2$  settle accounts for the moment of time arbitrary.

Functions  $y_b^M(t)$  and  $y_o^M(t)$  characterize possible scopes which the values of check characteristic are guaranteed within the limits of UAV OE with the set with a given probability  $P_s$ . These functions are formed:

$$\begin{aligned} y_b^M(t) &= v_1(t) - \sqrt{U_1^2(t) \mu_2(t)}; \\ y_o^M(t) &= v_1(t) + \sqrt{U_2^2(t) \mu_2(t)}, \end{aligned}$$

where  $U_1(t), U_2(t)$  is density coefficients of of casual processes distribution of UAV OE drift characteristic check, whose values are determined according to the following options:

$$U_1(t) = f[\beta_1(t), P_s]; \quad U_2(t) = f[\beta_2(t), P_s].$$

2.8. Values  $y_b, y_o$  defines in the moment of calculation  $t_k$ .

2.9. Assessments  $y_b^M(t_k)$  and  $y_o^M(t_k)$  compared to the bilateral allowance (5). This allowance is set on a characteristic of UAV OE.

2.10. The time value  $t_k$  at which the condition (5) in accordance with paragraphs 2.9 will be the best for

checking the technical condition of UAV OE of this type.

### Consequences

Thus, a method is designed as a model for the approximation of the moment functions of a random process of UAV OE casual drift characteristics of check. Method the offered is used original polynomials of architecture at the investment of Chebyshev polynomials, satisfying known orthogonality conditions. The Use of the proposed model will allow you a full range of material-requirements-filed proxy to this kind of problems, including:

- ensuring the best predictive properties of the known criteria;
- adequate representation of the real process parameter drift of UAV OE;
- uncritical attitude to the form and possible deformation of drift distribution laws, knowledge of the parameters of UAV OE in time.

Implementation of these requirements will ensure the reliable determination of the forecast period of UAV OE for next check to determine its technical state.

In the future can be realized in the algorithms offered in a method in the form of nomograms (graphs), as well as the development of appropriate software.

This will allow the use of proposal method specialists serving of UAV, as well as in the calculations for Considerations for extending the resources not only of UAV OE, but also land, including start-up equipment.

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#### МЕТОД ОБҐРУНТУВАННЯ ТЕРМІНІВ КОНТРОЛЮ ТЕХНІЧНОГО СТАНУ БЕЗПІЛОТНИХ ЛЕТАЛЬНИХ АПАРАТІВ

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*У статті показаний вплив надійності (відсутність відмов) бортового обладнання безпілотного літального апарату на ефективність його застосування. Сформульований метод обґрунтування термінів контролю технічного стану бортового обладнання керованого безпілотного летального апарату. Розроблені алгоритми статистичного аналізу результатів контролю технічного стану бортового обладнання безпілотного апарату у період його експлуатації, показаний вплив дрейфу параметрів вимірювання апарату на терміни контролю технічного стану бортового обладнання. Зроблені пропозиції щодо використання запропонованого методу.*

**Ключові слова:** технічний стан, бортове обладнання, безпілотний літальний апарат, параметри контролю, метод.

#### МЕТОД ОБОСНОВАНИЯ ПЕРИОДИЧНОСТИ КОНТРОЛЯ ТЕХНИЧЕСКОГО СОСТОЯНИЯ БЕСПИЛОТНЫХ ЛЕТАТЕЛЬНЫХ АППАРАТОВ

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*В статье показано влияние надежности (отсутствие отказов) бортового оборудования беспилотного летательного аппарата на эффективность его приложения. Сформулирован метод обоснования сроков контроля технического состояния бортового оборудования управляемого беспилотного летательного аппарата. Разработаны алгоритмы статистического анализа результатов контроля технического состояния бортового оборудования беспилотного аппарата в период его эксплуатации, показано влияние дрейфа параметров измерения аппарата на сроки контроля технического состояния бортового оборудования. Сделаны предложения относительно использования предложенного метода.*

**Ключевые слова:** техническое состояние, бортовое оборудование, беспилотный летательный аппарат, параметры контроля, метод.