Journal of Contemporary Issues in Business and Government Vol. 27, No. 2, 2021
https://cibg.org.au/

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2021.27.02.180

Model for determining the efficiency of operation of modularly distributed systems of aircraft considering cost factors and uncertainty factors

GORELOV BORIS ALEKSEEVICH[1], BURDINA ANNA ANATOLYEVNA[2], DAVYDOV ALEXEY DMITRIEVICH[3], KALOSHINA MARINA NIKOLAEVNA[4], BONDARENKO ANNA VIKTOROVNA[5]

[1]PhD, docent, Department of Innovative Economics, Finance and Project Management Moscow Aviation Institute (National Research University). Moscow. Russia.
[2]Doctor of Economics. Professor. Department of Innovative Economics, Finance and Project Management Moscow Aviation Institute (National Research University). Moscow. Russia.
[3]PhD, docent, Department of Innovative Economics, Finance and Project Management, Moscow Aviation Institute (National Research University). Moscow. Russia.
[4]PhD, docent, Department of Innovative Economics, Finance and Project Management Moscow Aviation Institute (National Research University). Moscow. Russia.
[5]PhD in Economics. Senior lecturer. Moscow Aviation Institute (National Research University). Moscow. Russia.
Email:annaburdina555@mail.ru[1],annaburdina555@mail.ru[2],annaburdina555@mail.ru[3],annaburdina555@mail.ru[4], annachem@mail.ru[5]

Abstract: The study examines modularly distributed systems using the example of unmanned aerial vehicles (UAVs). It is determined that UAVs are divided into three main classes: strategic, tactical and special purpose. The concept of the efficiency of operation of modularly distributed systems of aviation technology is introduced, considering the factors of uncertainty and cost. In comparison with the manned aircraft, there are emphasized the properties and advantages of the UAV. The scenario of joint use of UAVs has been substantiated. A model is being developed for determining the required number of UAVs in a group based on preliminary information regarding the tactical situation in the group's area of operations; the estimated number and nature of targets located in the target area and other parameters. A probabilistic model for analyzing the effectiveness of the actions of a group of modularly distributed systems of aircraft, considering the cost factors and uncertainty in extinguishing forest fires, is proposed.

Keywords: aeronautical engineering (AT), modularly distributed systems, unmanned aerial vehicles (UAVs), efficiency of UAV group actions, probability of UAV loss, probability of successful completion of a UAV mission.

INTRODUCTION

By modularly distributed systems we mean systems for which the ratios of the locations of elements (or groups of elements) play an essential role from the point of view of the functioning of the system, and, therefore, from the point of view of analysis and synthesis of the system [1]. The study of world trends in the development of unmanned aerial vehicles as distributed systems, the prospects for their group use confirms the feasibility of using UAVs in the interests of solving target problems, in particular, for extinguishing forest fires.

The whole variety of existing and developed unmanned aerial vehicles (UAVs) is subdivided into three main classes: strategic: high-altitude long flight duration (HALE) 24-48 hours, maximum take-off weight, 12000 kg, range of more than 2000 km. Tactical: Medium range (MR) 6-10 hours, maximum takeoff weight, 1250 kg, range over 150 km. Medium-range and long-duration flight (MRE) 10-18 hours, maximum take-off weight 1250 kg, range over 500 km. et al [1,2]. And also a special purpose UAV. Each class has a more detailed gradation: by size, range, duration and altitude of flight, as well as by the nature of use. The study of existing and prospective UAVs allows us to consider UAVs as an effective tool for solving various target tasks, for example, extinguishing forest fires. Table 1, the properties of UAVs are highlighted in comparison with manned aircraft [2,9].

Table 1

UAV properties	**Advantages of UAVs over manned**
Autonomy	- the ability to carry out continuous monitoring of target objects; - reduction of the required number of aircraft for loitering in the target area; - no dependence on crew fatigue; - reduction in the cost of completing target tasks.
Lack of crew	- the ability to perform target tasks associated with an unacceptable load on the pilot; - the ability to perform target tasks in conditions of radiation contamination; - significantly lower cost of the UAV compared to the submarine; - no problems caused by crew fatigue; - reduction of requirements for the power of the power plant. - no costs for crew training; elimination of costly tests to ensure the safety of the crew.
Automation of all onboard operations	simplification of the on-board control system in comparison with manned aircraft
UAV groups organization	- the ability to quickly rebuild within the loitering zone; - ample opportunities for monitoring and diagnosing the external environment
Low-altitude flight capability	- improving the accuracy of diagnostics when performing target tasks; - the ability to act in the vicinity of target objects

As follows from the table. 1, one of the most important qualities of UAVs, which allows us to consider them as an effective alternative to manned vehicles, is the autonomy of the flight mission. Significant efforts of the developers of aviation unmanned vehicles are directed, first of all, to the development of this particular quality of UAVs. Progress in the development of unmanned aviation is associated with the creation of UAVs with a level of autonomy for performing target tasks comparable to manned aircraft. Another important quality of the UAV is the ability to automatically perform target tasks without the participation of the crew.
The aim of the study is to develop a probabilistic model for analyzing the effectiveness of the actions of a group of modularly distributed systems of aircraft, considering the cost factors and uncertainty in extinguishing forest fires.

LITERATURE REVIEW.
According to domestic and foreign researchers, the advantage of using groups of UAVs is most manifested in detection operations. The properties and advantages of UAVs in comparison with manned ones are highlighted [1, 2, 5, 9]. However, the authors do not propose methods for assessing the efficiency of the operation of UAV groups, taking into account uncertainty and cost factors. Technologies for determining the required number of UAVs in a group based on preliminary information regarding the tactical situation in the group's area of operations are not offered; the estimated number and nature of targets located in the target area, the cost of the operation and other parameters.

MATERIALS AND METHODS
The study assumes that it is advisable to use a group of UAVs to detect and eliminate fire places in forests in a given area. Their presence can be established during the movement of the UAV using the radar and optical-electronic means available on board. At the same time, we believe that in the area of targeted use of a group of UAVs, there may be zones that are closed for flight due to weather conditions, the location of which is known at the stage of pre-flight planning. Thus, the scenario of joint use of UAVs for extinguishing forest fires has been substantiated.

The provision of UAV group actions in the operation of detecting fire extinguishing, the efficiency of operation of modularly distributed AT systems, taking into account uncertainty factors, begins with the stage of pre-flight planning, which is implemented by means of control.
The purpose of pre-flight planning is:
1. Determination of the number of UAVs in the group based on:
- preliminary information on the tactical situation about forest fires in the area of operations of the group;
- the estimated number and nature of forest fires located in the target area;
- the level of potential sources of threat;
- presence / absence of zones closed for overflight, for example, due to meteorological conditions;
- the composition and characteristics of optoelectronic equipment located on board the UAV
2. Determination of the composition of the means necessary for extinguishing forest fires located on the UAV.
3. Laying routes for the UAV.
4. Determination of the type and optimal parameters of the formation (speed, heading angle, flight altitude, intervals and distances between UAVs) in the process of UAV movement to the area of application [1,3].
As a result of pre-flight planning, flight tasks are formed for each UAV in the group. After the group leaves the area of targeted use, the transition to the stage of search, diagnosis of complexity and subsequent elimination of forest fires takes place. For this, the target area of the group is divided into non-overlapping areas, called execution zones, and each UAV provides search and detection of targets in its own execution zone.
Determination of the number of executive zones, their size and assignment for each UAV occurs at the stage of pre-flight planning in such a way as to best (in accordance with the criterion) solve the task of eliminating forest fires in the sector. It is assumed that the UAV is equipped with an autopilot, which ensures its loitering in the executive zone. In the process of loitering with the use of optoelectronic means and other means located on board the UAV, forest fires are detected and eliminated. Information about the state of each UAV, the coordinates of the detected forest fires, is transmitted to all members of the group via information exchange channels. It is assumed that the capacity of these channels is sufficient to provide information interaction between UAVs in a group in real time.
Taking into account the possibility of UAV loss during the search stage, either as a result of onboard equipment failures, or as a result of forest fire suppression, it is possible to promptly correct the organizational structure of the group in such a way that the best (in terms of the selected criteria) way to ensure the fulfillment of the task of search and diagnostics assigned to the group complexity and extinguishing of forest fires.
After the elimination of forest fires on board each UAV in the group, routes are calculated for returning to the area where the group is assembled for subsequent movement to the home airfield.
The study shows the need to implement a scenario of UAV group actions to eliminate forest fires. However, the feasibility of implementing such a scenario requires obtaining preliminary estimates of the effectiveness of joint UAV actions within the framework of the scenario under consideration and determining the requirements for the composition and characteristics of the UAV, under which the maximum effect can be expected.
It is obvious that an accurate assessment of the effectiveness of the UAV group's actions in extinguishing forest fires within the framework of the scenario under consideration can be obtained using a set of mathematical models that most adequately describe the space-time state of all UAVs, the conditions and results of the use of extinguishing means, interference environment, scale, degree of complexity fire. Evaluation of the efficiency of operation of modularly distributed AT systems, namely the actions of the UAV group in the search operation, diagnostics of complexity and extinguishing forest fires, must be carried out taking into account the factors of uncertainty and the cost of the operation. It is necessary to develop a model that allows, with acceptable accuracy, to quickly obtain probabilistic estimates of the effectiveness of UAV group actions, taking into account the number of UAVs involved, the capabilities of diagnostic tools and fire suppression located on their sides [3,8].
When developing a model for analyzing the effectiveness of the actions of a group of modularly distributed AT systems, taking into account the cost factors and uncertainty when extinguishing forest fires, we will assume that the group is formed by N similar UAVs that search for and possible liquidation of forest fires in a given area of target application. At the same time, we believe that all UAVs in the group operate independently of each other. In other words, the possibility of coordinating the actions of the group within the framework of the model considered below is not taken into account. Each UAV patrols in the target area until a forest fire is detected. Having found a target, the UAV identifies it (determines the degree of ignition, complexity) and makes a decision on elimination, if possible by the forces of a specific UAV, after which its participation in the operation ends. Otherwise, the UAV informs the control body about the impossibility of liquidation, due to the large area of destruction, the complexity of liquidation. We assume that there is preliminary information about the number of NC ignition points concentrated in the area of the UAV's target application.
Since the described scheme of actions of a group of modularly distributed AT systems during extinguishing forest fires does not take into account the possibility of coordinating the actions of UAVs, the estimates of the

group's effectiveness presented below can be considered as estimates "from below" corresponding to the most unfavorable, in terms of the expected effect, option of joint use of UAVs for liquidation fires.
Let us formalize the probabilistic model for assessing the effectiveness of the actions of a group of modularly distributed AT systems, taking into account the cost factors and uncertainty when extinguishing UAV forest fires, taking into account the assumptions:
1) the duration of time t1, during which the UAV remains operational, is assumed to be a random variable having an exponential distribution with a known probability density function [2,7]

$$p(t_1) = \theta exp(-\theta t_1), \quad (1)$$

$\theta = \frac{1}{\bar{t}_1}$, $\bar{t}_1 = M[t_1]$ - the average time, assumed by the given, during which the UAV used to extinguish the fire remains operational. We believe that the UAV loses its performance either due to failures of on-board equipment or as a result of difficult flight conditions. Thus, the value $\bar{t}_1$ depends on the reliability of the UAV onboard equipment and the presence of potential threat sources.
2) the length of time $\mathbf{t_2}$ required for identification, diagnostics of the complexity of a detected forest fire, as a potential target for elimination, and making a decision to eliminate the fire by forces of a specific UAV. The duration $\mathbf{t_2}$ is an integral characteristic of the optoelectronic surveillance equipment and the onboard computer installed on the UAV. We assume that the duration $\mathbf{t_2}$ is a random variable with an exponential distribution with a probability density function:

$$p(t_2) = \lambda exp(-\lambda t_2), \quad (2)$$

$\lambda = \frac{1}{\bar{t}_2}$, $\bar{t}_2 = M[t_2]$ - the average time, assumed to be specified, during which the UAV identifies a detected forest fire, taking into account the degree of ignition, as a target for elimination. As mentioned above, this time depends on the characteristics of the optoelectronic surveillance equipment used on board the UAV and the power of computing facilities, the amount of means for extinguishing a fire.
3) the duration of the elimination of the fire $\mathbf{t_3}$, defined as the time from the moment of identification of the detected forest fire to the moment of its elimination by the selected means. The duration $\mathbf{t_3}$ is an integral characteristic of the fire extinguishing means located on board the UAV. The duration of the elimination of a forest fire $\mathbf{t_3}$ is also interpreted as a random variable having an exponential distribution with a probability density function:

$$p(t_3) = \mu exp(-\mu t_3), \quad (3)$$

$\mu = \frac{1}{\bar{t}_3}$, $\bar{t}_3 = M[t_3]$ - the average time to extinguish a fire, assumed to be given, which depends on the means used and on the complexity of the fire.
The choice of exponential distribution laws (1) - (3) is due to the fact that the process of detecting and eliminating a forest fire is a sequence of three random events "UAV loitering until the fire is detected during time $\mathbf{t_1}$," - "identification, diagnostics of the complexity of the detected fire as a target possible liquidation during the time $\mathbf{t_2}$ "-" extinguishing the fire during the time $\mathbf{t_3}$ ". It is known that the exponential distribution is the most adequate statistical model describing the time between successive occurrences of random events.
4) the probability **p** that the fire will be extinguished is assumed to be given, since the UAV diagnoses events, conditions and makes a decision on elimination only with a high probability of extinguishing. This probability, together with the average duration of the impact $\bar{t}_3$, is a characteristic of the fire extinguishing equipment located on the UAV.
To determine the probability of a UAV loss (either due to a failure, or as a result of exposure to fire or environmental conditions) by the time **t**, it is proposed to use the model [3,6]:

$$P_1(t) = \frac{\lambda\theta}{\mu+\theta}\int_0^t e^{-(\lambda+\theta)s}(1-e^{-(\mu+\theta)(t-s)})ds + \theta\int_0^t e^{-(\lambda+\theta)s}ds \quad (4)$$

Calculating the integral (4), we obtain:

$$P_1(\theta,\lambda,\mu,t)=\begin{cases}\dfrac{\lambda\theta}{\mu+\theta}\left[\dfrac{1-e^{-(\lambda+\theta)s}}{\lambda+\theta}-\dfrac{1-e^{-(\mu+\theta)s}}{\lambda-\mu}(1-e^{-(\lambda-\mu)s})\right]+\dfrac{\theta}{\lambda+\theta}\left(1-e^{-(\lambda+\theta)s}\right),\lambda\neq\mu\\ \dfrac{\lambda\theta}{\mu+\theta}\left[\dfrac{1-e^{-(\lambda+\theta)s}}{\lambda+\theta}-te^{-(\lambda+\theta)s}\right]+\dfrac{\theta}{\lambda+\theta}\left(1-e^{-(\lambda+\theta)s}\right),\lambda=\mu\end{cases} \quad (5)$$

The probability that the UAV will successfully complete its mission by the time t, that is, eliminate the fire, will be determined using the model: $P_2(\theta,\lambda,\mu,t)=\dfrac{\lambda\mu}{\mu+\theta}\int_0^t e^{-(\lambda+\theta)s}(1-e^{-(\mu+\theta)(t-s)})ds$

(6)

From which follows:

$$P_2(\theta,\lambda,\mu,t)=\begin{cases}\dfrac{\lambda\mu}{\mu+\theta}\left[\dfrac{1-e^{-(\lambda+\theta)s}}{\lambda+\theta}-\dfrac{e^{-(\mu+\theta)s}(1-e^{-(\lambda-\mu)s})}{\lambda-\mu}\right],\lambda\neq\mu,\\ \dfrac{\lambda^2}{\lambda+\theta}\left[\dfrac{1-e^{-(\lambda+\theta)s}}{\lambda+\theta}-te^{-(\lambda+\theta)s}\right],\lambda=\mu\end{cases} \quad (7)$$

The use of relations (5) and (7), in turn, makes it possible to calculate the estimates of the effectiveness of the actions of a group of modularly distributed systems of aviation equipment (group actions of UAVs), taking into account the cost factors and uncertainty in extinguishing forest fires. These include:

1) the mathematical expectation of the number of UAVs that will suffer damage by the time **t**:

$$N_1(t,\theta,\lambda,\mu,N)=NP_1(t,\theta,\lambda,\mu) \quad (8)$$

or the proportion of UAVs from their initial number that will suffer damage, which may be lost by time **t**:

$$\frac{N_1(t,\theta,\lambda,\mu,N)}{N}=P_1(t,\theta,\lambda,\mu) \quad (9)$$

2) the mathematical expectation of the number of forest fires that will be eliminated by time **t.** This indicator can be calculated based on (7). Indeed, the probability $P_2(\theta,\lambda,\mu,t)$ in (7) expresses the probability of detecting a fire and eliminating any of the targets (or the first or second or, ..., or target with a number $N_Ц$) concentrated in the area of operations of the UAV group. Then, the probability that some specific target (forest fire) will be detected and extinguished by a separate UAV can be calculated as $\dfrac{P_2(\theta,\lambda,\mu,t)}{N_Ц}$.

Accordingly, the probability that a specific forest fire will be extinguished by a separate UAV is $\dfrac{P_2(\theta,\lambda,\mu,t)}{N_Ц}p$.

As mentioned above, it is assumed that UAVs operate independently of each other, the possibility of their coordinated interaction in the process of searching for forest fires and eliminating them within the framework of the probabilistic model under consideration is not taken into account. Under this assumption, the probability that the fire will not be extinguished by any of the N UAVs involved in the operation is $(1-\dfrac{P_2(\theta,\lambda,\mu,t)}{N_Ц}p)^N$.

Hence, we obtain the probability of eliminating the fire by at least one of the UAVs [4,5]:

$$P_Ö(N_Ö,N,\theta,\lambda,\mu,p,t)=1-\left(1-\frac{P_2(\theta,\lambda,\mu,t)}{N_Ö}p\right)^N \quad (10)$$

From (10) we find the mathematical expectation of the number of fires that will be detected and eliminated by the UAV by the time **t** :

$$N_2(N_{Ö}, N, \theta, \lambda, \mu, p, t) = N_{Ö}\left(1-\left(1-\frac{P_2(\theta, \lambda, \mu, t)}{N_{Ö}}p\right)^N\right) \quad (11)$$

or their fraction of their maximum number $N_{Ц}$:

$$\frac{N_2(N_{Ö}, N, \theta, \lambda, \mu, p, t)}{N_{Ö}} = 1-\left(1-\frac{P_2(\theta, \lambda, \mu, t)}{N_{Ö}}p\right)^N \quad (12)$$

The greatest efficiency of the group's actions is achieved when the number of forest fires detected and eliminated by a certain point in time is maximum. However, at the minimum cost of an operation to extinguish fires in a given region (COST), depending on the cost of the UAV ($Cost0$), the cost of servicing the operation to eliminate the fire ($Cost1$), the number of lost or damaged UAVs participating in the operation. Based on this, it is possible to determine the optimal number of UAVs involved in the operation, and their characteristics, ensuring the simultaneous fulfillment of two conditions:

$$\begin{cases} COST(Cost0, Cost1, N_1(t, \theta, \lambda, \mu, N)) \rightarrow \min\limits_{\theta, \lambda, \mu, N} \\ N_2(N_{Ц}, N, \theta, \lambda, \mu, p, t) \rightarrow \max\limits_{\theta, \lambda, \mu, N} \end{cases} \quad (13)$$

Thus, a probabilistic model for analyzing the effectiveness of actions of a group of modularly distributed systems of aviation equipment is proposed, taking into account the cost factors and uncertainty in extinguishing forest fires.

RESULTS

In the study, the reachability sets were determined, calculated for the assumed number of goals $N_{Ц}$ = 5, 10 ..., the planned duration of the operation t = 50 ... min. and different probabilities of forest fire elimination. The maximum efficiency of the actions of a group of modularly distributed AT systems, taking into account the cost factors and uncertainty in extinguishing forest fires, is ensured if the UAVs have the following characteristics:

1) the average time during which the UAV remains operational, $\bar{t}_1$ = 200 min;

2) the average time of detection and diagnostics of a forest fire UAV $\bar{t}_2$ = 15 min.

3) the average time to extinguish a fire, that is, the time interval between the detection of the place of fire and the moment in time when the fire will be extinguished $\bar{t}_3$ = 25 min.

The number of UAVs involved in the operation to eliminate fires in the area has been determined. If the estimated number of targets in the area of application of the UAV group is equal to $N_{Ц}$ = 5, then the optimal composition of the group includes N = 20 UAVs, the capabilities of which are sufficient to detect and eliminate 4-5 fires (depending on the probability of destruction), taking into account the costs and the amount of losses.

DISCUSSION

The problem is that conditions (13) are contradictory, which makes it impossible to obtain a mathematically rigorous solution to the multicriteria optimization problem (13). In such conditions, we can talk about finding a solution based on an acceptable compromise between the conditions present in (13). There are various methods for solving multicriteria optimization problems [3,4], the most common of which are scalar convolution of criteria and obtaining a Pareto-optimal solution to problem (13).

CONCLUSION

In practical situations, it becomes necessary to assess the effectiveness of the actions of a group that brings together a certain number of UAVs that have certain characteristics. The study examines modularly distributed systems using the example of unmanned aerial vehicles. The properties and advantages of the UAV in comparison with the manned are highlighted. A technology is being developed for determining the required number of UAVs in a group based on preliminary information regarding the tactical situation in the group's area of operations; the estimated number and nature of targets located in the target area and other parameters. The developed probabilistic model for analyzing the effectiveness of the actions of a group of modularly distributed AT systems, taking into account the cost factors and uncertainty when extinguishing forest fires, allows us to formulate requirements for the composition and characteristics of UAVs, at which the maximum efficiency of the group's actions to search for and eliminate fires is achieved.

Thanks. The authors are grateful to colleagues for their help. The article was prepared with the financial support of the RFBR. Project 20-010-00428

REFERENCES

1. Gorelov B.A., Davydov A.D., Silaev A.V., Tikhonov A.V. Models for managing the development of distributed technical systems. Proceedings of universities. Mechanical engineering. 2018, No. 3, pp. 92-103.
2. Sobol I.M. The choice of optimal parameters in problems with many criteria. - M .: Bustard, 2006.
3. Kashtanov V., Medvedev A. .. The theory of reliability of complex systems. - 2018 .-- P. 498 .-- 608 p.
4. Keeney RL, Raifa H. Decision making under multiple criteria: preferences and substitutions. - M: Radio and communication, 1981.
5. Kuprin I.L., Davydov A.D., Teplov Yu.A. Key trends in the development of transformable high-tech complexes. –M: National interests: priorities and security. 2013. No. 46. Pp. 20-30.
6. Rukosuev A., Bashlykov V., Baldin K. Fundamentals of the theory of probability and mathematical statistics. Textbook. - Litres, 2016-03-26. - P. 80 .-- 489 p. - ISBN 9785457365889.
7. Sheremet A.D. The theory of economic analysis: Textbook. - 2nd ed., Add. - M .: INFRA-M, 2005 - 638p.
8. Sheremet A.D., Ionova A.F. Enterprise finance: management and analysis. - M .: INFRA-M, 2004 .-- 538p.
9. Troshin A.N., Burdina A.A., Moskvicheva N.V., Nikulina E.N., Tarasova E.V., Rogulenko T.M. Mechanism to analyze economic reliability of the innovational potential of aircraft enterprises//International Journal of Applied Business and Economic Research. 2016. T. 14. № 14. C. 747-765.