New Measures of Operational Readiness for Multi-states Avionics Integrated Systems with Reduced Efficiency

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Abstract. The paper presents a method of analysis and determination of partial operational readiness coefficients and a way of its assessment, as well as guidelines for making decisions in the field of rational management and efficient use of the aircraft with equipment that is partially non-airworthy under conditions of the occurrence of, e.g. armed conflict, state threat, and crisis state. It was indicated that for efficient management of the operation of military aircraft and helicopters under conditions of ensuring flight safety, it is necessary to support a decision-making process with the use of IT systems that allow for current determination of the partial and complete operational readiness level of individual aircraft on-board systems with many states with reduced usability.

Keywords: Integrated communications systems · Possibilities and conditions of forming operational readiness aircraft Reliability centered maintenance

1 Introduction

The operational readiness of aircraft is a level of readiness of on-board systems, as well as aviation personnel, aviation and engineering service, logistic equipment, and any equipment that is necessary to learn, prepare, and perform the initial operating capability and to develop the ways of checking the ability to perform them [4, 5, 13]. In the Polish military aviation, in the conditions of peace, the applied priority is to absolutely ensure the flight safety, while resigning from the performance of air tasks with the use of the un air worthy aircraft. It is possible to undertake the implementation of these tasks, when the aircraft is improved and restored to the state of airworthiness. In the situations of a direct risk, it may be necessary to use the aircraft with equipment usable for the selected mission implementation, including damage to the on-board devices, which do not directly affect the flight safety and will not be used during the performance of a given task [17, 18].

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Such cases occur in the conditions, when the mission performance requires the usability of the selected on-board systems and devices, which are used for the implementation of, among others, a search and rescue mission (SAR) and a combat search and rescue mission (CSAR). The situation may relate to the on-board systems with many partial usability states using component devices participating in the selected modes of the system operation, depending on the type of the performed task [10, 12].

The aircraft readiness is a property characterising the usability to undertake an air task immediately or at a given time t with a forecast of its successful completion within the time interval τ. The aircraft can perform various aerial operations and be in one of the selected reliability states (airworthiness, non-airworthiness, partial airworthiness) and of the operational states (combat duty performance, aircraft subject to operation, renovation and diagnosis, etc.). The appropriate technical condition of a given aircraft is a condition insufficient to perform the above-mentioned tasks. As a condition for the air task implementation, it is necessary to perform logistic undertakings providing the condition of readiness. Therefore, readiness is considered in three aspects as: initial readiness, technical readiness and operational readiness [2, 5].

Readiness as a measure of quality of the aircraft and its related operation system, determines the ability to provide the military aircraft or helicopter operation within the determined time intervals and the ability to the maximum operation time within the considered operation period, timely task performance, and also to the maximum time of the combat duty while minimising the preparation time to start random tasks occurring in the intervention systems, among others, defensive, protection and armed conflict ones.

The aircraft readiness measures in a given operation system are the probabilistic characteristics of the time of the aircraft and operation system staying in the states ensuring the ability to operate in the desirable states.

The Air Force Institute of Technology (AFIT), as the first one in Poland, has developed and built an Integrated Communication System (ZSŁ) and it has taken the measures aimed at development of new operational readiness measures, systems increasing the reliability and functionality of the communication system with many states with reduced usability [8, 10, 19].

2 Integrated Communication System as a Complex Avionic System

In order to improve the situational awareness of the crews operating *Mi8/Mi17/Mi24 and W-3PL* helicopters, the integrated communication system provides a minimum set of air and tactical radios, which is necessary to implement the task (Fig. 1). It protects overt and covert communication with the use of frequency coding (the so-called TRANSEC) and speech and data encryption (the so-called COMSEC). Owing to their help, the crew during the whole performed flight is provided with communication and control of their parameters during the flight. The status of use of individual on-board radios is illustrated on the communication control panels and/or multifunction monitors [2, 8].

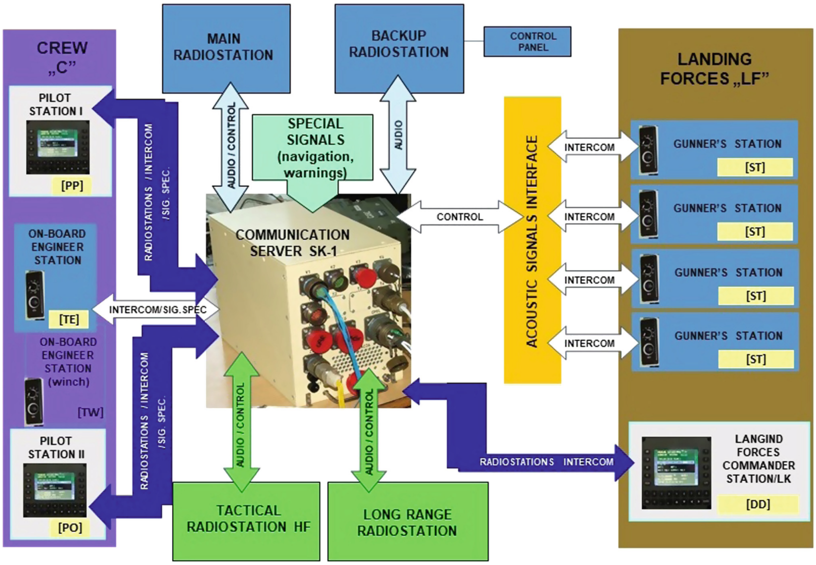

Fig. 1. View of the integrated communication system architecture [8]

The integrated communication system, like modern Western solutions [6, 13], is based on IT technologies and it constitutes an analogy of a computer system based on a digital data exchange bus in accordance with the adopted standard, among others, MIL-1553B (is a military standard the mechanical, electrical, and functional characteristics of a serial data bus.).

The main element of the integrated communication system is a communication server (SK-1), which is the "heart of the system", and it provides the control and management of the on-board radio communication network. It controls the internal and external communication system in the crew circuit, as well as within the crew circuit via communication control panels or multifunction monitors. It provides the helicopter crew with special signals, including disconnectable navigation signals (e.g. marker) and non-disconnectable –warning signals (e.g. dangerous flight altitude) [7, 8, 15].

The integrated communication system is designed to provide the external communication with subscribers outside the helicopter (air traffic control, command posts, army subunits, other aircraft) and internal communication on the helicopter board between the crew members and the troop compartment. The connections are implemented from the designated communication positions without the necessity of replacing the headset–, regardless of the type of the carried-out radio communication. The internal communication system consists of communication positions equipped with the communication control panels and user plates.

The internal communication system provides the crew with the playback of special signals (coming from the transponder systems, radio altimeter), voice signals

Fig. 2. Architectural view of the integrated communication system on *W-3PL* aircraft [8]

(RI65 voice warning system) and signals from navigation devices (VOR/LOC, TACAN, MARKER, ARK/UD/2). The external communication system consists of four air and tactical radios providing the frequency band coverage in the range of 1.6÷400 MHz, the use of which is available from the one selected among three communication control panels and/or multifunction monitors mounted on the boards of *Mi8/Mi17/Mi24 and W-3PL* helicopters (Fig. 2).

The application software, which was developed by AFIT specialists, is implemented on the communication server [8–10].

The communication server elements during operation are subject to ageing, degradation and wear processes. The provision of radio communication and flight safety requires the fulfilment of many design requirements by the communication server, and above all –the appropriate level of its reliability and adequate life and durability [10].

In order to test the application software of individual air and tactical radios, the Integration Station [9, 14], the task of which is to optimise the developed communication systems in terms of their architecture, organisation and detailed management of individual modes of operation (Fig. 3).

Fig. 3. View of the Integration Station of the integrated communication system [8]

3 Determination of Readiness Measures of Aircraft

The determination of readiness measures includes a phase of the identification process and creation of calculation algorithms as well as a phase of measurements and data collection necessary to determine the values of the parameters used in the algorithms [1, 2, 6, 11]. The above-discussed sets of operational states of aircraft and the distinguished states of airworthiness create the states of readiness. The sets of states that allow for the air task performance or operation in the determined time interval are called task readiness states, and those which allow for correct operation at a given moment t are called technical readiness states. The sets of states, which give the opportunity to start the task performance after the set time are the initial readiness states, the sets providing the opportunity to start the task after the set time are known as potential readiness states [5].

The aircraft readiness can be treated as the probability of an event that the aircraft being at the moment t in technical readiness started the implementation of the air task reported at the t after the time $\Delta\Theta$ shorter than Θ, and it will perform the task within the time interval τ, which means:

$$G(t, \Theta, \tau) = K_{t_1} \cdot \mathrm{P}[\Delta\Theta \leq \Theta, \tau] \tag{1}$$

where:

K_{t_1} – technical readiness; $\mathrm{P}[\Delta\Theta \leq \Theta]$ – probability of readiness to perform the air task.

In case of high values $t(t \to \infty)$ the above-described relationship can be presented in the following form:

$$G(\infty, \Theta) = K_{t_1} \left\{ 1 - \exp\left[-\int_0^{\Theta} \lambda(\vartheta) \mathrm{d}\vartheta \right] \right\} \tag{2}$$

where: $\lambda(\vartheta)$ – intensity of changing the readiness states within the time interval $[t, \Theta]$; ϑ – current time for the time interval $\Delta\Theta$.

In the operation process, the aircraft can be in the states of airworthiness or in the states of non-airworthiness. From the states of airworthiness, it is possible to distinguish a subset of the states of airworthiness of the aircraft to perform a given task and a subset of the states of airworthiness to operation in case of the task performance, but without the possibility of its completion. Among the non-airworthiness states of the aircraft to be used, one can distinguish a subset of such states, in which –within the framework of the time reserve, an appropriate maintenance task can be performed, which introduces the aircraft into a subset of usability –the task performance or into the subset of usability states to perform this task [5, 19].

An example can be the state of potential readiness of the aircraft to perform a given air task for the set time reserve, which is included in the set of states of airworthiness and non-airworthiness or in the set of states with the insufficient usability potential for proper operation in order to perform the task.

It is forecasted that within the time reserve, the service position will be started and the service introducing the aircraft into the state of readiness for the air task performance will be implemented [2, 9]. The shorter the time reserve, the higher the degree of readiness. The state of readiness at this reserve is a state of task readiness of the aircraft for a given task.

The operation strategy according to the status of the reliability control level (Eng. Reliability-Centered Maintenance –RCM) is used for systems that are required to have high operational reliability due to flight safety. The research and assessment of reliability within the strategy is conducted with the use of statistical methods for events and computer simulation technology methods, the so-called reliability testing programming. The purpose of using this method is not to ensure the maximum reliability of devices on the aircraft board, but to provide it on such a level that is required by the function implementation by the object under given conditions of the task performance [18].

4 New Operational Readiness Measures for the Complex System

The integrated communication system has various types of the operation modes, with the use of component devices for their implementation. It results in the fact that it can be treated as a complex system having many states of partial usability, which enable the implementation of selected air tasks and missions (Fig. 4).

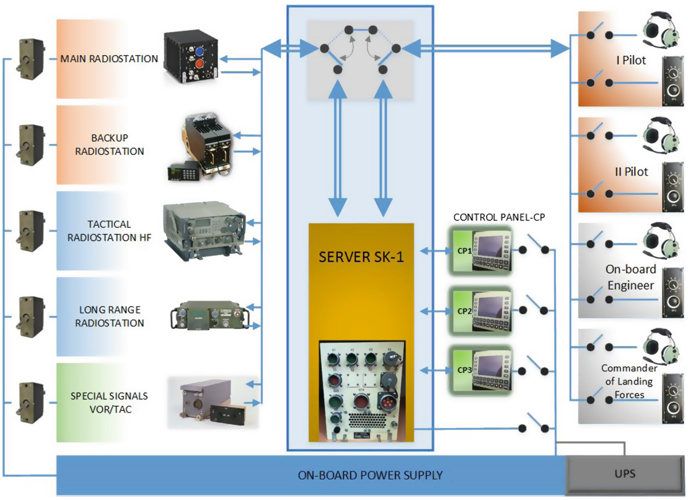

Fig. 4. The operation organisation of the integrated communication system [8]

For example, in order to implement the search and rescue tasks (SAR), the system must have two efficient air radios, however, in combat operations (CSAR), a necessary condition is to provide the covert (coded) air communication. In addition, with the use of troop groups, the aircraft crew must be in contact with the troop compartment in order to transfer commands and supplementary information to the landing group commander and on-board shooters.

4.1 Tasks Performed in Peacetime and the States of Higher Combat Readiness by the Integrated Communication System

In the time of peace (P state), the integrated communication system with an open architecture that allows for mounting both on the military and civil aircraft is provided for the following tasks [8]:

- The SAR rescue mission (complete usability of the system is required, with no use of covert/coded communication);
- Transport of living force (required communication with the troop compartment);
- Freight transport (communication with the troop compartment is not required);
- Air operations in P time (covert/coded communication is not required).

In the event of threat, crisis, catastrophes, natural disasters and war (W state), the integrated communication system is intended for the following tasks [8]:

- CSAR mission (required complete usability of the system, covert/coded communication is used);
- Freight transport (communication with the troop compartment is not required);
- Transport of living force (communication with the troop compartment is required);
- Other air tasks in W time (covert/coded communication is not required).

On the basis of the analysis of the above tasks, it is possible to distinguish the states of usability of the integrated communication system, and hence, several configurations covering a specific set of component devices with the set states of usability, for which the operational readiness, which is required to perform particular tasks included in a set of P time and W time tasks, will be maintained.

The configurations were presented in Table 1.

On the basis of the obtained analyses, it is possible to distinguish the following categories of the tasks implemented by the integrated communication system with many states with reduced usability [8]:

A—category of air tasks possible to be performed by the system, i.e. complete state of usability (all elements of the integrated communication system are efficient);
B—category of air tasks possible to be performed by the integrated communication system, in case, when it is in the state of reduced usability, i.e. one inefficient device managing the operation of the entire system (unfit SK-1);

Table 1. Configurations of a set of component devices with usability states

Configuration of the system	Required composition of the System	Performed task	Probability/period of occurrence
System with SK-1	Integrated communication system	Flight SAR, CSAR	System with SK-1
System without covert/coded communication	Integrated communication system	Freight transport	System without tactical communication
System without tactical communication	Air radio without the integrated communication system	Living force transport	System without SK-1
System without SK-1	Air radio without the integrated communication system	Other air tasks in W time	System without SK-1

C—category of air tasks possible to be performed by the integrated communication system, in case, when it is in the state of reduced usability with one inefficient device of the system (unfit tactical communication radio);
D—category of air tasks possible to be performed by the integrated communication system, in case, when it is in the state of reduced usability with many inefficient component devices of the entire system, i.e. one inefficient device managing the operation of the entire system and one inefficient device of the system (unfit SK-1 and tactical communication radio).

The integrated communication system staying in the category A means that it can perform all the tasks provided for the aircraft, e.g. (SAR, CSAR) with the use of air and tactical communication, a change in the overt and covert communication parameters with the use of the communication control panels, the radio communication with the troop compartment is carried out during the task performance.

The integrated communication system staying in the category B means that it can perform only the tasks provided for the aircraft, which do not require the use of SK-1 server, e.g. task performance with the use of air communication, but without the need to use PSŁ-1 communication control panels (communication parameters are constant or introduced during flight with the use of the backup radio panel).

The integrated communication system staying in the category C means that it can perform only the tasks provided for the aircraft, which do not require the use of the tactical radio, e.g. living force transport, freight transport. The use of the air radio with the necessity of using SK-1 server (management of the system operation and recording of messages) and the communication control panels (change in radio parameters and radio frequency ranges during the task performance).

The integrated communication system staying in the category D means that it can perform only the tasks provided for the aircraft, which do not require the use of SK-1 server and the tactical radio, e.g. task performance with the use of a backup air radio, without the need to use the communication control panels (communication parameters are constant or introduced during flight with the use of the radio control panel).

4.2 Applied Operational Readiness Measures in the States of Higher Combat Readiness

In the available specialist and standardisation literature [20–23], the mathematical relationship describing the determination of the operational readiness coefficient of the system with the use of the probabilities of staying in only one of two possible states: in the state of usability or in the state of unfitness, are available [16].

For a system (or device composed of many elements) with one state of usability, the operational readiness is specified in the following form [19]:

$$G(t,\tau) = G_F(t) \cdot G_Z(\tau) = K_g(t) \cdot R(\tau) \tag{3}$$

where: $G(t,\tau)$ – operational readiness of the system determined for the selected moment of time t and the selected time interval of the task duration τ; $G_F(t)$ – functional readiness of the system determined for the selected moment of time t; $G_Z(\tau)$ –

task readiness of the system determined for the selected time interval of the task duration τ; $K_g(t)$ functional readiness coefficient; $R(\tau)$ – system reliability function determined for the selected time interval of the task duration τ.

For a system (or device composed of many elements) with one state of usability, the functional readiness coefficient can be determined in the form of the probability or time of staying in the state of usability in relation to the total probability or time of the system staying in the states of usability and unfitness [19]:

$$G_F(t) = K_g(t) = \frac{p_Z(t)}{p_Z(t) + p_N(t)} \text{ lub } G_F(t) = K_g(t) = \frac{T_Z(t)}{T_Z(t) + T_N(t)} \tag{4}$$

where: $p_Z(t)$ – probability of the system staying in the state of usability in the selected moment t;

$p_N(t)$ – probability of the system staying in the state of unfitness in the selected moment t; $T_Z(t)$ – average time of the system staying in the state of usability to the selected moment t; $T_N(t)$ – average time of the system staying in the state of unfitness to the selected moment t.

The data needed to determine the time of staying in individual operational states are obtained from IT systems (data base of the Integration Station of the Integrated Communication System of the Avionics Division of AFIT) or paper records kept by aviation units, which use the integrated communication system.

For a system (or device composed of many elements) with one state of usability, the task readiness coefficient can be determined on the basis of knowledge of the reliability function determined for the time interval of the task performance [19]:

$$G_Z(\tau) = R(\tau) = e^{-\lambda \cdot \tau} \tag{5}$$

where: λ – intensity of the system damage determined on the basis of the operational data or determined at the design stage (within the framework of the implementation of the adopted reliability management strategy).

On the basis of the above, the operational readiness of the system can be determined in the following form [19]:

$$G(t, \tau) = K_g(t) \cdot R(\tau) = \frac{p_Z(t)}{p_Z(t) + p_N(t)} \cdot e^{-\lambda \cdot \tau} \tag{6}$$

Example:
For the data, determined on the basis of the analysis, collected in the IT system of the Integration Station of the Integrated Communication System, for the integrated communication system operated in *Mi8/Mi17/Mi24* helicopters, analysed as a set of three components connected in series in the reliability chain (SK-1 server, tactical radio and the so-called core of the system including other devices, among others, communication control panels, headphones, microphones, user plates), the following was adopted:

- The functional readiness coefficient of the system in the state of complete usability is: $K_g = 0.900$;

- The reliability function coefficient of the system in the state of complete usability is: $R(\tau) = 0.729$

hence, the calculated operational readiness is:

$$G(t,\tau) = K_g(t) \cdot R(\tau) = 0,900 \cdot 0,729 = 0,656 \tag{7}$$

The operational readiness of the system (or device), determined in the above manner, with one state of usability specifies the probability of the event that the integrated communication system will be usable at a given time t and that it will maintain this usability during the task performance with the selected time interval τ.

4.3 New Operational Readiness Measures in the States of Higher Combat Readiness

A new approach to determining the operational readiness measures is based on an attempt of using the current standard-sanctioned description of the class of devices of the integrated communication system, operating in many states with reduced usability. It applies both to one device and the entire system, which consists of many devices, i.e. with one state of usability or many states of usability [3, 19].

The proposed new measures relate to the system description (or device composed of many elements), which in addition to the state of complete usability, where all its elements are efficient, can stay in one of the states of reduced usability, which allows the performance of the selected tasks, for which all elements of the system are not required to be in the state of its usability.

For the system (or device composed of many elements) with many states of usability (complete and reduced usability), the functional readiness coefficient can be determined in the form of probability or time of staying in the state of usability in relation to the joint probability of time of the system staying in the states of usability and unfitness:

$$K_g(t) = \frac{\sum_{i=1}^{i=M} p_{Zi}(t)}{\sum_{i=1}^{i=M} p_{Zi}(t) + \sum_{i=1}^{i=M} p_{Ni}(t)} \quad \text{lub} \quad K_g(t) = \frac{\sum_{i=1}^{i=M} T_{Zi}(t)}{\sum_{i=1}^{i=M} T_{Zi}(t) + \sum_{i=1}^{i=M} T_{Ni}(t)} \tag{8}$$

where:

$\sum_{i=1}^{i=M} p_{Zi}(t)$ – the sum of probabilities of the system staying in the states of complete and reduced usability at a given time t; $\sum_{i=1}^{i=M} p_{Ni}(t)$ – the sum of probabilities of the system staying in the states of unfitness at a given time t; $\sum_{i=1}^{i=M} T_{Zi}(t)$ – the sum of average times of the system staying in the states of complete and reduced usability at a given time t; $\sum_{i=1}^{i=M} T_{Ni}(t)$ – the sum of probabilities of the system staying in the states of unfitness to a given time t.

The above relationship can be presented in a detailed form showing individual probabilities of the system (or device composed of many elements) staying in the state of complete usability and in the states of reduced usability:

$$K_g(t) = \frac{p_{Z1}(t) + p_{Z2}(t) + \ldots + p_{ZM}(t)}{\sum_{i=1}^{i=M} p_Z(t) + \sum_{i=1}^{i=M} p_N(t)} \tag{9}$$

where: $p_{Z1}(t)$ – probability of the system staying in the *1st* state of usability (complete usability); $p_{Z2}(t)$ – probability of the system staying in the *2nd* state of usability (reduced usability); $p_{ZM}(t)$ – probability of the system staying in the M state of usability (reduced usability), which can be then written as separate components of the sum in the following form:

$$K_g(t) = \frac{p_{Z1}(t)}{\sum_{i=1}^{i=M} p_Z(t) + \sum_{i=1}^{i=M} p_N(t)} + \frac{p_{Z2}(t)}{\sum_{i=1}^{i=M} p_Z(t) + \sum_{i=1}^{i=M} p_N(t)} + \ldots + \frac{p_{ZM}(t)}{\sum_{i=1}^{i=M} p_Z(t) + \sum_{i=1}^{i=M} p_N(t)} \tag{10}$$

On the basis of the analysis of the above relationship, it can be concluded that the readiness coefficient for the system (or device composed of many elements) with many states of usability (complete and reduced usability) can be presented as the sum of component coefficients:

$$K_g(t) = K_{g1}(t) + K_{g2}(t) + \ldots + K_{gM}(t) \tag{11}$$

where:

$K_{g1}(t)$ – readiness coefficient of the system staying in the *1st* state of usability (complete usability); $K_{g2}(t)$ – readiness coefficient of the system staying in the *2nd* state of usability (reduced usability); $K_{gM}(t)$ – readiness coefficient of the system staying in the M state of usability (reduced usability).

$$K_g(t) = \sum_{i=1}^{i=M} K_{gi}(t) \tag{12}$$

In order to emphasise the significance of the states of usability, the operational readiness coefficient can be presented in the form dependent on the weight of the partial operational readiness coefficient:

$$K_g^*(t) = W_1 \cdot K_{g1}(t) + W_2 \cdot K_{g2}(t) + \ldots + W_M \cdot K_{gM}(t) \tag{13}$$

where: W_1 – weight of the readiness coefficient of the system staying in the *1st* state of usability (complete usability); W_2 – weight of the readiness coefficient of the system staying in the $2nd$ state of usability (reduced usability); W_M – weight of the readiness coefficient of the system staying in the M state of usability (reduced usability), which can be written in the following form:

$$K_g^*(t) = \sum_{i=1}^{i=M} W_i \cdot K_{gi}(t) \tag{14}$$

The functional readiness coefficient measures in the modified version can be written in the following form: for the weight $W_1 = 1$ and other weights $W_2 \div W_M = 0$.

Then, the new measure adopts the form of the functional readiness coefficient, previously used for the system staying only in the state of complete usability.

The measures for the functional readiness coefficient of the system with many states of reduced usability can be written in the form of a matrix:

$$\begin{bmatrix} K_{g1}^*(t) \\ K_{g2}^*(t) \\ \cdots \\ K_{gM}^*(t) \end{bmatrix} = \begin{bmatrix} K_{g1}(t) & 0 & \cdots & 0 \\ 0 & K_{g2}(t) & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & K_{gM}(t) \end{bmatrix} x \begin{bmatrix} W_1 \\ W_2 \\ \cdots \\ W_M \end{bmatrix} \tag{15}$$

then, the operational readiness can be presented in the matrix form:

$$\begin{bmatrix} G_{11}(t,\tau) \\ G_{12}(t,\tau) \\ \cdots \\ G_{1M}(t,\tau) \end{bmatrix} = \begin{bmatrix} K_{g1}(t) & 0 & \cdots & 0 \\ K_{g1}(t) & K_{g2}(t) & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ K_{g1}(t) & K_{g2}(t) & \cdots & K_{gM}(t) \end{bmatrix} x \begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ \cdots \\ R_{1M}(\tau) \end{bmatrix} \tag{16}$$

The operational readiness determined for the system with many states and reduced usability presented in the matrix form allows to assess the use of the system in aerial operations, for which the usability of all component elements of the system is not required.

For these elements, the matrix record allows to determine the required reliability value for the complex operational readiness value. The reliability levels can be determined with the use of a matrix of the operational readiness coefficients after its reversal (matrix reversibility condition must be met), which can be presented in the following form:

$$\begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ \cdots \\ R_{1M}(\tau) \end{bmatrix} = \begin{bmatrix} K_{g1}(t) & 0 & \cdots & 0 \\ K_{g1}(t) & K_{g2}(t) & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ K_{g1}(t) & K_{g2}(t) & \cdots & K_{gM}(t) \end{bmatrix}^{-1} x \begin{bmatrix} G_{11}(t,\tau) \\ G_{12}(t,\tau) \\ \cdots \\ G_{1M}(t,\tau) \end{bmatrix} \tag{17}$$

The determination of the required reliability values allows to specify its level at the design stage or at the operational stage (by introducing correction changes, i.e.

replacement of elements with reduced reliability into elements with reliability determined in the above manner. The new measures may constitute a tool for supporting the operation process according to the strategy with controlled reliability [2, 5, 6, 18].

Example:
For the data, determined on the basis of the analysis, collected in the IT system of the Integration Station of the Integrated Communication System, for the integrated communication system operated in *Mi8/Mi17/Mi24* helicopters, analysed as a set of three components connected in series in the reliability chain (SK-1 server, tactical radio and the so-called core of the system including other devices, among others, communication control panels, headphones, microphones, user plates), the following was adopted:

- The functional readiness coefficient of the system in the state of complete usability is: $K_g = K_{g1} = 0.900$, and in case of reduced usability, it is: $K_{g2} = 0.050$; $K_{g3} = 0.030$; $K_{g4} = 0.010$;
- The reliability function coefficient of the system in the state of complete usability is: $R(\tau) = R_{11}(\tau) = 0.729$, and in case of reduced usability, it is: $R_{12}(\tau) = 0.810$; $R_{13}(\tau) = 0.810$; $R_{14}(\tau) = 0.900$

thus, the calculated operational readiness of the system in the state of complete usability is:

$$G(t,\tau) = K_g(t) \cdot R(\tau) = 0,900 \cdot 0,729 = 0,656 \tag{18}$$

The use of the new measure allows to present the operational readiness of the integrated communication system staying in many states of reduced usability in the following form:

$$\begin{bmatrix} G_{11}(t,\tau) \\ G_{12}(t,\tau) \\ G_{13}(t,\tau) \\ G_{14}(t,\tau) \end{bmatrix} = \begin{bmatrix} K_{g1}(t) & 0 & 0 & 0 \\ K_{g1}(t) & K_{g2}(t) & 0 & 0 \\ K_{g1}(t) & K_{g2}(t) & K_{g3}(t) & 0 \\ K_{g1}(t) & K_{g2}(t) & K_{g3}(t) & K_{g4}(t) \end{bmatrix} x \begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ R_{13}(\tau) \\ R_{14}(\tau) \end{bmatrix} \tag{19}$$

where: $G_{11}(t,\tau)$ – operational readiness of the system staying in the state of complete usability (all elements are usable); $G_{12}(t,\tau)$ – operational readiness of the system staying in the state of reduced usability (unfit SK-1 server); $G_{13}(t,\tau)$ – operational readiness of the system staying in the state of reduced usability (unfit tactical radio); $G_{14}(t,\tau)$ – operational readiness of the system staying in the state of reduced usability (unfit SK-1 server and tactical radio).

For the adopted values of the functional readiness coefficient and reliability determined on the basis of the data obtained from the IT system of the Integration Station of the Integrated Communication System, the operational readiness values of the system were obtained with the use of the following relationship (19):

$$\begin{bmatrix} G_{11}(t,\tau) \\ G_{12}(t,\tau) \\ G_{13}(t,\tau) \\ G_{14}(t,\tau) \end{bmatrix} = \begin{bmatrix} 0,656 \\ 0,697 \\ 0,721 \\ 0,730 \end{bmatrix} = \begin{bmatrix} 0,900 & 0 & 0 & 0 \\ 0,900 & 0,050 & 0 & 0 \\ 0,900 & 0,050 & 0,030 & 0 \\ 0,900 & 0,050 & 0,030 & 0,010 \end{bmatrix} x \begin{bmatrix} 0,729 \\ 0,810 \\ 0,810 \\ 0,900 \end{bmatrix} \tag{20}$$

The new measures also allow to implement a reverse process consisting in determining the necessary reliability level of components at the set operational readiness of the system.

The values of the required reliability of individual configurations for the adopted operational readiness level of the system (70% in the state of complete usability, 80% in the state of reduced usability without SK-1 server and the tactical radio), can be determined with the use of the relationship (17) and presented in the matrix form:

$$\begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ R_{13}(\tau) \\ R_{14}(\tau) \end{bmatrix} = \begin{bmatrix} 0,778 \\ 0,900 \\ 0,900 \\ 0,900 \end{bmatrix} = \begin{bmatrix} 0,900 & 0 & 0 & 0 \\ 0,900 & 0,050 & 0 & 0 \\ 0,900 & 0,050 & 0,030 & 0 \\ 0,900 & 0,050 & 0,030 & 0,010 \end{bmatrix}^{-1} x \begin{bmatrix} 0,700 \\ 0,745 \\ 0,772 \\ 0,800 \end{bmatrix} \tag{21}$$

For the increased requirements in the field of the reliability values for the adopted operational readiness level of the system (70% in the state of complete usability, 85% in the state of reduced usability without SK-1 server and the tactical radio), the reliability level values of individual elements of the system can be determined with the use of the relationship (17) and presented in the matrix form:

$$\begin{bmatrix} R_{11}(\tau) \\ R_{12}(\tau) \\ R_{13}(\tau) \\ R_{14}(\tau) \end{bmatrix} = \begin{bmatrix} 0,833 \\ 0,900 \\ 0,900 \\ 1,000 \end{bmatrix} = \begin{bmatrix} 0,900 & 0 & 0 & 0 \\ 0,900 & 0,050 & 0 & 0 \\ 0,900 & 0,050 & 0,030 & 0 \\ 0,900 & 0,050 & 0,030 & 0,010 \end{bmatrix}^{-1} x \begin{bmatrix} 0,750 \\ 0,795 \\ 0,822 \\ 0,850 \end{bmatrix} \tag{22}$$

On the basis of the analysis of the obtained results, it can be stated that in order to obtain the operational readiness at the level of 75% (0.750) for the system in the state of complete usability and 85% (0.850) for the system in the state of reduced usability (without SK-1 server and the tactical radio) should be completely usable (not damaged).

The obtained results indicate the achievement of limit reliability values and they can be used for assessing the operation process with the adopted strategy for managing their reliability.

5 Conclusion

In the military aviation, the proposed new measures can be used in the reliability management strategy for operation of aviation systems in the crisis states. However, it requires additional analytical and verification work that is currently conducted in AFIT. Every aircraft, even older generation ones, after installing of a modern communications system shall expand its performance capabilities with previously unavailable applications, which is why the design of such a system in terms of hardware, i.e., purchasing equipment, does not currently present much of a problem, whereas, developing adequate, efficient and reliable software, which meets the requirements in the scope of ensuring internal and external communication on-board an aircraft, is a big challenge. Such a task was attempted by the AFIT, which was the first in Poland to perform integration on modernized helicopters of the Land Forces Command. The possession of such a station allowed AFIT to integrate new radio-electronic equipment while modernizing a W3PL helicopter. An integrated communications system is operated on Mi8/Mi17/Mi24 and W3PL helicopters, which performed combat tasks, i.a., for PKW (Polish Military Contingent) in Iraq and Afghanistan. The target task for an integrated communications system is obtaining a fully functional version on-board an aircraft. Optimizing the elements of an integrated communication system at an integration station is always limited relative to the organization of a system on-board an aircraft. Nonetheless, it allows testing a series of solutions, which are too expensive to be implemented on-board an aircraft for research purposes. One of the main tasks of such optimization is to achieve high operating capability of the constructed equipment.

Improvement and optimization of the operating process of integrated communications systems requires new evaluation methods and IT systems supporting the decision-making process in the scope of defining and shaping the operating readiness.

The data accumulated in the system allows the determination of the intervals between failures, damage intensities and the damage probability distributions, and on that basis, factors characterizing the operating capability of individual elements of a ZSŁ system. The constructed model enables current evaluation and forming of the operating capability of an SK-1 communication server, which is the main component of a ZSŁ system. The proposed new measures for determining the operational readiness for the integrated communication system with many states of reduced usability, and the developed method of analysis can be used in the reliability management strategy for rational (scientific) operation of the on-board aviation systems.

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