**AGING PROCESSES AS A PRIMARY ASPECT OF PRE-
DICTING RELIABILITY AND LIFE
OF AERONAUTICAL HARDWARE**

**PROCESY STARZENIA JAKO PODSTAWOWY
ASPEKT PROGNOZOWANIA NIEZAWODNOŚCI
I TRWAŁOŚCI URZĄDZEŃ OSPRZĘTU LOTNICZEGO**

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Abstract: The forecasting of reliability and life of aeronautical hardware requires recognition of many and various destructive processes that deteriorate the health/maintenance status thereof. The aging of technical components of aircraft as an armament system proves of outstanding significance to reliability and safety of the whole system. The aging process is usually induced by many and various factors, just to mention mechanical, biological, climatic, or chemical ones. The aging is an irreversible process and considerably affects (i.e. Reduces) reliability and life of aeronautical equipment.

Keywords: aircraft, durability, reliability

Streszczenie: Prognozowanie niezawodności i trwałości urządzeń lotniczych wymaga rozpoznania wielu procesów destrukcyjnych pogarszających ich stan techniczny. Niezwykle istotny wpływ na niezawodność i bezpieczeństwo całego systemu uzbrojenia lotniczego ma starzenie jego elementów technicznych. Proces starzenia spowodowany jest działaniem wielu czynników m.in. mechanicznych, biologicznych, klimatycznych czy chemicznych. Starzenie ma charakter nieodwracalny i wpływa na obniżenie niezawodności i trwałości urządzeń lotniczych. W niniejszym artykule przedstawiono deterministyczną i stochastyczną analizę procesów starzenia wybranych urządzeń osprzętu lotniczego.

Słowa kluczowe: statki powietrzne, trwałość, niezawodność

1. Introduction

The aging processes that affect aeronautical equipment are to a greater or lesser degree correlated with the item's time of operation or the number of cycles of its operation. In terms of aging processes the items of aeronautical equipment can be divided into three groups:

- those with strongly correlated changes in values of diagnostic parameters with time or amount of operation,
- those with poorly correlated changes in values of diagnostic parameters with time or amount of operation, and
- ones showing no correlation changes in values of diagnostic parameters with time or amount of operation.

For the items representing the first group one can predict the instance of time when the diagnostic parameter's boundary condition occurs. One can also predict the time instance of the item's safe shut down and then plan appropriate maintenance actions to be carried out.

2. A method to forecast reliability and life of some selected items of aeronautical equipment as based on changes in values of diagnostic parameters available in the course of operation

What has been assumed in the already developed method is as follows:

1. Health/maintenance status of any item included in the aeronautical equipment can be described with diagnostic parameters available throughout the operational phase, and designated in the following way:

$$X = (X_1, X_2, X_3, \dots, X_n) \quad (1)$$

2. Values of diagnostic parameters change due to aging processes going on all the time. It is assumed that these changes are monotonic in nature; they can be presented in the following way:

$$\Delta X_i = |X_i - X_i^{nom}|, \quad i = 1, 2, 3, \dots, n \quad (2)$$

where: ΔX_i = absolute value of deviation of the diagnostic parameter from the nominal value;

X_i = current value of the i -th parameter;

X_i^{nom} = nominal value of the i -th parameter.

3. Any item of the aeronautical equipment is serviceable (fit for use) if the following dependence occurs:

$$\Delta X_i \leq \Delta X_i^g \quad (3)$$

where: ΔX_i^g = absolute value of boundary deviation of the diagnostic parameter from the nominal value.

To be clearer, the following terms (notations) have been introduced:

$$\Delta X_i = z_i \quad (4)$$

$$\Delta X_i^g = z_i^g \quad (5)$$

where: z_i = absolute value of deviation of the diagnostic parameter from the nominal value;

z_i^g = absolute value of boundary deviation of the diagnostic parameter from the nominal value.

Equation (3) can be, therefore, written down in the following form:

$$z_i \leq z_i^g \quad (6)$$

4. Values of changes in diagnostic parameters grow randomly.
5. Changes in diagnostic parameters accepted for the assessment of health/maintenance status of individual items of aeronautical equipment are independent random variables, i.e. any change of any of these parameters does not result in any change in values of other parameters.
6. The method has been dedicated to some selected items of the aeronautical equipment, namely to those for which the rate of changes in diagnostic parameters can be described with the following dependence:

$$\frac{dz_i}{dt} = C \quad (7)$$

where: C = operating-conditions dependant random variable; t = calendar time.

The dynamics of changes in values of deviations of assumed diagnostic parameters, if approached randomly, is described with a difference equation. One arbitrarily chosen parameter z_i has been accepted for analysis. The difference equation for the assumptions made takes the form:

$$U_{z_i, t + \Delta t} = P U_{z_i - \Delta z_i, t} \quad (8)$$

where: $U_{z_i, t}$ = probability that at the instance of time t the deviation of a diagnostic parameter takes value z_i ; P = probability that the value of the deviation increases by value Δz_i within time interval of Δt .

Equation (8) takes the following form if function notation is used:

$$u(z_i, t + \Delta t) = u(z_i - \Delta z_i, t) \quad (9)$$

where: $u(z_i, t)$ = time-dependant density function of changes in diagnostic parameter.

Equation (9) is now rearranged to take the form of a partial differential equation of the Fokker-Planck type:

$$\frac{\partial u(z_i, t)}{\partial t} = -C \frac{\partial u(z_i, t)}{\partial z_i} + \frac{1}{2} C^2 \frac{\partial^2 u(z_i, t)}{\partial z_i^2} \quad (10)$$

Since C is a random variable, an average value of this variable is introduced. It has the form:

$$E[c] = \int_{C_d}^{C_g} cf(c)dc \quad (11)$$

where: $f(c)$ = density function of the random variable C ; C_g , C_d = upper and lower values of the random variable C .

Taking account of equation (11) while considering formula (10) the following dependence is arrived at:

$$\frac{\partial u(z_i, t)}{\partial t} = -b \frac{\partial u(z_i, t)}{\partial z_i} + \frac{1}{2} a \frac{\partial^2 u(z_i, t)}{\partial z_i^2} \quad (12)$$

where: $b = E[c]$ – an average increment of value of deviation of the diagnostic parameter per time unit; $a = E[c^2]$ – a mean square increment of value of deviation of the diagnostic parameter per time unit.

We need to find a partial solution of equation (12), one that at $t \rightarrow 0$ is convergent with the so-called Dirac function: $u(z_i, t) \rightarrow 0$ for $z_i \neq 0$, but in such a way that the function integral $u(z_i, t)$ equals to unity for all $t > 0$. This solution takes the form:

$$u(z_i, t) = \frac{1}{\sqrt{2\pi A(t)}} e^{-\frac{(z_i - B(t))^2}{2A(t)}} \quad (13)$$

where:

$$A(t) = \int_0^t a dt = at \quad B(t) = \int_0^t b dt = bt$$

Function (13) is a probabilistic characteristic of changes of the diagnostic parameter due to effects of aging processes, the rate of which can be determined with equation (7). Density function of changes in value of the diagnostic parameter can be used directly to estimate reliability and life of an aeronautical device, the health/maintenance status of which is estimated with this parameter. Applying the density function of changes in values of the diagnostic parameter to determine distribution of time of exceeding the boundary condition is a good example of such a solution. Probability of exceeding the boundary value by the diagnostic parameter can be presented using density functions of changes in the diagnostic parameter:

$$Q(t, z_i^g) = \int_{z_i^g}^{\infty} \frac{1}{\sqrt{2\pi at}} e^{-\frac{(z_i - bt)^2}{2at}} dz \quad (14)$$

To determine the density function of time of exceeding the admissible value of deviation z_i^g for the first time one should use the following dependence:

$$f(t) = \frac{\partial}{\partial t} Q(t, z_i^g) \quad (15)$$

Substitution with equation (14), introduced in equation (15), gives:

$$f(t) = \frac{\partial}{\partial t} \int_{z_i^g}^{\infty} \frac{1}{\sqrt{2\pi at}} e^{-\frac{(z_i - bt)^2}{2at}} dz \quad (16)$$

Using properties of the differentiation and integration, the following dependence is arrived at:

$$f(t)_{z_i^g} = \frac{z_i^g + bt}{2t} \frac{1}{\sqrt{2\pi at}} e^{-\frac{(z_i^g - bt)^2}{2at}} \quad (17)$$

Equation (17) determines density function of time of exceeding the boundary condition by values of the diagnostic parameter. What is to be found next is the dependence that determines the expected value of time of exceeding the boundary condition by the diagnostic parameter:

$$E[T] = \int_0^{\infty} t f(t)_{z_i^g} dt \quad (18)$$

Hence

$$E[T] = \frac{z_i^g}{2b} + \frac{z_i^g}{2b} + \frac{a}{2b^2} = \frac{z_i^g}{b} + \frac{a}{2b^2} \quad (19)$$

We also need to find the dependence that determines the variance of distribution of time of exceeding the boundary condition by the diagnostic parameter. In general, this variance is determined with dependence (20):

$$\sigma^2 = \int_0^{\infty} t^2 f(t)_{z_i^g} dt - (E[T])^2 \quad (20)$$

Hence

$$\sigma^2 = \frac{az_i^g + \sqrt{b}(z_i^g)^2}{b^3} + \frac{5a^2}{4b^4} - \frac{(z_i^g)^2}{2b^2} \quad (21)$$

The presented method of determining the distribution of time of exceeding the boundary condition by the diagnostic parameter allows of finding the density function) of time of reaching the boundary state. On the basis thereof one can determine reliability of a given item of aeronautical equipment, the health/maintenance status of which is estimated by means of the diagnostic parameter under consideration:

$$R(t) = 1 - \int_0^t f(t)_{z_i^g} dt \quad (22)$$

The probability density function that determines distribution of time of the diagnostic parameter's value passing through the boundary condition allows also of calculating the aeronautical item's life. Therefore, the level of risk of exceeding the boundary condition should be found:

$$Q(t)_{z_i^g} = \int_0^t f(t)_{z_i^g} dt \quad (23)$$

The value of time, for which the right side of equation (23) equals to the left one, determines life of an item of aeronautical equipment under conditions defined with the above-made assumptions.

3. Estimates of life and reliability of airborne storage batteries

Airborne storage batteries are those items of aeronautical equipment that show strong correlation between changes in values of diagnostic parameters and time or amount of operating time. Capacitance Q is a diagnostic parameter directly correlated with aging processes that take place while operating airborne storage batteries, one which explicitly determines the expiry date thereof. The presented method allows of estimating the reliability and residual life of airborne storage batteries using diagnostic parameters recorded in the course of operating them. Gained with the hitherto made calculations for the airborne storage batteries 12-SAM-28 are the following characteristics of the density function of time of exceeding the boundary condition by values of the diagnostic parameter $f(t)$ and the reliability function $R(t)$. They are shown in Figs 1 and 2.

Fig. 1 Characteristic curves of the density function $f(t)$ for storage batteries 12-SAM-28.

Fig. 2 Characteristic curves of the reliability function $R(t)$ for storage batteries 12-SAM-28.

With the above-presented method applied, the following values of life T and residual life T_r have been gained for particular storage batteries 12-SAM-28 (see Table 1).

Table 1. Estimated values of life and residual life

STORAGE BATTERIES 12-SAM-28			
N o	Battery No.	T [months]	T_r [months]
1	109	27.7	13.76
2	574	29.2	11.28
3	180	34.54	17.5
4	112	41.19	23.47
5	525	50.71	32.17
6	170	47.8	30.38
7	159	26.13	10.61
8	330	23.73	6.98
9	280	29.12	12.32
10	596	20.85	5.7

Conclusions

The method introduced in this paper allows of analysis of health/maintenance status of some selected items of aeronautical equipment because of the nature of changes in values of diagnostic parameters available throughout the operational phase thereof. Determination of how the values of diagnostic parameters and devia-

tions thereof increase enables determination of time interval, within which a given item remains fit for use (serviceable).

Dependence for the rate of changes in value of the diagnostic parameter, i.e. equation (7), is of primary significance in this method. The method will not change substantially if other forms of this dependence (i.e. equation (7)) are used. These different forms may result in changes of coefficients in the Fokker-Planck equation (10), which in turn will result in changes of the dependences for both an average value and variance of the density function of changes of the diagnostic parameter. The method offers also a capability of describing aging and wear-and-tear processes within a multi-dimensional system. The above-presented method allows of:

- assessment of residual life of some selected items of aeronautical equipment with the required reliability level maintained,
- estimation of reliability and life of some selected items of aeronautical equipment on the grounds of diagnostic parameters recorded in the process of operating them,
- verification of the process of operating some selected items of aeronautical equipment to maintain the required level of reliability between particular checks.

The way of proceeding suggested in the method under examination can be adopted for specific characteristics of aging and wear-and-tear processes that affect various items of aeronautical equipment throughout operational phase thereof.

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