UDC 656.7.071: 656.7.052.002.5 (045)
DOI: 10.18372/1990-5548.57.13227

[1]O. V. Solomentsev,
[2]M. Yu. Zaliskyi,
[3]T. S. Herasymenko

RADIO ELECTRONIC EQUIPMENT FAILURES MODEL

[1,2,3]Aviation Radio Electronic Complexes Department, National Aviation University, Kyiv, Ukraine
E-mails: [1]avsolomentsev@ukr.net, [2]maximus2812@ukr.net, [3]milusga@meta.ua

Abstract*—The article deals with the problem of radio electronic equipment failures model building. The model adequacy checking is performed according to the simulation results. The simulation problem is associated with the case when failures can be described by two-dimensional probability density function. This distribution corresponds to the event when whole radio electronic equipment failure occurs only in case of simultaneous failures of two structural units of the system. The article concentrates on two methods for exponential correlated field formation. The analytical expression for two-dimensional probability density function for correlated failures is presented in the article. The modeling results can be used during the design of operation strategy according to the condition with diagnostic variables control to determine the optimal time interval for preventive maintenance action realization*.

Index Terms—Radio electronic equipment; operation system; statistical data processing; failure mode; processing model; condition-based maintenance.

I. INTRODUCTION

Radio electronic equipment (REE) in civil aviation is used to ensure the safety and regularity of flights. In general case, REE consists of communication, navigation and surveillance devices. Each of these devices contains electronics units, software and sometimes mechatronic units. During REE operation failures can occur. These failures reasons are associated with radio electronic equipment wear, degradation process of electronic and mechatronic elementary components, power supply voltage instability, wrong actions of maintenance staff, etc.

To provide REE operation efficiency we can use the operation system (OS). In general, OS is the system of systems. The aim of OS is the formation of timely control and preventive actions regarding the operation object to ensure its serviceable condition [1], [2]. The OS consists of an operation object (REE), documentation, resources, maintenance staff, processes, etc.

II. LITERATURE ANALYSIS

Literature analysis shows that basic process during REE operation is data processing. Procedures of data processing can use measured variables concerning useful information [3] – [5] and reliability parameters [6] – [8]. In case of reliability parameters processing, researchers try to solve two problems: detection and parameters estimation. Detection problems are associated with the analysis of processes during radio system condition deterioration. Estimation problems aim is to develop efficient algorithms for reliability indices (mean time to failure, availability factor, etc.) evaluation [9].

The data processing procedures are often developed at the design stage. Experience of REE intended use shows that not enough attention is paid to the problems of operation systems design. Attempts of methodological basis formation for solving operation systems design problem were made in [10].

In general, reliability data processing during equipment operation is basis for timely decision making. For example, one of the ways to do it can be obtained on the multi-optional basis [11].

So it can be concluded that the REE operation efficiency depends on the quality of reliability data processing algorithms.

III PROBLEM STATEMENT

The aim of data processing algorithms $\vec{A}$ is reducing uncertainty during REE operation. It should be noted, that the reduction of uncertainty contributes to the operation system efficiency E increasing. In general case, operation system efficiency is a function

$$E = f\,(y(t_0),\ z(t,t_0,p(t),\vec{A}),x(t)) \,,$$

where $p(t)$ is a trend of parameters under control in OS, t_0 is an initial time, $y(t_0)$ is a function that describes OS mathematical model at the initial time, $x(t)$ are input influences that characterizes operation conditions, $z(t,t_0,p(t),\vec{A})$ is a vector of influences for OS.

If trend $p(t)$ describes reliability indexes, researchers often consider the one-dimensional case with one parameter under control (e.g., times between failures of the whole system). But more difficult cases exist, when $p(t)$ determines n-dimensional vector. This situation is typical for the radio electronic system that includes several subsystems, and the failure of each subsystem separately doesn't affect on the whole system serviceability. A non-serviceable condition occurs when all subsystems fail. In addition, failures of individual subsystems are correlated. In this paper, we consider the case when the serviceable condition of REE is determined by its two subsystems conditions.

Data processing algorithms $\vec{A}$ are necessary to synthesize in such a way that

$$f(y(t_0), z(t,t_0,p(t),\vec{A}), x(t)) \to \text{maximum}.$$

So this paper deals with the first step of data processing algorithms design associated with the simulation of correlated failures that described by the two-dimensional exponential distribution.

III. Correlated Failures Modeling and Analysis

Let us consider REE as two unit system. If one of these units breaks down, then another unit operates in a more loaded condition, but whole system condition is serviceable. Dependence between failures of two subsystems is characterized by the correlation coefficient r.

For one unit systems, exponential distribution is often used to describe times between failures of radio equipment. For two unit systems, the distributions are more complicated. Analysis of different distributions for such situation was presented in paper [12]. According to [12] we can use:

– Gumbel's bivariate exponential distribution;
– Hougaard's bivariate exponential distribution;
– Downton's bivariate exponential distribution;
– Arnold and Strauss' bivariate exponential distribution;
– Freund's bivariate exponential distribution;
– Marshall and Olkin's bivariate exponential distribution.

System reliability evaluation in case of bivariate exponential and bivariate normal distributions was considered in [13].

It should be noted, that multivariate exponential probability density function can be generated from correlated Gaussian random variables [14]. Example of correlated Gaussian random variables formation was considered in [15].

Let us consider the problem of samples with two-dimensional exponential distribution $f(x,y)$ generation.

The first approach consists of four steps and is shown in Fig. 1.

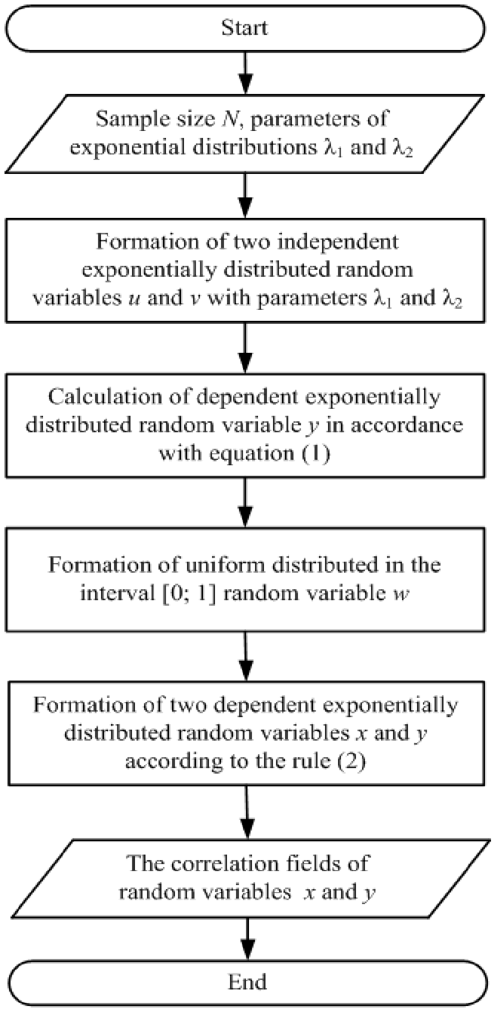


Fig. 1. The first approach for the generation of samples with two-dimensional exponential distribution

The samples in Fig. 1 are generated in accordance with the equations:

$$s_i = ru_i + \sqrt{1-r^2}v_i, \ i \in [1; N]. \quad (1)$$

$$x_i = \begin{cases} s_i, \text{ if } w_i < 0.5, \\ u_i, \text{if } w_i \geq 0.5. \end{cases} \quad y_i = \begin{cases} u_i, \text{ if } w_i < 0.5, \\ s_i, \text{if } w_i \geq 0.5. \end{cases} \quad (2)$$

Let us analyze the simulation results according to this approach.

The correlation field of random variables u and s for initial parameters $\lambda_1 = \lambda_2 = 1$, $N = 10000$, $r = 0.5$ is shown in Fig. 2.

The correlation fields of random variables x and y for initial parameters $\lambda_1 = \lambda_2 = 1$, $N = 10000$ and different correlation coefficients are shown in Fig. 3.

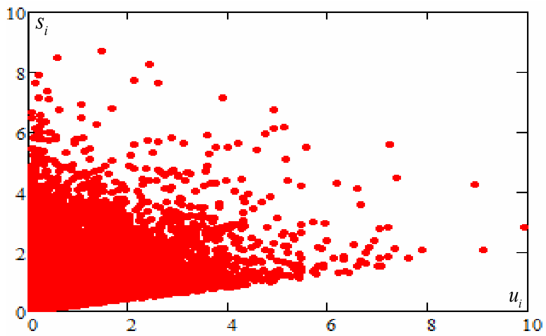
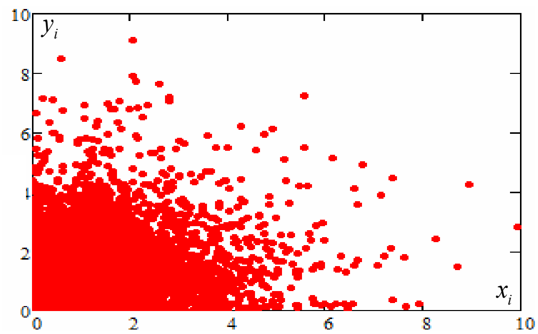
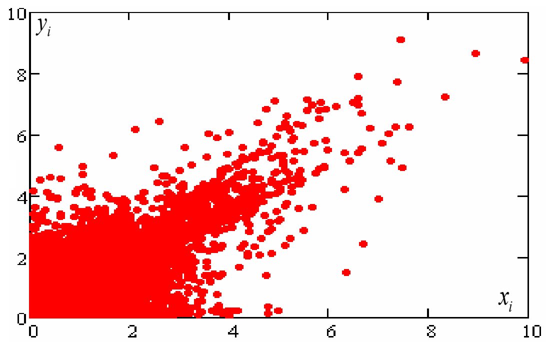


Fig. 2. Examples of correlation field of random variables u and s

The correlation coefficient for random variables u and s in this particular case is equal to 0.512. But there aren't points below the line $s = ru$ on the Fig. 1. To eliminate this disadvantage we used step 3 and 4 in this approach of samples generation. The correlation coefficient for random variables x and y is equal to 0.201 and 0.740 (for Fig. 3a and b).



(a)

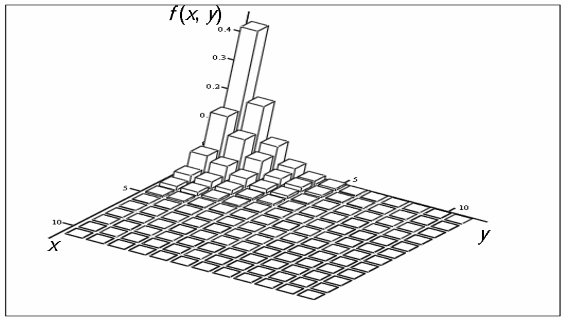


(b)

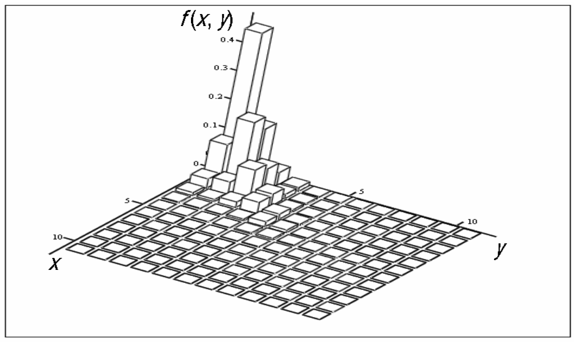
Fig. 3. Examples of correlation field of random variables x and y: (a) $r = 0.2$; (b) $r = 0.8$

Simulation results for the wide range of initial data showed that for the first approach of correlated failures formation deviation of required and obtained correlation coefficient is approximately 10 percent (in the case when $\lambda_1 = \lambda_2$).

The probability density functions for simulation results (presented in Fig. 3) are shown in Fig. 4.



(a)



(b)

Fig. 4. Probability density functions of correlated exponentially distributed random variables: (a) $r = 0.2$; (b) $r = 0.8$

Analysis of probability density functions curves gives us the possibility to conclude that correlation coefficient increasing leads to probability density increasing for plots when $y = x$. The decrease of probability density along the line $y = x$ is characterized by an exponential law.

According to this conclusion to describe such correlation fields, we can use Marshall and Olkin's bivariate exponential distribution. This distribution has the following probability density function [16]

$$f(x,y) = \begin{cases} \lambda_1(\lambda_2+\lambda_3)e^{-\lambda_1 x-(\lambda_2+\lambda_3)y}, \text{ if } x < y, \\ \lambda_2(\lambda_1+\lambda_3)e^{-\lambda_2 y-(\lambda_1+\lambda_3)x}, \text{ if } x > y, \\ \lambda_3 e^{-(\lambda_1+\lambda_2+\lambda_3)x}, \text{ if } x = y, \end{cases}$$

where $x \ge 0$, $y \ge 0$, $\lambda_1 > 0$, $\lambda_2 > 0$, $\lambda_3 > 0$. In this equation λ_3 is a parameter that depends on the correlation coefficient. According to [16] correlation coefficient is equal to

$$r = \frac{\lambda_3}{\lambda_1+\lambda_2+\lambda_3}.$$

So

$$\lambda_3 = \frac{(\lambda_1+\lambda_2)r}{1-r}.$$

The second approach consists of four steps and is shown in Fig. 5.

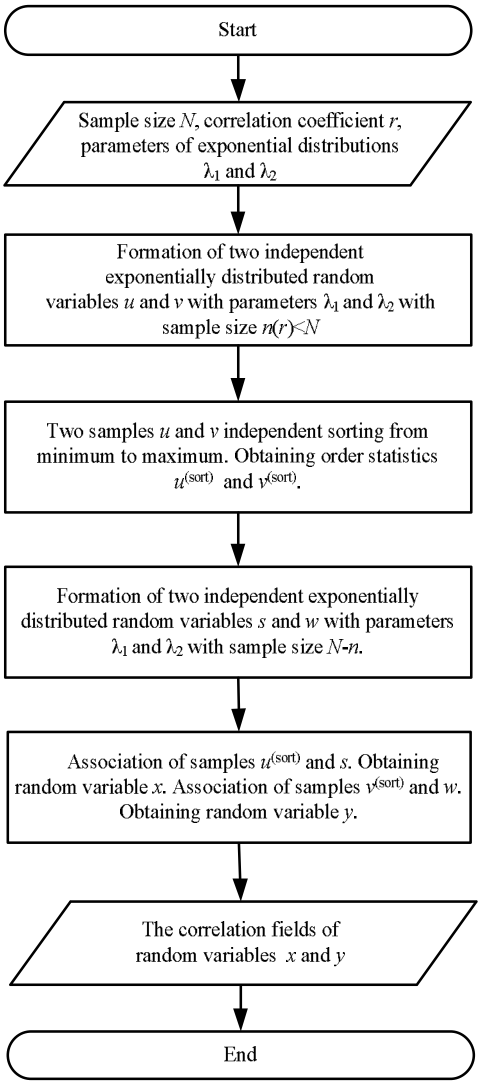


Fig. 5. The second approach for generation of samples with two-dimensional exponential distribution

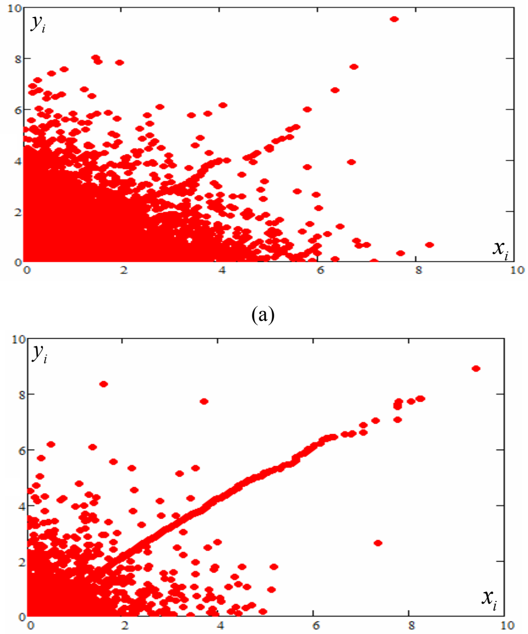
The correlation fields of random variables x and y for initial parameters $\lambda_1 = \lambda_2 = 1$, $N = 10000$ and different correlation coefficients are shown in Fig. 6.

Probability density functions for simulation results (presented in Fig. 6) are shown in Fig. 7.

Comparison of correlation fields presented in Fig. 2 and 4 shows that in case of the first method for correlated random variables modeling the points at x0y plane more scattered. In the case of the second method usage, the points are aligned along a straight line $y = x$. With the increase of correlation coefficient value, the number of points along this line increases.

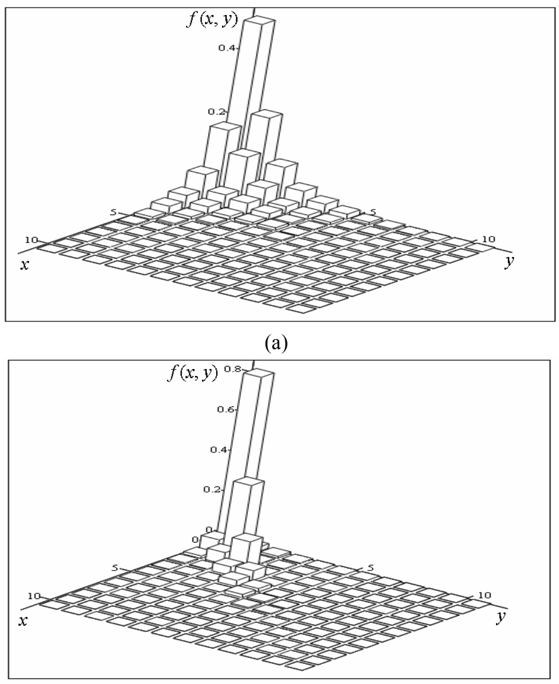
The nature of probability density functions (Fig. 5) is the same as for the first method. So to describe probability density function we can use Marshall and Olkin's model.

The first and second approaches of correlated samples modeling can be used during data processing algorithms design in OS of REE.



(a) (b)

Fig. 6. Examples of correlation field of random variables x and y: a) $r = 0.1$; b) $r = 0.9$



(a) (b)

Fig. 7. Probability density functions of correlated exponentially distributed random variables: (a) $r = 0.1$; (b) $r = 0.9$

VI. Conclusion

Two methods for correlated exponentially distributed random variables generation were considered. Such variables describe failures occurrence in two unit radio electronic system. Two-dimensional probability density function according to Marshall and Olkin's bivariate exponential distribution is the most acceptable for such data description. Correlated variables modeling was performed for the possibility of testing various data processing algorithms by simulating them using the Monte–Carlo method.

The obtained results can be used during design and improvement of statistical data processing algorithms for radio electronic system OS.

REFERENCES

[1] B. S. Dhillon, Maintainability, maintenance, and reliability for engineers. New York: Taylor & Francis Group, 2006, 214 p.

[2] R. E. Barlow and F. Proschan, Mathematical Theory of Reliability. New York: John Wiley and Sons, 1965, 256 p.

[3] V. Sineglazov and S. Shildskyi, "Navigation systems based on GSM," *IEEE 3rd International Conference on Methods and Systems of Navigation and Motion Control (MSNMC)*, October 14-17, 2014, Proceedings, 2014, pp. 95–98.

[4] V. Sineglazov, "Data processing in landmarks navigation system," *IEEE 3rd International Conference on Methods and Systems of Navigation and Motion Control (MSNMC)*, October 14-17, 2014, Proceedings, 2014, pp. 82–85.

[5] O. A. Sushchenko and V. O. Golitsyn, "Data processing system for altitude navigation sensor," *IEEE 4th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC)*, October 18-20, 2016, Proceedings, 2016, pp. 84–87.

[6] O. Solomentsev, M. Zaliskyi, Yu. Nemyrovets, and M. Asanov, "Signal processing in case of radio equipment technical state deterioration," *Signal Processing Symposium 2015 (SPS 2015), Proceedings*, June 10-12, 2015 (Debe, Poland), pp. 1–5.

[7] O. Solomentsev, M. Zaliskyi, O. Kozhokhina, and T. Herasymenko, "Efficiency of Data Processing for UAV Operation System," *IEEE 4th International Conference on Actual Problems of UAV Developments (APUAVD)*, October 17-19, 2017, Proceedings, 2017, pp. 27–31.

[8] O. V. Solomentsev, M. U. Zaliskyi, M. M. Asanov, and O. V. Zuiev, "Data processing in operation system of unmanned aerial vehicles radioelectronic equipment," *IEEE 2nd International Conference on Actual Problems of Unmanned Air Vehicles Developments (APUAVD)*, October 15-17, 2013, Proceedings, 2013, pp. 77–80.

[9] O. Solomentsev, M. Zaliskyi, and O. Zuiev, "Estimation of quality parameters in the radio flight support operational system," *Aviation*, 2016, vol. 20, no. 3, pp. 123–128.

[10] O. V. Solomentsev, V. H. Melkumyan, M. Yu. Zaliskyi, and M. M. Asanov, "UAV operation system designing," *IEEE 3rd International Conference on Actual Problems of Unmanned Air Vehicles Developments (APUAVD)*, October 13-15, 2015, Proceedings, 2015, pp. 95–98.

[11] A. V. Goncharenko, "Optimal UAV maintenance periodicity obtained on the multi-optional basis," *IEEE 4th International Conference on Actual Problems of Unmanned Air Vehicles Developments (APUAVD)*, October 17-19, 2017, Proceedings, pp. 65–68.

[12] S. Nadarajah and S. Kotz, "Reliability for some bivariate exponential distributions," *Mathematical Problems in Engineering*, vol. 2006, pp. 1–14.

[13] H. Sarper and P. R. Chacon, "The reliability of correlated two unit systems," *Annual Reliability and Maintainability Symposium*, January 23-26, pp. 422–427, 2006.

[14] R. K. Mallik, "On multivariate Rayleigh and exponential distributions," *IEEE Transactions on Information Theory*, vol. 49, Issue 6, 2003, pp. 1499–1515.

[15] I. G. Prokopenko, S. V. Migel, and K. I. Prokopenko, "Signal modeling for the efficient target detection tasks," *International Radar Symposium (IRS)*, June 19-21, 2013, Proceedings, vol. II, pp. 976–982.

[16] A. W. Marshall and I. Olkin, A multivariate exponential distribution. Boeing scientific research laboratories document D1-82-0505, 1966, 41 p.

Received April 16, 2018.

Solomentsev Oleksandr. Doctor of Engineering Science. Professor.
Aviation Radio Electronic Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Civil Aviation Engineers Institute, Kyiv, Ukraine, (1972).
Research area: operation system, maintenance, statistical data processing, radio engineering equipment.
Publications: 210.
E-mail: avsolomentsev@ukr.net

Zaliskyi Maksym. Candidate of Science (Engineering).
Aviation Radio Electronic Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2007).
Research area: operation system, maintenance, statistical data processing, radio engineering equipment.
Publications: 95.
E-mail: maximus2812@ukr.net

Herasymenko Tetyana. Post-graduate student.
Aviation Radio Electronic Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2014).
Research area: maintenance, statistical data processing, radio engineering equipment.
Publications: 20.
E-mail: milusga@meta.ua

О. В. Соломенцев, М. Ю. Заліський, Т. С. Герасименко. Модель відмов радіоелектронного обладнання
В статті розглянуто задачу побудови моделі відмов радіоелектронного обладнання. Перевірка адекватності моделі виконується відповідно до результатів моделювання. Під час моделювання використовувалась двовимірна щільність розподілу імовірності напрацювань до відмови. Цей розподіл відповідає події, коли відмова всього радіоелектронного обладнання відбувається лише у випадку одночасних відмов двох структурних одиниць системи. Наведено два методи моделювання експоненціального корельованого поля. Отримано аналітичний вираз для двовимірної щільності розподілу імовірності корельованих відмов. Результати моделювання можна використовувати у випадку розробки стратегії технічного обслуговування за станом з контролем визначальних параметрів для визначення оптимального інтервалу часу для реалізації превентивних дій.
Ключові слова: радіоелектронне обладнання; система експлуатації; статистична обробка даних; модель відмов; модель обробки даних; технічне обслуговування за станом.

Соломенцев Олександр Васильович. Доктор технічних наук. Професор.
Кафедра авіаційних радіоелектронних комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Київський інститут інженерів цивільної авіації, Київ, Україна, (1972).
Напрям наукової діяльності: системи експлуатації, обробка статистичних даних, радіоелектронне обладнання.
Кількість публікацій: 210.
E-mail: avsolomentsev@ukr.net

Заліський Максим Юрійович. Кандидат технічних наук.
Кафедра авіаційних радіоелектронних комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, (2007).
Напрям наукової діяльності: системи експлуатації, обробка статистичних даних, радіоелектронне обладнання.
Кількість публікацій: 95.
E-mail: maximus2812@ukr.net

Герасименко Тетяна Сергіївна. Аспірант.
Кафедра авіаційних радіоелектронних комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, (2014).
Напрям наукової діяльності: системи експлуатації, обробка статистичних даних, радіоелектронне обладнання.
Кількість публікацій: 20.
E-mail: milusga@meta.ua

А. В. Соломенцев, М. Ю Залисский, Т. С. Герасименко. Модель отказов радиоэлектронного оборудования
В статье рассмотрена задача построения модели отказов радиоэлектронного оборудования. Проверка адекватности модели выполняется на основе результатов моделирования. При моделировании использовалась двумерная плотность распределения вероятностей наработок до отказа. Это распределение соответствует событию, когда отказ всего радиоэлектронного оборудования происходит только в случае одновременных отказов двух структурных единиц системы. Приведены два метода формирования экспоненциального коррелированного поля. Получено аналитическое выражение для двумерной плотности распределения вероятности коррелированных отказов. Результаты моделирования можно использовать в случае разработки стратегии технического обслуживания по состоянию с контролем определяющих параметров для определения оптимального интервала времени для реализации превентивных действий.
Ключевые слова: радиоэлектронное оборудование; система эксплуатации; статистическая обработка данных; модель отказов; модель обработки данных; техническое обслуживание по состоянию.

Соломенцев Александр Васильевич. Доктор технических наук. Профессор.
Кафедра авиационных радиоэлектронных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Киевский институт инженеров гражданской авиации, Киев, Украина, (1972).
Направление научной деятельности: системы эксплуатации; обработка статистических данных; радиоэлектронное оборудование.
Количество публикаций: 210.
E-mail: avsolomentsev@ukr.net

Залисский Максим Юрьевич. Кандидат технических наук.
Кафедра авиационных радиоэлектронных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина, (2007).
Направление научной деятельности: системы эксплуатации, обработка статистических данных, радиоэлектронное оборудование.
Количество публикаций: 95.
E-mail: maximus2812@ukr.net

Герасименко Татьяна Сергеевна. Аспирант.
Кафедра авиационных радиоэлектронных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина, (2014).
Направление научной деятельности: системы эксплуатации, обработка статистических данных, радиоэлектронное оборудование.
Количество публикаций: 20.
E-mail: milusga@meta.ua