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The Analysis of the Maintenance Process of the Military Aircraft

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1. Introduction

This chapter presents the analysis of the maintenance process of a military aircraft with a detailed description of two areas, i.e. the process of maintaining and the process of operating. Each of these processes is briefly characterized. The section also involves methods enabling the determination of: residual durability of specified devices/systems of a military aircraft on the basis of the diagnostic parameters of these devices/systems, and the effectiveness of a combat task execution on the basis of information registered in the process of aiming. Each presented method is illustrated by a computational example.

2. Tasks executed by the military aircraft

A modern military aircraft (MMA) is a hybrid of the most up-to-date achievements in the field of materials engineering (the use of light metal alloys and composite structures), electronic engineering (fast microprocessor systems, modern systems in the field of power electronics), and specialized software supporting the maintenance process (automatic flight control system, integrated diagnostic systems). Due to such combination, tasks executed by MMA comprise a wide range that can be divided into two groups: with the use of aerial combat means and without the use of aerial combat means.

Depending on the nature of a mission, tasks including the use of aerial combat means can be generally classified as:

1. The gaining and maintenance of domination of airspace. This type of task is executed by fast and manoeuvrable aircrafts that are equipped with the most modern armament for aerial combat, i.e. air-to-air missiles and aircraft guns.
2. The support for the operations of ground forces and the navy. As regards this task, aircrafts equipped with air-to-ground weaponry, including rockets, bombs, and aircraft guns, play an important role.
3. The combating of a selected target of an air attack using precision-guided munitions launched from manned and unmanned aircrafts.

When analyzing the use of MMA in respect of the combat task realization without the use of aerial combat means, we can distinguish the following main tasks:

1. Air reconnaissance performed using both aircrafts equipped with specialized apparatus and unmanned flying objects configured for the performance of this type of a mission.
2. Air transport ensuring fast and efficient transfer of both infrastructure elements and soldiers into the area of a new localization for troops.

The support for the operations of different types of forces by means of, among other things, managing a mission on the basis of spatial information obtained via reconnaissance systems installed, for example, on an AWACS-type platform, or enabling the in-flight refuelling.

The analysis of the operations of the armed forces in recent armed conflicts indicates that MMAs are the basic element of the system of military operations. MMAs are used in the first instance to execute all of the above-mentioned tasks.

3. The organization of the maintenance process of the military aircraft

The technical objects maintenance is defined as a set of intentional organizational and economical operations of the people on the technical objects and the relationships between them from the beginning of the object lifecycle up to the end of lifecycle and object disposal. Relationships recognition and identification of the operations which appear between subjects based on the knowledge and experience of the technical objects designers, developers and engineers. The maintenance compliance and utility of product mainly depends on the engineers and designers crew professional competence. However the design presumptions can be altered many times during object lifecycle. These operations are performed to decrease maintenance “waste effect” and maximize “utility effect”.

The modern military aircraft, which is the basic technical object in Polish Air Force organization structure, is the complex product including various constructional, technological, engineering and organizational concepts. Design of so sophisticated product based on tactical and technical military requirements which was created after modern battlefield analysis.

The aircraft construction is based on the module structure (Fig. 1) which allows dividing the specified tasks between separate functional blocks. This solution improves the maintenance process and facilitates service and operational use of the aircraft.

The conditions in which the aircrafts are operated are so specific that involves the specified requirements regarding high level of reliability, durability, effectiveness and safety parameters as far as airborne technology is concerned. Required levels of parameters are provided by determining specified functional structure of devices and specified level of redundancy.

Due to specific character of aircraft operations the aircraft maintenance can be performed only within specified system which provides the conditions indispensable for correct aircraft operation. This specified system is called Air System (AR) and contains the aircraft frame, the people who participate in the maintenance process and the devices building the system which ensure process permanence (in functional way) - Fig. 1.

The primary target in military aircraft maintenance process during peace is maintaining both the technical equipment and the personnel on the specified reliability and training level. It is required to provide high level of efficacy and effectiveness during wartime.

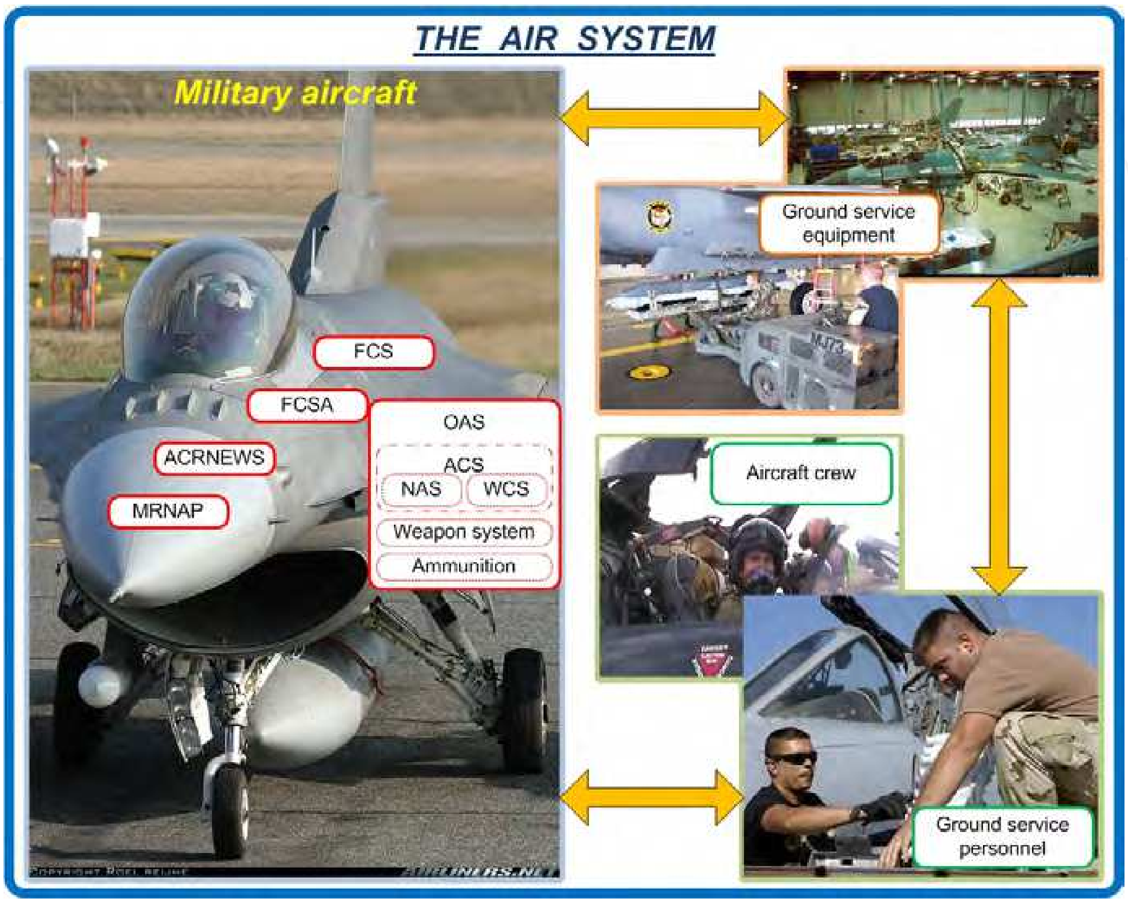

Fig. 1. Structural diagram of the military aircraft and the air system: FCSA – Flight Control System Actuators (frame construction with plating); FCS – Flight Control System; ACRNEWS – Airborne Communication, Radio Navigation and Electronic Warfare Systems.; MRNAP – Multifunctional Radar and Navigation and Aiming Pod; OAS – On-board Armament System; ACS – Armament Control System; WCS – Weapon Control System; NAS – Navigation and Aiming System.

Due to many various external factors, which influence negatively on the specified technical elements of the Air System, it can be claimed, that during operating process the elements are getting "used up". Therefore, due to maintain Air System in the appropriate reliability condition there is required to perform technical service. This action contains adjustment, tuning and replacement of particular devices or whole aggregates, in order to slow down the "using up" process.

In practice there are three aircraft maintenance strategies (Fig. 2.):

1. maintenance system containing prevention services schedule (recurring maintenance).
2. operational maintenance system.
3. preventive/predictive maintenance system.

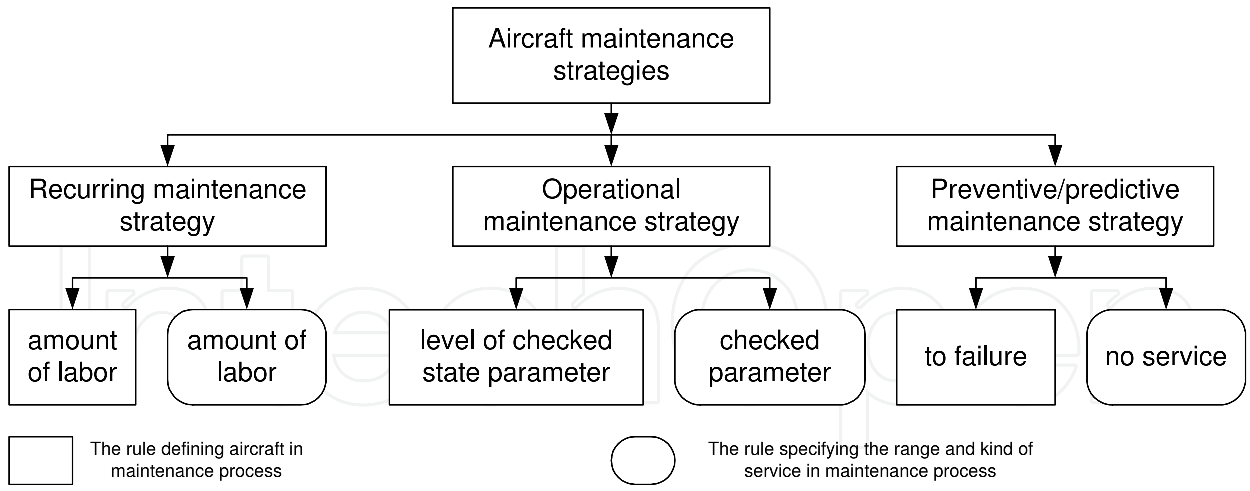

Fig. 2. Military aircrafts maintenance strategies.

Organization and scheme of military aircrafts recurring maintenance strategy is presented on Fig. 3. The basis of this maintenance strategy is the measurement of the amount of labor executed by the plant. As far as aircraft is concerned the amount of labor is defined as a number of hours in the sky.

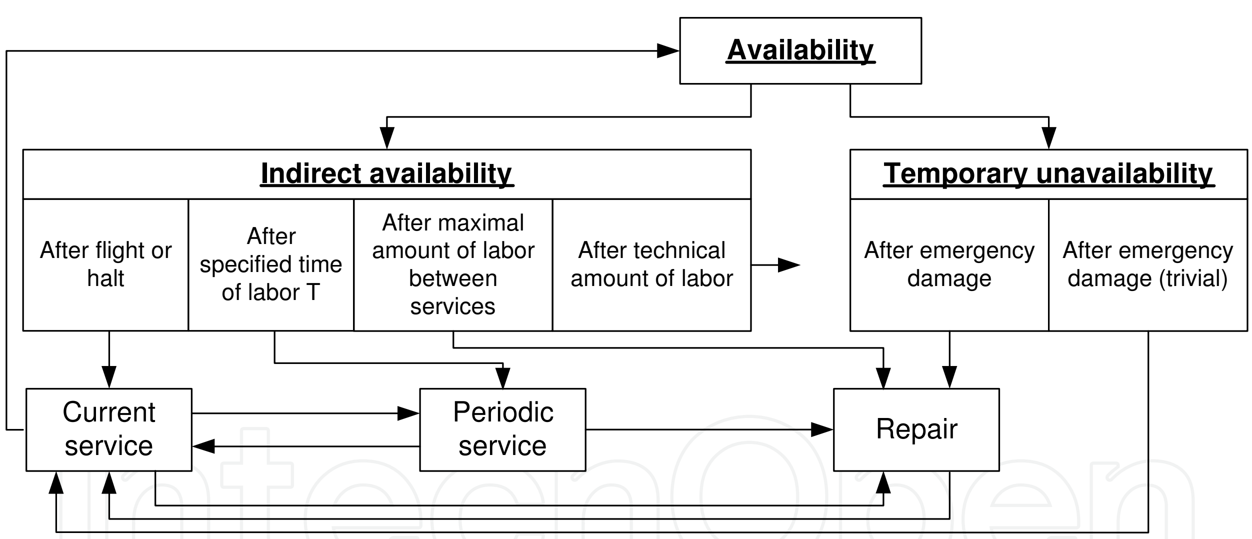

Fig. 3. Recurring maintenance strategy scheme.

One of the maintenance states in the recurring maintenance process is the indirect airworthiness state. The aircraft in this state is mostly working correctly but it lost the flying ability in order to circumstances determined on figure 3. After execution the specified amount of labor (hours of fly) the aircraft lifecycle should be either terminated or directed to the professional service to determine the new amount of labor possible to execute.

As far as operational maintenance strategy is concerned there is the rule the aircraft is in operation as long as the levels of specified parameters do not exceed the specified limits of error. The knowledge about the maintenance state of the device is determining by the external and internal diagnostic equipment. The service operations during this maintenance strategy are executed according to levels of measured diagnostic parameters. The proper control of operational maintenance strategy even for the considerable fleet of aircrafts requires control of every aircraft separately.

The preventive/predictive maintenance strategy defines the reliability as a designed characteristic. The level (value) of the reliability must be provided in the device design and manufacturing process and is maintaining during the device lifecycle. The maintenance schedule which is based on preventive/predictive maintenance strategy provides the desirable or defined levels of both reliability and flight safety. The all of described aircrafts maintenance strategies are followed during the real conditions fleet maintenance process.

Due to the development of diagnostic systems, military aircraft on-board systems include diagnostic procedures enabling the assessment of a current technical state of a given system. The procedure of assessing a given system is performed before an air operation. The procedure results provide information on a technical state of a military aircraft. Based on this information, a pilot decides either to perform a task or to withdraw from performing the task.

Apart from integrated diagnostic systems installed on board, there is a number of devices whose technical state is examined via monitoring and measuring equipment after its disassembly from the board of MMA. During maintenance works, diagnostic parameters of the examined devices are recorded and compared with the range of permissible changes. Any deviation beyond the assumed tolerance limits leads to the implementation of either appropriate maintenance procedures aiming at reducing the resultant deviation or appropriate corrections eliminating the deviation. The ability to predict the service life of MMA when diagnostic parameter tolerance might be exceeded would enable the appropriate management of the maintenance system of MMA. Thus, it is possible to optimize the time when MMA is under certain maintenance works and is not combat ready.

4. The process of maintaining the military aircraft

4.1 The influence of destructive factors on the technical state of devices used on the military aircraft

During the operation process of a military aircraft we can observe the change of technical parameters of selected devices along with the time of their operation. This change causes the deterioration of working conditions of a system and the loss of rated values of technical parameters. Factors influencing the above-mentioned changes include:

- changes of temperature and air-pressure,
- g-forces,
- vibrations,
- ageing process, etc.

The construction of technical systems is based on the assumption that a device fulfils its role when its operational/diagnostic parameters are within acceptable error limits. This assumption depends on the accuracy of work of particular system elements. Thus, in order to assure a faultless functioning of a military aircraft, we cannot allow operational parameters to exceed the acceptable error limits, which can be done in two ways: by frequent checks of operational parameter values of a device/system and its switch off when parameters are close to the fixed limit, or by determining the time after which operational parameters exceed values of the acceptable error.

The first way is onerous with regard to its organization and it is also time consuming and money consuming. Besides, the time spent on checking excludes a military aircraft from its use in a combat task, which consequently leads to a temporal decrease of the fighting efficiency of the air forces.

The second way is based on the use of a particular mathematical method enabling the description of value changes of operational parameters of a device/system and the evaluation of time in which a device/system is in operational state.

It is stated above that military aircrafts undergo changes during the exploitation of operational parameter values of particular devices in avionics system. The changes cause that operational parameter values approximate to the fixed acceptable limit. When parameter values equate with the limit value or exceed it, an adjustment must be done in order to restore nominal conditions of a device/system operation or the operation must be stopped. Figure 4 presents a theoretical course of changes of diagnostic parameter values.

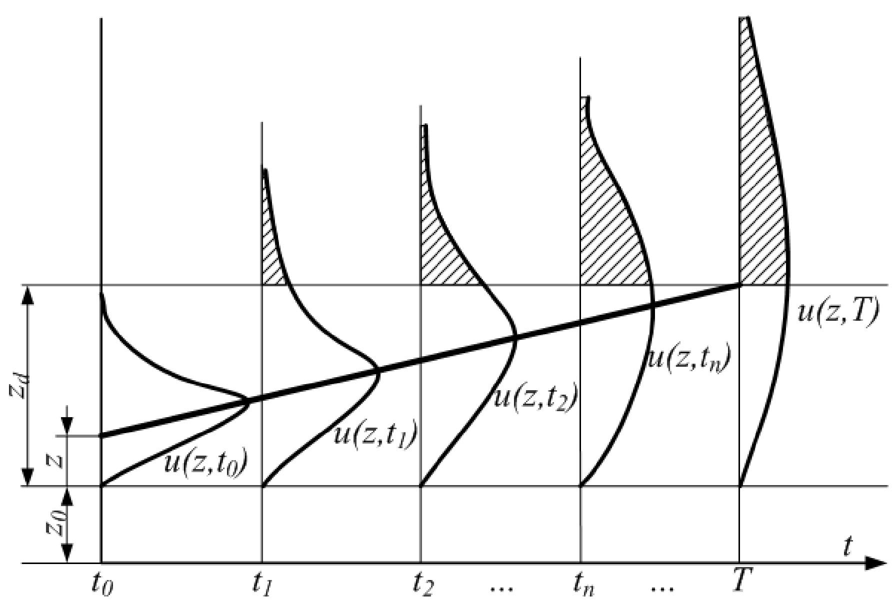

Fig. 4. Diagram of changes of diagnostic parameter values: z_0 – nominal value of a parameter, z – current value of a parameter, z_d – the limit of acceptable changes of parameter values

The second way is based on the use of a particular mathematical method enabling the description of value changes of operational parameters of a device/system and the evaluation of time in which a device/system is in operational state.

4.2 The model of diagnostic parameter changes in the aspect of the occurrence of destructive factors

In the figure, current value of a parameter is marked as "z". If $z < z_d$ then an element is fit for use, but if $z \geq z_d$ the elements losses its operational state. The change of diagnostic parameter values will be of a random character because of a specific character of MA operation process and the influence of destructive processes. So, let's consider "the wear of a device" of avionics system as a random process occurring during the operation of an aircraft.

Getting down to the analytical description of the diagram in Figure 4 and the determination of the density function of the changes of a diagnostic parameter values, the following assumptions were accepted:

1. The technical condition of an element is described by one diagnostic parameter which is marked as „z".
2. The change of the value of the parameter „z" happens only during the operation of a device, i.e. during the flight of an aircraft.
3. The parameter „z" is non-decreasing.
4. The change of the diagnostic parameter „z" is described by the following equation (1).

$$\frac{dz}{dN} = c \tag{1}$$

where:

c - random variable which depends on operational conditions of an element;
N - the number of flights of an aircraft.

1. If $z \in [0, z_d]$ then an element is fit for use, in other case the element is considered as unfit for use.
2. The intensity of flights of an aircraft is described by the following dependence (2).

$$\lambda = \frac{P}{\Delta t} \tag{2}$$

where:

Δt - the range of time in which the flight of an aircraft can be performed with the probability P,
P - the probability of the flight performance within the time interval with length Δt.

The time interval with length Δt shall be selected in such a way as to fulfil the following inequality (3).

$$\lambda \Delta t \le 1 \tag{3}$$

The intensity of flights λ enables the determination of the number of flights of an aircraft up to the moment t form the following formula:

$$N = \lambda t \tag{4}$$

Using the formula (4), the equation (1) can be written in the following form:

$$\frac{dz}{dt} = \lambda c \tag{5}$$

The dynamics of the changes of a diagnostic parameter can be described by the following difference equation (6).

$$U_{z,t+\Delta t} = (1 - \lambda \Delta t) U_{z,t} + \lambda \Delta t \, U_{z-\Delta z,t} \tag{6}$$

where:

$U_{z,t}$ - the probability that in the moment *t* the value of a diagnostic parameter will be *z*;

Δz - the increment of the diagnostic parameter *z* during one flight of an aircraft.

The functional notation of the equation (6) has the following form:

$$u(z, t + \Delta t) = (1 - \lambda \Delta t)\, u(z,t) + \lambda \Delta t\, u(z - \Delta z, t) \tag{7}$$

where:

$u(z,t)$ - the density function of the probability of the diagnostic parameter value *z* in the moment *t*;

$(1 - \lambda \Delta t)$ - the probability that in the time interval with length Δt the flight will not be performed;

$\lambda \Delta t$ - the probability of the flight performance in the time interval with length Δt.

The equation (7) was transformed by substituting the following differential equation (8).

$$\frac{\partial u(z, t)}{\partial z} = -\lambda \Delta z \frac{\partial u(z, t)}{\partial z} + \frac{1}{2} \lambda (\Delta z)^2 \frac{\partial^2 u(z, t)}{\partial z^2} \tag{8}$$

where: $\Delta z = c$.

Due to the fact that *c* is a random variable, the following mean value was introduced:

$$E[c] = \int_{c_d}^{c_g} c\, f(c)\, dc \tag{9}$$

where: *f*(*c*) - the density function of the random variable *c*;

c_g, c_u - the limits of variation of *c*.

Taking into consideration the dependence (9), the differential equation (8) can be written in the following form:

$$\frac{\partial u(z, t)}{\partial t} \Delta t = -\lambda E[c] \frac{\partial u(z, t)}{\partial z} + \frac{1}{2} \lambda (E[c])^2 \frac{\partial^2 u(z, t)}{\partial z^2} \tag{10}$$

where: $\lambda E[c]$ - the mean increment of the parameter value per time unit;

$\lambda (E[c])^2$ - the mean square increment of the value of the diagnostic parameter per time unit.

The solution of the equation (10) is the unknown density function of the probability of the random variable *z* in the following form:

$$u(z,t) = \frac{1}{\sqrt{2\pi\, A(t)}}\; e^{-\frac{(z-B(t))^2}{2A(t)}} \tag{11}$$

where:

$$B(t) = \int_0^t \lambda E[c]\,dt = \lambda E[c]\,t\,, \quad A(t) = \int_0^t \lambda \left(E[c]\right)^2 dt = \lambda E[c]^2\, t \tag{12}$$

Assuming that:

$$b = \lambda E[c]\,, \quad a = \lambda E[c]^2 \tag{13}$$

the density function (11) has the following form:

$$u(z,t) = \frac{1}{\sqrt{2\pi\, a\, t}}\; e^{-\frac{(z-bt)^2}{2at}} \tag{14}$$

The dependence (14) is the probabilistic characterisation of the increase of the wear in the function of the flying time. However, it is important to know the distribution of the time (the flying time) of the exceedance of the acceptable error value of the parameter z.

The probability of the exceedance of the acceptable value by the current value of the diagnostic parameter „z" can be written in the following form:

$$Q(t; z_d) = \int_{z_d}^{\infty} \frac{1}{\sqrt{2\pi\, at}}\; e^{-\frac{(z-bt)^2}{2at}}\, dz \tag{15}$$

The density function of the time distribution of the exceedance of the acceptable state z_d has the following form:

$$f(t) = \frac{\partial}{\partial t} Q(t; z_d) \tag{16}$$

Thus

$$f(t) = \frac{\partial}{\partial t} \int_{z_d}^{\infty} \frac{1}{\sqrt{2\pi\, at}}\; e^{-\frac{(z-bt)^2}{2at}}\, dz \tag{17}$$

$$f(t) = \int_{z_d}^{\infty} \left\{ \frac{\partial}{\partial t} \left[\frac{1}{\sqrt{2\pi\, at}}\; e^{-\frac{(z-bt)^2}{2at}} \right] \right\} dz \tag{18}$$

After calculating the derivative, we obtain:

$$f(t)_{z_d} = \int_{z_d}^{\infty} \left[u(z,t) \left(\frac{z^2 - b^2 t^2 - at}{2at^2} \right) \right] dz \tag{19}$$

The original function with regard to the integrand of the dependence (19) has the following form (20).

$$w(z,t) = u(z,t) \left(-\frac{z+bt}{2t} \right) \tag{20}$$

We calculate the integral (19).

$$f(t)_{z_d} = u(z,t) \left(-\frac{z+bt}{2t} \right) \Bigg|_{z_d}^{\infty} = \frac{z_d + bt}{2t} \frac{1}{\sqrt{2\pi at}} e^{-\frac{(z_d - bt)^2}{2at}} \tag{21}$$

Thus, the dependence (21) determines the density function of the time of the first transition of the current value of the parameter „z" through the acceptable state.

Having the above-mentioned data, we can determine the durability of a device with respect to the change of the value of the parameter z. For this purpose, we can write down that the formula for the reliability of a device has the following form:

$$R(t) = 1 - \int_0^t f(t)_{z_d} \, dt \tag{22}$$

where the density function $f(t)_{z_d}$ is determined by the formula (21).

The unreliability of a device can be determined from the dependence (23).

$$Q(t) = \int_0^t \frac{z_d + bt}{2t} \cdot \frac{1}{\sqrt{2\pi at}} e^{-\frac{(z_d - bt)^2}{2at}} dt \tag{23}$$

The integral (23) has to be simplified. It can be observed that the integrand can be written in the following form:

$$\frac{z_d + bt}{2t} \cdot \frac{1}{\sqrt{2\pi at}} e^{-\frac{(z_d - bt)^2}{2at}} = \frac{z_d + bt}{2t} \cdot \frac{1}{\sqrt{2\pi at}} e^{-\frac{(bt - z_d)^2}{2at}} \tag{24}$$

and now we have to solve the indefinite integral.

$$\int \frac{(z_d + bt)}{2t} \cdot \frac{1}{\sqrt{2\pi at}} e^{-\frac{(bt - z_d)^2}{2at}} dt \tag{25}$$

We make the substitution in the above-mentioned integral.

$$\frac{(bt - z_d)^2}{2at} = u \tag{26}$$

Thus

$$\frac{du}{dt} = \frac{bt + z_d}{2at^2}(bt - z_d) \tag{27}$$

$$dt = \frac{2at^2}{(bt + z_d)(bt - z_d)}\, du \tag{28}$$

After the substitution, the integral (25) has the following form (29).

$$\int \frac{z_d + bt}{2t} \cdot \frac{1}{\sqrt{2\pi\, at}} e^{-u} \cdot \frac{2at^2}{(bt + z_d)(bt - z_d)}\, du = \frac{1}{2\sqrt{\pi}} \int \frac{1}{\sqrt{u}} e^{-u} du \tag{29}$$

Then, we make the second substitution.

$$\sqrt{u} = w, \rightarrow \frac{dw}{du} = \frac{1}{2\sqrt{u}}, \rightarrow \frac{du}{dw} = 2w, \rightarrow du = 2w\, dw \tag{30}$$

Taking into consideration the above-mentioned dependencies, the integral (29) can be written in the following form:

$$\frac{1}{2\sqrt{\pi}} \int \frac{1}{w} e^{-w^2}\, 2w\, dw = \frac{1}{\sqrt{\pi}} \int e^{-w^2} dw \tag{31}$$

We make one more substitution.

$$w^2 = \frac{y^2}{2}, \rightarrow 2w\, dw = y\, dy, \rightarrow dw = \frac{y}{2w} dy, \rightarrow dw = \frac{y}{\sqrt{2}} \tag{32}$$

Thus, we obtain the integral in the following form:

$$\frac{1}{\sqrt{2\pi}} \int e^{-\frac{y^2}{2}} dy \tag{33}$$

where:

$$y = \frac{bt - z_d}{\sqrt{at}} \tag{34}$$

Substituting the results into the formula (22) and remembering the appropriate notation of the integration limits, we obtain the formula for the reliability:

$$R(t) = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{bt - z_d}{\sqrt{at}}} e^{-\frac{y^2}{2}} dy \tag{35}$$

The distribution function for the standard normal distribution has the following form (36).

$$\Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{y^2}{2}} dy \tag{36}$$

Finally, the formula for the reliability of a system has the form of the following dependence:

$$R^*(t) = 1 - \Phi\left(\frac{b^* t - z_d}{\sqrt{a^* t}}\right) \tag{37}$$

where b^* and a^* are coefficients after the estimation on the basis of data obtained from the exploitation of military aircrafts.

Thus, the risk of a device damage can be determined from the following dependence (38).

$$Q^* = 1 - R^*(t) = \Phi(\gamma) \tag{38}$$

where:

$$\gamma = \frac{b^* t - z_d}{\sqrt{a^* t}} \tag{39}$$

Assuming a specified level of damage risk, we can find γ (by reading values on the tables of the normal distribution). Knowing the value of γ, we can determine the durability (i.e. t) from the dependence (39). For this purpose, the dependence (39) was transformed into the following square equation (40).

$$b^{*2} t^2 - \left(\gamma^2 a^* + 2b^* z_d\right) t + z_d^2 = 0 \tag{40}$$

Thus, the durability:

$$T = \frac{\left(\gamma^2 a^* + 2b^* z_d\right) - \sqrt{\left(2b^* z_d + \gamma^* a^*\right)^2 - 4b^{*2} z_d^2}}{2b^{*2}} \tag{41}$$

4.3 A computational example

The efficiency of the chosen system is determined with the help of diagnostic parameters describing the technical condition of particular devices of the system. An aiming head (a navigation and aiming device) is an important device of avionics system. Its technical condition is described by two diagnostic parameters: ε and β which describe the coordinates of position of sight marker.

On the basis of analyzing results of checks of a particular population of aiming heads it was established that as the time of operation goes by and as a result of the influence of destructive factors, the values of these parameters undergo changes. Table 1 presents an exemplary course of changes of values of the diagnostic parameters ε and β during an operation process.

T [months]	0	27	40	57	83	94	102	110	116
ε	0	0,01	0,01	0,01	0,07	0,48	0,48	0,54	0,73
β	0	0,23	0,26	0,26	0,39	0,50	0,53	0,56	0,59

Table 1. Changes of diagnostic parameter values in an aiming head during an operation process

Having data describing the values of deviation of a diagnostic parameter in the following form $[(z_0, t_0), (z_1, t_1), (z_2, t_2), ..., (z_n, t_n)]$, and basing on the following formulas,

$$b^* = \frac{z_n}{t_n}, \quad a^* = \frac{1}{n}\sum_{k=0}^{n-1}\frac{\left[(z_{k+1} - z_k) - b^*(t_{k+1} - t_k)\right]^2}{(t_{k+1} - t_k)} \tag{42}$$

the values of the density function coefficients for both diagnostic parameters were determined:

$$a_\varepsilon^* = 0{,}002; \quad b_\varepsilon^* = 0{,}0063; \quad a_\beta^* = 0{,}0003; \quad b_\beta^* = 0{,}0051 \tag{43}$$

Assuming the following level of reliability $R^*(t) = 0{,}99$, the value of the parameter $\gamma = 2{,}32$ was read on the tables of normal distribution. The parameter z_d was determined on the basis of a technical documentation which is used for service works and includes information on the acceptable values of deviations of the diagnostic parameters.

The values of the parameters a, b, γ, z_d were substituted into the equation (41), and the time after which the values of the diagnostic parameter deviations exceed the limit state was calculated. In this case, the time comes to:

$$T_\varepsilon=5[\text{months}], \quad T_\beta=33[\text{months}] \tag{44}$$

since the last check of the diagnostic parameters. The values (44) can be used in technical service depending on the adopted service strategy.

Summing up, we can state that the above-presented method seems to be correct and enables the analysis of a device/system technical condition with respect to the character of changes of values of the diagnostic parameters. The above-presented calculation example enabled the verification of the developed model and showed application qualities of the method. This method can be useful in future work on the improvement of both the operation process and the way of use of aircrafts with avionics system because it enables the determination of time during which a device is fit for use.

Moreover, due to its universal character, the method can be used to determine the residual life of any technical object whose technical condition is determined by analyzing values of the diagnostic parameters.

5. The process of operating the military aircraft

5.1 The influence of destructive factors on the course of the process of operating the military aircraft

The use of military aircrafts concerns mainly the performance of a particular combat task, which often involves the use of aerial combat means. As far as an airborne function of a military aircraft is concerned, the main stages of its operation comprise the take-off, the staying in the air, and the landing. On the other hand, when analyzing the process of the operation of the on-board armament system, we can assume that the operational effect is the sum of the partial effects gained during the flight phase in relation to:

- target detection;
- the execution of the aiming process;
- the execution of the process of attacking.

The level of effect of munitions on a target is the most commonly assumed rate that characterizes the operational effect obtained during the execution of a combat task involving the use of aerial combat means. As regards the on-board armament system, the obtained effect comes down to the determination of the difference between the value of target coordinates and the coordinate values of a drop point of combat armament.

Based on the structural diagram (Fig. 1) and the functions of the on-board armament system, we can assume that the Armament Control System (ACS) is the basic element that affects the value of the operational effect. Both at the stage of maintenance and operation, ACS provides information that is essential for the accurate functioning of the on-board armament system (OAS). In turn, as regards the ACS, its most crucial element involves the navigation and aiming system (NAS). Its basic task comprises the realization of a set of algorithms. Their solution enables – in the maintenance system - the reconstruction of the nominal values of particular initial parameters; - in the operation system – the proper usage of combat means (the intended use). The latter system is the subject of further discussion.

The analysis of the operational effect can be performed on the basis of the assessment of conditions in which NAS is used and the determination of causes that have a negative impact on the final value of the obtained effect. As regards NAS, during the execution of a combat task, the operational effect is the total angular correction represented as an aiming indicator in a pilot’s field of view. The process of aiming and attacking is executed on the basis of the total angular correction. Thus, we can assume that the assessment of the operational effect involves the determination of accuracy in defining and reproducing the position of a moving aiming indicator.

The next aspect concerns the use of the aiming correction by a pilot. When the correction is defined and illustrated, the task comes down to the determination of the flight conditions in which an aiming indicator coincides with a target at the moment of using combat means. Based on the conducted analysis, we can assume that the execution of a combat task under real conditions is not an easy process. The causes of errors affecting the value of the operational effect connected with the aiming process execution can be represented as the equation for the pooled error of the aiming process execution Δ_Σ:

$$\Delta_\Sigma = (\Delta_M + \Delta_K + \Delta_I + \Delta_A) + (\Delta_C + \Delta_W + \Delta_R + \Delta_O) + \Delta_N \tag{45}$$

The error of the method for solving the aiming-related equations Δ_M characterizes two groups of causes:

1. connected with the relative uncertainty resulting from the processing of initial data concerning the aiming process by NAS functional elements, and
2. concerning the error function of equations for aiming.

The system configuration error Δ_K connects with entering invalid control signals (that characterize the combat task being performed) into NAS.

The instrumental error Δ_I connects with the accuracy of determining the operational parameters of NAS by particular information transmitters. This error concerns mainly the measurement error.

The reconstruction error Δ_A characterizes the adequacy of a physical combat situation taking place during the execution of the aiming process to the assumed attack diagram which was used to determine the aiming equations.

The causes of variance between the aiming indicator position and the target Δ_C result from an incorrect approach of an aircraft to an attack path.

The causes of the failure to maintain the required conditions for aiming and attacking Δ_W connect with the failure to keep the required angle of diving, flight speed, bank angle, etc., i.e. the exceeding of the nominal values of particular parameters describing a combat task.

The effect of the weapon position Δ_R on the pooled error value Δ_Σ, concerns mainly the process of aiming during the execution of the process of attacking with the use of aerial combat means (that are applied in a time series of particular length).

Environmental conditions determining the value of the error Δ_O significantly influence the execution of the aiming process. Due to the fact that an aircraft moves at high speed in a heterogeneous space, it may encounter various conditions prevailing in space layers or areas, which directly translates into the perturbation of flight-related parameter values.

The general error Δ_N concerns causes which are not included in the presented classification and are the resultant of the lack of possibility to learn or describe them in an analytical way at the present state of knowledge.

All the above-mentioned errors can be of two kinds: determined errors (systematic errors) and probabilistic errors (random errors). So, their accumulated form Δ_Σ will be burdened with both types of errors. The phenomenon of the random error occurrence is not precisely determined, that is why an attempt to evaluate its value is fully justified. A random character of compound errors causes that the operational effect of MMA application is burdened with the random error, too.

5.2 The model of the assessment of the execution of a combat mission by the military aircraft

The execution of the aiming process generally comes down to the process of making an aiming indicator coincide with a target. Significant elements of this process include parameters that determine the aiming indicator position and a set of actions aiming at pointing the indicator at a target. Based on these elements, we can consider the process of aiming as the execution of the process of building the aiming triangle using: a pilot – the system operator, an aiming indicator – the quantity describing the appropriate spatial orientation of an aircraft, and a target – the basic point in the execution of the aiming process. The aim of the process is to align these three elements.

The aiming correction is obtained by recording particular parameters (necessary to solve aiming equations) and processing them in NAS. The aiming correction value is represented as the central point of a moving aiming indicator which is displayed on the reflector of the sight head. Due to the effect of various constraints, the aiming indicator can adopt different positions in the assumed flat coordinate system (Fig. 6) placed on the plane of the sight head reflector. The indicator can either move in one out of four directions or move back to the previously occupied position.

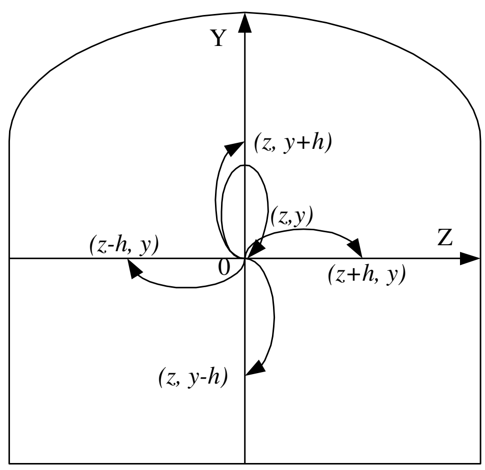

Fig. 6. A graphical representation of the occurrence of possible deviations of the central point of the moving indicator during the execution of the aiming process

$U_{z,y,t}$ denotes the probability that at the moment t the position deviations of the central point of the moving indicator are z and y, where t is the current time of the process of aiming. This probability is characterized by the density function denoted as $U(z,y,t)$. Therefore, using the density function $U(z,y,t)$ we can describe the dynamics of changes in the position deviations of the central point of the moving indicator by a difference equation.

Regarding the issue being discussed above, the difference equation is as follows:

$$U(z,y,t+\Delta t) = P_{00}U(z,y,t) + P_{10}U(z-h,y,t) + P_{20}U(z+h,y,t) + \\ + P_{01}U(z,y-h,t) + P_{02}U(z,y+h,t) \quad (46)$$

where:

U(z,y,t) - the probability density function of deviation values at the moment *t*;
Δt - the time value between the specified deviations;
h - the deviation value along the specified axes;
P_{00} - the probability that the deviation value will not change;
P_{10} - the probability that the deviation value along the OZ axis will change by *-h* at the time *Δt*;
P_{20} - the probability that the deviation value along the OZ axis will change by *h* at the time *Δt*;
P_{01} - the probability that the deviation value along the OY axis will change by *-h* at the time *Δt*;
P_{02} - the probability that the deviation value along the OY axis will change by *h* at the time *Δt*;

When we use expressions obtained from the expansion of the function *U(z,y,t)* in the Taylor series in the surrounding of the point *(z,y)* and the time *t* in accordance with the relationships of the following set of equations:

$$\left.\begin{aligned} U(z,y,t+\Delta t) &= U+\frac{\partial U}{\partial t}\Delta t \\ U(z-h,y,t) &= U-\frac{\partial U}{\partial z}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2} \\ U(z+h,y,t) &= U+\frac{\partial U}{\partial z}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2} \\ U(z,y-h,t) &= U-\frac{\partial U}{\partial y}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2} \\ U(z,y+h,t) &= U+\frac{\partial U}{\partial y}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2} \end{aligned}\right\} \tag{47}$$

where *U*=*U(z,y,t)*, and the fact that $P_{00}+P_{10}+P_{20}+P_{01}+P_{02}=1$, the equation (47) takes the following form:

$$\begin{aligned} U+\frac{\partial U}{\partial t}\Delta t = P_{00}U + P_{10}\left(U-\frac{\partial U}{\partial z}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2}\right)+P_{20}\left(U+\frac{\partial U}{\partial z}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2}\right)+ \\ +P_{01}\left(U-\frac{\partial U}{\partial y}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2}\right)+P_{02}\left(U+\frac{\partial U}{\partial y}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2}\right) \end{aligned} \tag{48}$$

When adding and subtracting *U* in the equation (48) and multiplying appropriate expressions in the brackets and taking the parameter *U* outside the brackets, the following result was obtained:

$$\begin{aligned} \frac{\partial U}{\partial t}\Delta t = -U + (P_{00}+P_{10}+P_{20}+P_{01}+P_{02})U + P_{10}\left(-\frac{\partial U}{\partial z}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2}\right)+ \\ +P_{20}\left(\frac{\partial U}{\partial z}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2}\right)+P_{01}\left(-\frac{\partial U}{\partial y}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2}\right)+ \\ +P_{02}\left(\frac{\partial U}{\partial y}h+\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2}\right) \end{aligned} \tag{49}$$

Using the assumption that the sum of all probabilities describing the weapon angular position equals one, the equation (49) takes the following form:

$$\frac{\partial U}{\partial t}\Delta t = -P_{10}\frac{\partial U}{\partial z}h + P_{10}\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2} + P_{20}\frac{\partial U}{\partial z}h + P_{20}\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2} - P_{01}\frac{\partial U}{\partial y}h + \\ + P_{01}\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2} + P_{02}\frac{\partial U}{\partial y}h + P_{02}\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2} \tag{50}$$

After grouping the quantities from the above equation, the following equation was obtained:

$$\frac{\partial U}{\partial t}\Delta t = -P_{10}\frac{\partial U}{\partial z}h + P_{20}\frac{\partial U}{\partial z}h + P_{10}\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2} + P_{20}\frac{1}{2}h^2\frac{\partial^2 U}{\partial z^2} - P_{01}\frac{\partial U}{\partial y}h + \\ + P_{02}\frac{\partial U}{\partial y}h + P_{01}\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2} + P_{02}\frac{1}{2}h^2\frac{\partial^2 U}{\partial y^2} \tag{51}$$

After dividing both sides of the equation (51) by Δt, the following result was obtained:

$$\frac{\partial U}{\partial t} = -\frac{(P_{10} - P_{20})h}{\Delta t}\frac{\partial U}{\partial z} + \frac{(P_{10} + P_{20})\frac{1}{2}h^2}{\Delta t}\frac{\partial^2 U}{\partial z^2} + \\ - \frac{(P_{01} - P_{02})h}{\Delta t}\frac{\partial U}{\partial y} + \frac{(P_{01} + P_{02})\frac{1}{2}h^2}{\Delta t}\frac{\partial^2 U}{\partial y^2} \tag{52}$$

By introducing the following denotations:

$$b_1 = \frac{(P_{10} - P_{20})h}{\Delta t}, \quad \mathrm{b}_2 = \frac{(P_{01} - P_{02})h}{\Delta t} \tag{53}$$

$$a_1 = \frac{(P_{10} + P_{20})h^2}{\Delta t}, \quad a_2 = \frac{(P_{01} + P_{02})h^2}{\Delta t} \tag{54}$$

and substituting them into the equation (52), the following differential equation was obtained:

$$\frac{\partial U}{\partial t} = -b_1\frac{\partial U}{\partial z} - b_2\frac{\partial U}{\partial y} + \frac{1}{2}a_1\frac{\partial^2 U}{\partial z^2} + \frac{1}{2}a_2\frac{\partial^2 U}{\partial y^2} \tag{55}$$

The following function is the solution of the above equation:

$$U(z,y,t) = \frac{1}{\sqrt{2\pi a_1 t}\sqrt{2\pi a_2 t}}e^{-\frac{1}{2}\left(\frac{(z-b_1 t)^2}{a_1 t} + \frac{(y-b_2 t)^2}{a_2 t}\right)} \tag{56}$$

Assuming that the probabilities P_{10} and P_{20} are of the same order, i.e. P_{10}=P_{20}, we can write that the coefficient $b_1 \approx 0$. Similarly, we can assume that the probabilities P_{01} and P_{02} are also of the same order, so the coefficient $b_2 \approx 0$. Given these assumptions, the equation (55) takes the following form:

$$\frac{\partial U}{\partial t} = \frac{1}{2} a_1 \frac{\partial^2 U}{\partial z^2} + \frac{1}{2} a_2 \frac{\partial^2 U}{\partial y^2} \tag{57}$$

The following form of the density function is the solution of the equation (57):

$$U(z, y, t) = \frac{1}{\sqrt{2\pi a_1 t}\sqrt{2\pi a_2 t}} e^{-\frac{1}{2}\left(\frac{z^2}{a_1 t} + \frac{y^2}{a_2 t}\right)} \tag{58}$$

The explicit form of the density function (58) requires determining the equation coefficients (57) and connects with:

- obtaining input data;
- determining the density function (58);
- determining the likelihood function L enabling the determination of the parameter estimates a_1 and a_2:

$$L = \frac{1}{(2\pi)^n (a_1 a_2)^{\frac{n}{2}}} \prod_{k=1}^{n-1} \frac{1}{(t_{k+1} - t_k)} \exp\left\{-\frac{1}{2}\left[\frac{(z_{k+1} - z_k)^2}{a_1 (t_{k+1} - t_k)} + \frac{(y_{k+1} - y_k)^2}{a_2 (t_{k+1} - t_k)}\right]\right\} \tag{59}$$

To determine the parameters a_1 and a_2 we can use the method of the maximum likelihood. The method consists in finding the parameter values a_1 and a_2 that maximize the likelihood function. So, we seek the solution of the set of equations

$$\begin{cases} \frac{\partial \ln L}{\partial a_1} = 0 \\ \frac{\partial \ln L}{\partial a_2} = 0 \end{cases} \tag{60}$$

Therefore, the logarithm of the likelihood function L takes the following form:

$$\ln L = -n \ln 2\pi - \frac{n}{2} \ln a_1 - \frac{n}{2} \ln a_2 + \\ + \sum_{k=1}^{n-1} \left[\ln(t_{k+1} - t_k) + \left[-\frac{1}{2} \left(\frac{(z_{k+1} - z_k)^2}{a_1 (t_{k+1} - t_k)} + \frac{(y_{k+1} - y_{*k})^2}{a_2 (t_{k+1} - t_k)} \right) \right] \right] \tag{61}$$

By determining the derivatives of the function L relative to specified parameters, the following set of equations was obtained:

$$\begin{cases} -\frac{n}{2a_1} + \sum_{k=1}^{n-1} \frac{(z_{k+1} - z_k)^2}{2a_1^2 (t_{k+1} - t_k)} = 0 \\ -\frac{n}{2a_2} + \sum_{k=1}^{n-1} \frac{(y_{k+1} - y_k)^2}{2a_2^2 (t_{k+1} - t_k)} = 0 \end{cases} \tag{62}$$

which after transformation provides the following equations (63):

$$\begin{cases} a_1 = \frac{1}{n} \sum_{k=1}^{n-1} \frac{(z_{k+1} - z_k)^2}{(t_{k+1} - t_k)} \\ a_2 = \frac{1}{n} \sum_{k=1}^{n-1} \frac{(y_{k+1} - y_k)^2}{(t_{k+1} - t_k)} \end{cases} \tag{63}$$

Therefore, the parameters a_1 and a_2 can be defined on the basis of the above set of equations. When analyzing the function notation (58), it can be assumed that in order to determine the variance characterizing the distribution of the indicator central point, the parameters a_1 and a_2 must be multiplied by time, which leads to the following result:

$$\begin{cases} \sigma_z^2(t_n) = a_1 t_n = \frac{1}{n} \sum_{k=1}^{n-1} \frac{(z_{k+1} - z_k)^2}{(t_{k+1} - t_k)} \sum_{k=1}^{n-1} (t_{k+1} - t_k) \\ \sigma_y^2(t_n) = a_2 t_n = \frac{1}{n} \sum_{k=1}^{n-1} \frac{(y_{k+1} - y_k)^2}{(t_{k+1} - t_k)} \sum_{k=1}^{n-1} (t_{k+1} - t_k) \end{cases} \tag{64}$$

The determination of the function parameters (58) will allow defining the probability density function of the correct position of the indicator central point.

As regards the case described, it is assumed that the probability of the occurrence of deviations in any direction of the assumed coordinate axes is the same. Such situation takes place when the process of aiming is performed correctly, i.e. when at the beginning of the aiming process, an aiming indicator coincides with a target and any dislocation of the indicator is compensated with its resetting on the target. A real process of aiming often involves the indicator dislocation relative to a target. The occurrence of such dislocation causes that the probability of the indicator dislocation in a specified direction is higher than the indicator dislocation in an opposite direction. Thus, the values of the parameters b_1 and b_2 are not 0. Therefore, the differential equation describing the aiming process takes the form of the equation (55). Its solution is the density function (56). The parameters b_1, b_2, a_1 and a_2 need to be determined for the function. Using the above-described technique, the likelihood function (65) was determined. It was used to estimate the sought parameters:

$$L = \frac{1}{(2\pi)^n (a_1 a_2)^{\frac{n}{2}}} \prod_{k=1}^{n-1} \frac{1}{(t_{k+1} - t_k)} \exp\left\{ -\frac{1}{2} \left[\frac{((z_{k+1} - z_k) - b_1 (t_{k+1} - t_k))^2}{a_1 (t_{k+1} - t_k)} + \frac{((y_{k+1} - y_k) - b_2 (t_{k+1} - t_k))^2}{a_2 (t_{k+1} - t_k)} \right] \right\} \tag{65}$$

The process of determining the function parameter (65) is analogous to the way of determining the equation coefficients (59). By determining the derivatives of the function logarithms (65) relative to specified coefficients and comparing them to 0, the following relationships were obtained:

$$b_1 = \frac{z_n}{t_n}, \qquad b_2 = \frac{y_n}{t_n}$$
$$a_1 = \frac{1}{n}\sum_{k=1}^{n-1}\frac{\left[\left(z_{k+1}-z_k\right)-b_1\left(t_{k+1}-t_k\right)\right]^2}{\left(t_{k+1}-t_k\right)} \tag{66}$$
$$a_2 = \frac{1}{n}\sum_{k=1}^{n-1}\frac{\left[\left(y_{k+1}-y_k\right)-b_2\left(t_{k+1}-t_k\right)\right]^2}{\left(t_{k+1}-t_k\right)}$$

By determining the values of the above coefficients and substituting them into the equation (56), we can determine the density function of the indicator position during the aiming process involving the indicator dislocation relative to a target.

The indicator path relative to a target (described for subsequent moments $t_0, t_1, t_2, \ldots, t_n$,) can be characterized by horizontal coordinates $z_0, z_1, z_2, \ldots, z_n$ and vertical coordinates $y_0, y_1, y_2, \ldots, y_n$ of the assumed coordinate system. When converting these quantities to current data, the time of recording the position of the aiming indicator can be replaced by the number of the registered positions (next coordinate values will constitute the sum of previous coordinates). Thus, the indicator position will be characterized by:

1. the number of registered positions: $0, 1, 2, \ldots, n$;
2. the deviation toward the 0Z axis: $0, z_1, (z_1+z_2), (z_1+z_2+z_3), \ldots, \sum_{i=1}^{n} z_i$;
3. the deviation toward the 0Y axis: $0, y_1, (y_1+y_2), (y_1+y_2+y_3), \ldots, \sum_{i=1}^{n} y_i$.

Based on the above, we can determine the following parameters:

$$b_1^* = \frac{\sum_{i=1}^{n} z_i}{n}, \qquad b_2^* = \frac{\sum_{i=1}^{n} y_i}{n} \tag{67}$$

$$\sigma_1^2 = a_1^* = \frac{1}{n}\sum_{k=1}^{n-1}\left[\left(\hat{z}_{k+1}-\hat{z}_k\right)-\left(\frac{1}{n}\sum_{i=1}^{n} z_i\right)\right]^2$$
$$\sigma_2^2 = a_2^* = \frac{1}{n}\sum_{k=1}^{n-1}\left[\left(\hat{y}_{k+1}-\hat{y}_k\right)-\left(\frac{1}{n}\sum_{i=1}^{n} y_i\right)\right]^2 \tag{68}$$

where:

$$\hat{z}_{k+1} = \sum_{i=1}^{k+1} z_i, \quad \hat{z}_k = \sum_{i=1}^{k} z_i$$
$$\hat{y}_{k+1} = \sum_{i=1}^{k+1} y_i, \quad \hat{y}_k = \sum_{i=1}^{k} y_i \tag{69}$$

Because

$$\hat{z}_{k+1} - \hat{z}_k = z_{k+1} \quad \text{and} \quad \hat{y}_{k+1} - \hat{y}_k = y_{k+1} \tag{70}$$

therefore:

$$\sigma_1^2 = \frac{1}{n}\sum_{k=1}^{n}\left[z_k - \frac{1}{n}\sum_{i=1}^{n} z_i\right]^2$$
$$\sigma_2^2 = \frac{1}{n}\sum_{k=1}^{n}\left[y_k - \frac{1}{n}\sum_{i=1}^{n} y_i\right]^2 \tag{71}$$

The above relationships can be used to describe the process of aiming under real-life conditions.

5.3 A computational example

The execution of a combat task with the use of aerial combat means is characterized by the fact that the possibility of their use is determined by conditions that constitute a set of various factors enabling the performance of a combat task at the required level and with the consideration of a current tactical, navigational, meteorological, and radio-technical situation. The basic determinants of these conditions involve combat capabilities of an aircraft and the level of competence among aircrew members. The essence of the aiming process comes down to the controlling of an aircraft in such a way that it reaches the point in space where the applied weapon will hit a target. This procedure is performed in the NAS environment on the basis of the following data:

- motion parameters of an aircraft executing an attack, a target, and parameters of the centre where an aircraft motion is executed;
- the required coordinates of a target;
- the actual coordinates of a target;
- the comparison between actual and required coordinates of a target.

A common method for analyzing the aiming process during an attack is the recorded material analysis (using either the film placed in a photo-control apparatus located in front of the sight head or a camera recording a tactical situation in front of MMA.) Based on the recorded material, it is possible to determine a mutual position of an aiming indicator and a target at the moment of a weapon use.

Having the material registered by photo-control devices (Fig. 6) and using the above-mentioned method, it is possible to define coordinates of the mutual position of a target and indicator in successive moments of the attacking process.

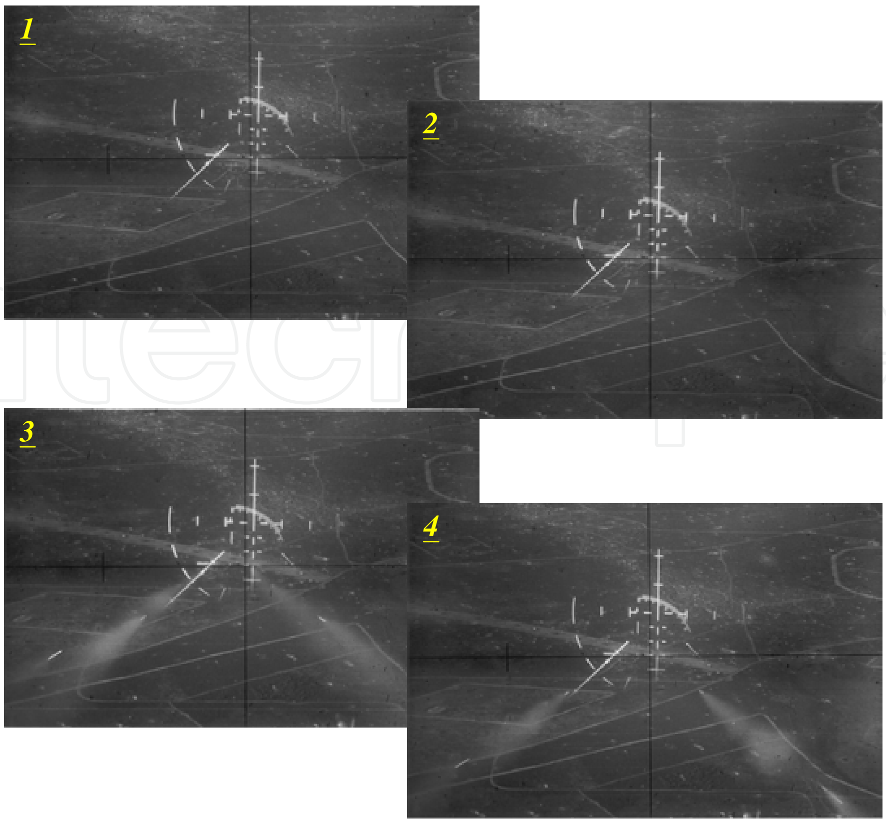

Fig. 6. Photos taken with a photo-control apparatus during the realization of the attacking process with the use of non-guided missiles

Based on the obtained data, it was possible to determine the aiming indicator path relative to a target. Figure 7 depicts the path. When analyzing the position of the central point of the aiming indicator, we can assume that the position adopting the chaotic motion of the indicator was the proper position that completely reflects the nature of the real process.

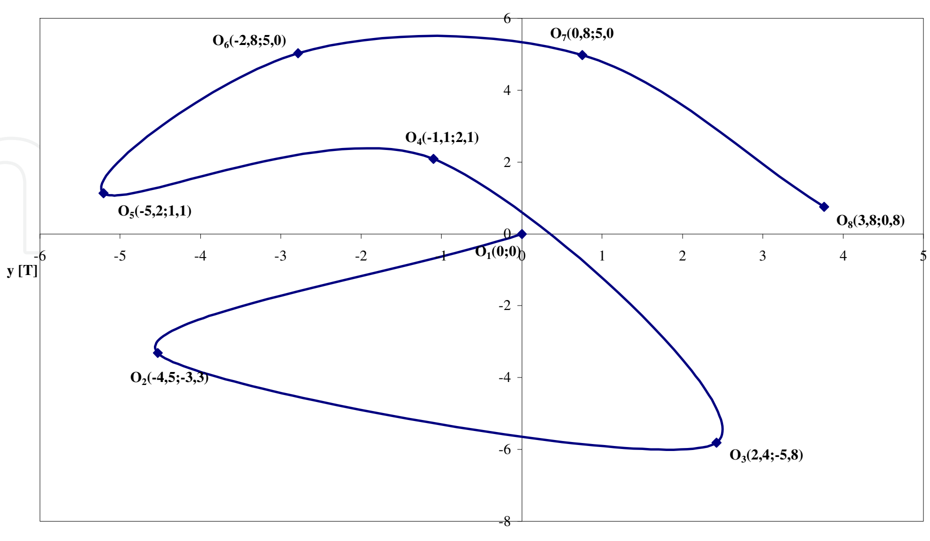

Fig. 7. The course of changes in the position of the aiming indicator relative to a target during the realization of the aiming process with the use of non-guided missiles.

The variance values were determined for the data presented in Fig. 7. The values are as follows:

$$\sigma_z^2 = 14{,}24\left[T^2\right], \qquad \sigma_y^2 = 22{,}80\left[T^2\right] \tag{72}$$

By substituting the above equation values (58) and on the basis of the recorded data, it was possible to determine a graphical form of the probability density function (Fig. 8) that characterizes the concurrence of the aiming indicator with a target during the execution of the aiming process.

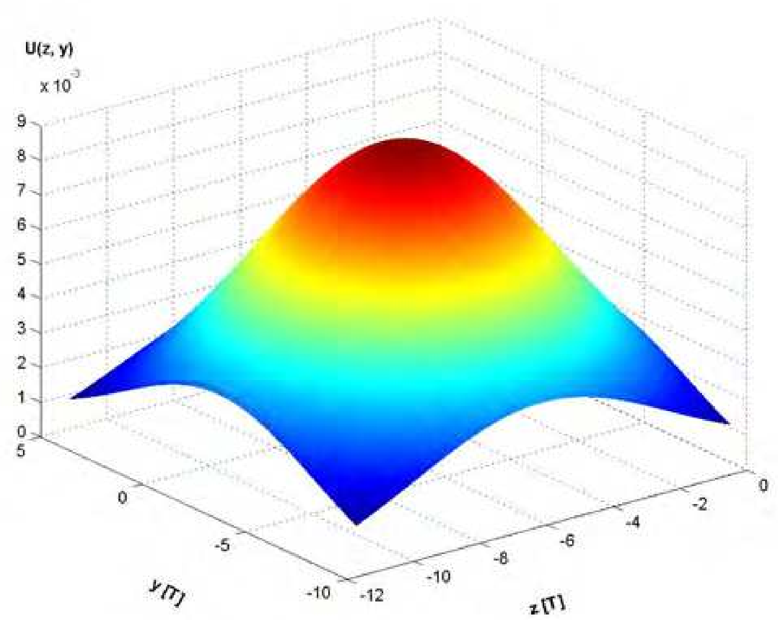

Fig. 8. A graph of the probability density function of indicator deviations during the execution of the aiming process with the use of non-guided missiles

6. Summary

Works carried out during the process of maintaining aim to ensure the required level of safety concerning aircraft engineering and to maintain it in good working condition. This is achieved by carrying out planned works and systematic checks of diagnostic parameter values. Apart from identification, diagnostic testing includes two more aspects concerning the technical state genesis and prediction. That is why, for safety and reliability reasons, it is important to develop methods enabling prediction of the technical state of devices on the basis of information obtained during the maintenance process. The 4rd chapter comprises the presentation of the probabilistic method for the determination of residual durability of devices on the basis of their diagnostic parameter changes registered during the process of maintaining. The application of the above-mentioned method may facilitate the military aircraft maintenance process by limiting the number of stoppages through the indication of a time of next maintenance works for a specified device/system. It shall be emphasized that the presented method is universal as it can be applied to the maintenance process modernization not only in respect of aircraft engineering but also in respect of any field where device/system diagnostic parameters are registered.

The process of operating is inevitably connected with "an operational effect" which results from the completion of a particular combat mission. Depending on a combat mission, this effect will concern, for example hitting the target, intercepting an enemy, identifying the target to attack, etc. The operational effect is always obtained during flight. Due to flying conditions of the military aircraft, we can list a number of destructive factors reducing the value of the obtained operational effect. Analyzing the process of operating, we can state that one of the most significant "cells" in this process is the flying military personnel – a pilot. His task involves the appropriate configuration of the military aircraft systems and the performance of the aiming process that generally comes down to the process of making an aiming indicator coincide with a target. The method presented in the 5th chapter enables the quantitative assessment of the aiming process quality. The results obtained in this way and supported by parameters describing conditions in which a combat task was conducted may constitute the basis for the evaluation of the realization of both a current combat task and the progress in training (considering the series of tasks of a given type in a specified time interval).

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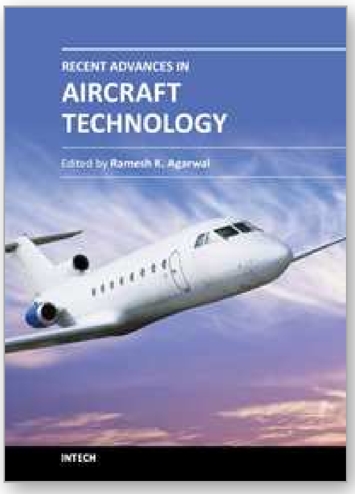

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The book describes the state of the art and latest advancements in technologies for various areas of aircraft systems. In particular it covers wide variety of topics in aircraft structures and advanced materials, control systems, electrical systems, inspection and maintenance, avionics and radar and some miscellaneous topics such as green aviation. The authors are leading experts in their fields. Both the researchers and the students should find the material useful in their work.