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AVIATION SAFETY AND IMPACT ON THE RELIABILITY OF DATA FROM DIFFERENT SOURCES OF PHYSICAL SIZES

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Abstract

One of the most effective methods for increasing the flight safety of modern and promising aircraft is to increase the amount and reliability of information to on-board control systems. Basically, this refers to ensuring high reliability of data obtained from various sources of physical quantities. An analysis of the main types of information redundancy has been performed to achieve more efficient and fault-tolerant information structures in aircraft management systems.

Introduction

The efficiency of aircraft functional systems and aircraft safety depends to a large extent on the reliability of information on the ongoing process. This applies both to information on the processes taking place on board the aircraft and to the processes taking place in the environment and affecting the flight of the aircraft. All this diverse information is reported in different information sensors and enters the on-board computers of the aircraft. The information is then processed and used to control and manage the flight parameters.

The use of on-board computers to control complex and dynamic flight processes allows information to be processed simultaneously from many real-time information sources. At the same time, this allows the information to be distributed to different users (actuators). In performing these functions, on-board computers perform a series of extremely important operations:

- periodically asks the sensors for their condition and for the measured values of the controlled parameters;
- determine the true values of the measured values according to the readings of the sensors;
- recognizes or detects occurred events;
- produces control signals for regulation and control of complex systems and devices;

- develops feedback to ensure adaptive optimal management;
- performs statistical processing of the information and its storage for the predetermined period of time (for example, until the end of the flight).

Effective and high-quality process management in functional systems during the flight requires reliable information, which is usually difficult to learn due to the presence of interference or errors in information sources, unreliable sensors and more.

Study area

The physical nature of the operation of an information system with real signal sensors shows that it can be in one of three random and incompatible states [1, 2]: a – probability of true message (true state message); b – probability of reporting a "false state"; d – probability of "skipping" the condition (not to detect deviation from the normal parameters of the controlled condition).

Such a system with probability states is sufficiently complete and accurately described by a trinomial distribution [3, 4], which is an extended binomial distribution.

The probability that from the ***n***-source of information ***k*** of them will miss messages, $(m-k)$ in number will report a „false" message, and $(n-m)$ in number will be described by the following distribution [3,4]:

(1) $$P_{(n-m,m-k,k)} = C_n^{n-m} a^{n-m} C_m^{m-k} b^{m-k} d^k,$$

where C_n^{n-m} is the number of combinations of n by (n – m), as well as:

(2) $$a + b + d = 1.$$

The probability characteristics a_n, b_n, d_n for n-number of parallel sources of information as follows [2–4]:

(3) $$\begin{cases} a_{n,1} = 1 - (1 - a)^n; \\ b_{n,1} = (1 - a)^n - d^n; \\ d_{n,1} = d^n. \end{cases}$$

If a request signal is sent periodically (during a certain time interval) to the same source of information and the information received by it is stored and stored, then according to Bayes' Theorem [2–4], then at given probabilistic characteristics of the sources of information (as stated above): probability a for a reliable message; probability b for false message and probability d for not detecting the condition, then with a priori probability α, the a posteriori probabilities can be determined for: P_{1B} - for reliable message, P_{2B} - for not detecting the controlled state and P_{3B} - for message for "false state", as follows:

$$
(4) \qquad \begin{cases} P_{1B} = \frac{\alpha.a}{\alpha.a+(1-\alpha a)b}; \\ P_{2B} = \frac{\alpha.a}{(1-\alpha)a+\alpha.d}; \\ P_{3B} = \frac{(1-\alpha)b}{\alpha.a+(1-\alpha)b}. \end{cases}
$$

The concept of coefficient of precedence in the controlled state can be introduced and denoted by $\beta = \frac{1-\alpha}{\alpha}$, assuming that $b = d$, it is possible to introduce another coefficient - the quality of the source of information γ, which will take values $\gamma = \frac{b}{a} = \frac{d}{a}$, then the posteriori probabilities P_{1B}, P_{2B} и P_{3B} after k- number of repeated consecutive queries to the same source of information can be defined as:

$$
(5) \qquad \begin{cases} P_{1B}(k) = \frac{1}{1+\beta\gamma^k}; \\ P_{2B}(k) = \frac{\beta\gamma^k}{1+\beta\gamma^k}; \\ P_{3B}(k) = \frac{\gamma^k}{\beta+\gamma^k}. \end{cases}
$$

To perform a comparative assessment of the effectiveness of sequential and parallel information redundancy, consisting in reducing the probabilities P_{2B} and P_{3B} depending on the number of consecutive queries- k to the same source of information and n-number of parallel sources of information. In such a case, coefficients may be introduced to take into account the impact of another request to reduce the likelihood of receiving a “false information” response to the condition or the likelihood of “missing” the condition (not to deviate from normal parameters controlled state) upon sequential reservation and, respectively, to be designated as $N_{b\text{A}}$ and $N_{d\text{A}}$. In this order, similar coefficients can be introduced for parallel reductions, denoted as $N_{b\text{A}}$ and $N_{d\text{A}}$. The values of the entered coefficients can be determined by the expressions determining the probability of answer for “false information” about the condition and for “skipping” the condition in the next $(k-1)$ and k-query to the source of information, respectively, at $(n-1)$ and n-th inclusion of the source of information [5]. As a result of such a number of operations and transformations the following expressions are obtained:

$$
(6) \qquad \begin{cases} N_{bB} = \frac{1+\beta\gamma^k}{\gamma(1+\beta\gamma^{k-1})}; \\ N_{bA} = \frac{(1-a)^{n-1}-d^{n-1}}{(1-a)^n-d^n}; \\ N_{dB} = \frac{\beta+\gamma^k}{(\beta+\gamma^{k-1})\gamma}; \\ N_{dA} = \frac{d^{n-1}}{d^n} = \frac{1}{d}. \end{cases}
$$

With high quality of the information source, when the order of values of $\gamma \to 0$, and increasing the values of k-number of consecutive queries of one information source, and n-number of parallel connected information sources, the following can be entered coefficients $\widetilde{N}x_{bB}, \widetilde{N}x_{bA}, \widetilde{N}x_{dA}, \widetilde{N}x_{dB}$, which are determined by (6). At the same time, these coefficients are asymptotically reduced to the following simple dependences (7):

$$(7) \qquad \begin{cases} \widetilde{N}_{bB} = \lim\limits_{k\to\infty} N_{bB} = \frac{1}{\gamma}; \\ \widetilde{N}_{bA} = \lim\limits_{k\to\infty} N_{bA} = \frac{1}{1-\alpha}; \\ \widetilde{N}_{dB} = \lim\limits_{k\to\infty} N_{dB} = \frac{1}{\gamma}; \\ \widetilde{N}_{dA} = N_{bA} = \frac{1}{d}. \end{cases}$$

When performing the majority attribute, for example at $Q = 2$ (which shows how many sources of information signal "yes"), the coefficients N_{bA2} and N_{dA2} to reduce the probability P_3 for reporting "false" state and the probability P_2 for not detecting the controlled state of the parallel information system, which consists of the $(n-1)$ source of information, with the inclusion of another additional source can be determined as follows:

$$(8) \qquad \begin{cases} N_{bA2} = \frac{P_3(2,n-1)}{P_3(2,n)} = \frac{(1-a)^{(n-1)} - d^{(n-1)} - (n-1)bd^{(n-2)}}{(1-a)^n - d^n - nbd^{(n-1)}}; \\ N_{dA2} = \frac{P_2(2,n-1)}{P_2(2,n)} = \frac{d^{(n-1)} + (n-1)bd^{(n-2)} + (n-1)ad^{(n-2)}}{d^n + nbd^{(n-1)} + nad^{(n-1)}}. \end{cases}$$

Based on the expressions in (6), (7) and (8), coefficients $D_{bA}, D_{dA}, D_{bB}, D_{dB}$ can be entered to reduce the probabilities P_3 and P_2, respectively, to provide information about the "false" state and not to detect of the controlled state at parallel and at consecutive reservation of the information for known, set values of k-number of consecutive inquiries and n-number of parallel connected information source. These coefficients are determined by the following expressions:

$$(9) \qquad \begin{cases} D_{bA} = \prod_{i=1}^{n} \frac{(1-a)^{(i-1)} - d^{(i-1)}}{(1-a)^i - d^i}; \\ D_{dA} = \frac{1}{d^n}; \\ D_{bB} = \prod_{i=1}^{k} \frac{1+\beta\gamma^i}{[1+\beta\gamma^{(i-1)}]\gamma}; \\ D_{dB} = D_{dB} = \prod_{i=1}^{k} \frac{\beta+\gamma^i}{[\beta+\gamma^{(i-1)}]\gamma}. \end{cases}$$

From this follow several conclusions. First of all, consistent reservation makes it possible to significantly reduce the likelihood of reporting false information by incurring acceptable economic and technical costs. On the other hand, the application of this method of reservation is limited by the time of “obsolescence” of information and correlations in case of accidental failures, in which the technical devices resume their work without the intervention of an operator or other technical device. The method of sequential information reservation is widely used in modern aircraft equipped with several on-board computers [6]. Consecutive information reservation is extremely effective in setting optimal criteria for confirming the authenticity of the message in cases where the m-number of possible (expected) messages received k in number and, assuming, for example, that k is equal to half of m, then the probability of submitting information about a “false” state and not detecting the controlled state will be equal. If the value of k is small enough, the probability of reporting “false” condition will be increased. If the value of k tends to the value of m, the probability of “skipping” the state will increase (not to deviate from the normal parameters of the controlled state).

Secondly, the parallel reservation of information significantly reduces the likelihood of “skipping” the condition (not to deviate from the normal parameters of the controlled state) and has little effect on reducing the likelihood of submitting information about “false” state. The application of the principle of majority logic allows reducing the likelihood of information with a “false” state, but at the same time requires an increase in the number of parallel channels, which in turn is associated with certain economic constraints.

Thirdly, the combined application of parallel and sequential redundancy allows to effectively reduce both the probability of information with a “false” state and the probability of “skipping” the state (not to deviate from the normal parameters of the controlled state) [7].

Using the approximate values of the coefficients $\widetilde{N}x_{bB}$, $\widetilde{N}x_{bA}$, $\widetilde{N}x_{dB}$ and $\widetilde{N}x_{dA}$, which are determined by (7) and (9), the following dependences can be written:

$$\begin{cases} \widetilde{D}_{bA} = \frac{1}{(1-a)^n}; \\ \widetilde{D}_{dA} = \frac{1}{d^n}; \\ \widetilde{D}_{bB} = \frac{1}{\gamma^k}; \\ \widetilde{D}_{dB} = \frac{1}{\gamma^k}. \end{cases} \quad (10)$$

Based on this expression, the value of k-number of consecutive queries to one source of information and n-number of parallel information channels can be determined, if the requirements of $\widetilde{D}_{bA}$, $\widetilde{D}_{dA}$, $\widetilde{D}_{bB}$ and $\widetilde{D}_{dB}$ to reduce the probability P_3 of submitting information about a “false” state and P_2 to “miss” the state, respectively, in parallel and sequential redundancy. The values of these probabilities can be determined as follows:

$$
(11) \quad \begin{cases} n_{bA} > -\frac{lnD_{bA}}{ln(1-a)}; \\ K_{bB} > -\frac{lnD_{dB}}{ln\gamma}; \\ n_{dA} > -\frac{lnD_{dA}}{lnd}; \\ K_{dB} > -\frac{lnD_{dB}}{ln\chi}. \end{cases}
$$

With the help of the above mathematical expressions, a number of practical problems can be solved. For example, consider controlling a fast-paced process. The speed of the process allows using no more than k number of consecutive queries to one source of information. In this case, the reduction of $\widetilde{D}_{bB}$ and $\widetilde{D}_{dB}$, obtained by expressions (10), can provide unsatisfactory values, and it can be conditioned that these probabilities be reduced, respectively, not less than Y and Z times. Then the minimum number of parallel sources n can be determined to ensure that the requirements of Y and Z are met, according to the expressions [3, 7]:

$$
(12) \quad \begin{cases} n_{bA} > -\frac{lnY - lnD_{bB}}{ln(1-a)}; \\ n_{dA} > -\frac{\ln Z - lnD_{dB}}{lnd}. \end{cases}
$$

Naturally, the larger of the numbers n_{bA} and n_{dA} must be chosen to meet the requirements. Tables 1, 2, 3 and 4 present matrices that characterize the total reduction coefficients calculated by formulas (9). It should be noted that the number of columns corresponds to the number k of consecutive queries to the same source, and the number of rows determines the number n of parallel sources of information. In each cell of the matrix there is a reduction factor determined for the number of consecutive queries for the corresponding column number and for the number of parallel connected sources corresponding to the row number. For better clarity, the results obtained in the calculations are presented in decimal form.

Table 1. Factors to reduce the probability of submission of "false" state information determined from input data: α=0,9; β=1; b=d=0,05

$\frac{k}{n}$	1	2	3	4	$\frac{k}{n}$	1	2	3	4
1	1	13,28	232,1	4139,3	1	-	1	2	3
2	12,39	105,73	1755	29274,3	2	-	2	3	4
3	57,42	906,1	15050	250885,4	3	1	2	3	5
4	609	8426,5	139965	2333208,2	4	2	3	5	6

Table 2. Coefficients for reducing the probability of "missing" a change in the observed condition, determined from baseline data: α=0,9; β=1; b=d=0,05

$\frac{k}{n}$	1	2	3	4	$\frac{k}{n}$	1	2	3	4
1	1	13,28	232,1	4139,3	-	-	1	2	3
2	15	315,6	5242,2	87388	1	-	2	3	4
3	300	6312	1048442	1747721,5	2	1	3	5	6
4	6000	126240	2096846,4	34954429,5	3	2	5	6	7

Table 3. Coefficients for reducing the probability of reporting "false" status, determined from baseline data: α=0,9; β=9; b=d=0,05

$\frac{k}{n}$	1	2	3	4	$\frac{k}{n}$	1	2	3	4
1	1	11,17	190,7	3007,4	-	-	1	2	3
2	6,7	74,8	1210,9	20149,3	-	-	1	3	4
3	57,42	641,4	10377,6	172682,4	1	1	2	4	5
4	609	5964,8	96510,1	1605928,7	2	2	3	4	6

Table 4. Coefficients for reducing the probability of "missing" a change in the observed condition, determined from baseline data α=0,9; β=9; b=d=0,05

$\frac{k}{n}$	1	2	3	4	$\frac{k}{n}$	1	2	3	4
1	1	16,56	276,1	4601,8	-	-	1	2	3
2	15	331,2	5521,1	92036,8	1	-	2	3	4
3	300	6624	110422,1	1840736	2	1	3	5	6
4	6000	132480	2208441,6	36814721,5	3	2	5	6	7

From the results presented in Table 1, 2, 3 and 4, the following conclusions can be drawn:

1. The values of the a priori probabilities have a negligible influence on the increase of the reliability of the information by increasing the number of consecutive inquiries to the sensors of the system.

2. The combined parallel-sequential redundancy system simultaneously reduces the likelihood of “skipping” the state (not deviating from the normal parameters of the controlled state) and providing information about a “false” state. More effective in this case is the effect on reducing the likelihood of “missing” the condition.

3. The set coefficients for reducing the probability of “missing” the condition and the probability of submitting information about a “false” condition can be provided in two ways: either by increasing the number of consecutive queries with a given number of parallel sources, or by increasing the number of parallel sources at a given number of consecutive queries.

The probability of a complete group of events [2,8,9] in parallel-sequential reservation is determined as follows:

$$P_{1B}(1-P_{1A}) + P_{1A}(1-P_{1B}) + P_{1A}P_{1B} + (1-P_{1A})(1-P_{1B}) = 1, \tag{13}$$

where P_{1A} and P_{1B} are the probabilities of true message, respectively, only for parallel and only for sequential reservation of the information system. From formula (13) the probability P_{1C} can be determined in case of parallel-consecutive information reservation of the system:

$$P_{1C} = 1 - (1-P_{1A})(1-P_{1B}), \tag{14}$$

where

$$\begin{cases} P_{1A} = 1-(1-a)^n; \\ P_{1B} = \frac{1}{1+\gamma^k}; \\ \gamma = \frac{1-a}{a}. \end{cases} \tag{15}$$

Substituting (15) into (14) after a series of transformations, the following dependence can be obtained:

$$P_{1C} = 1 - (1-a)^n \frac{(1-a)^k}{a^k+(1-a)^k}. \tag{16}$$

From the expression in (16) after some transformations we can get:

$$(1-a)^n = \frac{(1-P_{1C})[a^k+(1-a)^k]}{(1-a)^k}. \tag{17}$$

After logarithm of (17), the final expression can be determined to obtain the dependence $n(k)$ for the number of parallel sources of information from the number of consecutive queries k:

(18) $$n(k) = \frac{ln(1-P_{1C}) + ln[a^k + (1-a)^k] - k ln(1-a)}{ln(1-a)}.$$

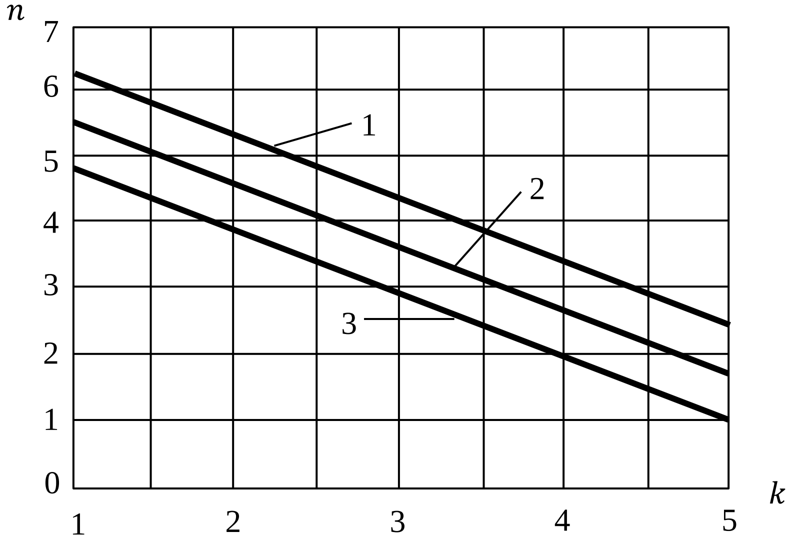

Fig. 1. Nomogram for the dependence $n(k)$ in case of parallel-consecutive reservation of information systems

Fig. 1 shows a nomogram based on the results of (18) with the following initial data: $k = 1, 2, 3, 4$ and 5; $a = 0{,}97$. The required probability P_{1C} for a true message in case of joint parallel-sequential reservation in the information system is presented in three variants: the first (1) $P_{1C} = 1 - 10^{-7}$, the second (2) $P_{1C} = 1 - 10^{-8}$ and the third (3) $P_{1C} = 1 - 10^{-9}$.

Thus, in accordance with the initial data of the nomogram, the required amount of n from parallel connected sources of information can be determined graphically at a given number k of consecutive incoming information (inquiries) from one source and, conversely, by a given number n the required number of consecutive queries can be determined from the parallel connected sources to ensure the required probability of P_{1C} in a system with parallel-sequential data reservation. To ensure the required probability P_{1C} by increasing the number of consecutive incoming data (inquiries), the number of parallel sources of information can be reduced. Similarly, as the number of n-parallel sources increases, the number k of consecutive queries can be reduced.

In the general case, the reliability of the information received from the individual sources of information, which determines the probabilities a, b and d, can be increased in two ways:

- by increasing the number n of information sources, increasing the probability P_{1n} of detecting and correctly recognizing the status of the controlled trait and, respectively, reducing the probabilities P_{3n} and P_{2n} of reporting false information and “miss” this state in a system of n-parallel sources of information;

- if k-number of inquiries are addressed to the same source of information in a certain time interval, it is obvious that the probability P_{1k} for the correct recognition of the state of the controlled feature after k-number of inquiries will also increase, and the probability P_{3n} for submitting information about the “false” state and P_{2k} about the probability of “missing” this state (not being detected), respectively, decrease.

It is also necessary to take into account the real limitations of the implementation of the two ways to increase the reliability of information. For the first of them, the increase in costs (by mass, financial, etc.) imposes certain restrictions related to increasing the amount of n sources of information. For the second method, the limitation is the time for “aging” (loss of relevance) of the information due to the extreme speed of the managed processes. The correlation between accidental short-term interruptions in work or self-correcting technical failures in the requested information source also has an impact. This should not exceed the time interval between two separate queries to the same information system sensor.

It can be argued that in the specific situation there are reservations for both n - in parallel reservation and k - in sequential reservation, which can significantly increase the reliability of information.

Conclusion

The method of parallel backup of information significantly reduces the likelihood of “missing” (not detecting) the observed condition and to a much lesser extent has the effect of reducing the likelihood of submitting information about a “false” condition. The application of the principles of majority logic allows reducing the likelihood of information with a “false” state of the information system, but to obtain this it is necessary to increase the number of parallel channels, which is associated with economic constraints.

The combined application of parallel and sequential redundancy allows to effectively reduce both the probability of a “false” state of the system and the probability of “missing” (not detecting) the observed state at minimal additional cost.

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АВИАЦИОННАТА БЕЗОПАСНОСТ И ВЛИЯНИЕ НА ДОСТОВЕРНОСТТА НА ДАННИТЕ ОТ РАЗЛИЧНИ ИЗТОЧНИЦИ НА ФИЗИЧНИ ВЕЛИЧИНИ

Н. Загорски

Резюме

Един от най-ефективните методи за повишаване на безопасността на полета на съвременните и перспективни въздухоплавателни средства е повишаване на количеството и достоверността на информацията към бордовите системи за управление. Основно това се отнася до осигуряването на висока надеждност на данните, получавани от различни източници на физични величини. Извършен е анализ на основните видове информационно резервиране за постигане на по-ефикасни и по-устойчиви на откази информационни структури в системите за управление на въздухоплавателни средства.