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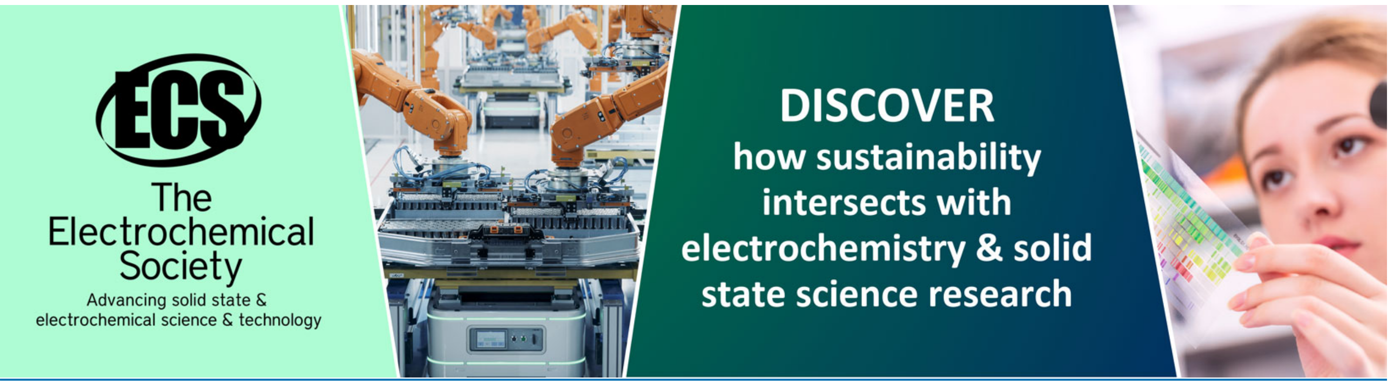

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On the problem of increasing the efficiency of UAVs technologies in agrarian business

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Abstract. The article considers the technological and economic application efficiency of the aviation unmanned systems in agrarian business. The most effective types of work for agricultural unmanned aircraft have been identified taking into account the global trend towards the introduction of precision farming technologies. The conversion of manned aircraft into unmanned aerial vehicles is also pointed out in the field of unmanned aviation. It is typical for cargo UAVs. The unmanned version of the AN-2 aircraft is an efficient transport platform for moving goods in rural areas, i.e., in the absence of financially costly infrastructure of modern airfields and airstrips. A mathematical model for the biotechnological system of the technological process in processing crops with aircraft of various carrying capacities is studied. The task of optimizing the aircraft load with chemicals is considered for two technological schemes for organizing their refueling with aviation fuel.

1. Introduction

According to the results of 2018, some experts (see https://russiandrone.ru/experts_opinion/) noted that the largest industry that applies UAVs is energy. The application of UAVs in transportation and the warehouse industry is growing rapidly [1]. However, agriculture takes the second place after energy in the UAVs market [2-4].

The article notes [5–9], that the aviation method of applying mineral fertilizers and chemical plant protection products is not inferior to the ground method in technical, economic, and efficiency, but in a number of indicators (advanced distribution of chemicals, high productivity, significant reduction in labor costs, and the possibility of treatments in optimal terms on moist soil, without compaction and destruction of its structure and mechanical damage to plants, etc.) exceeds. In this regard, agricultural enterprises and agricultural structures while planning a complex of agricultural mechanization are recommended to determine the place and volume of works for aviation and ground equipment in the crops cultivation technology, taking into account zonal features [7-9].

The agronomic and economic efficiency of aviation technologies application in agriculture convinces the reasonability of expanding the application scope of agricultural aviation in the most effective types of work, especially for feeding cereal crops, protecting plants from pests and diseases, and destroying weeds [10, 11].

Thus, nowadays, the UAVs application in agrarian business is associated with some trends in the agricultural sector development. The main ones are, firstly, the geography expansion of the agricultural holdings and large agricultural producers. Secondly, a global trend has emerged towards the introduction of precision farming technologies [12, 13]. It should also be noted the general interest of agrarian business in new technologies that allow making correct management decisions [14-16].

2. Directions for the UAVs application in agrarian business

At the present stage for the crop industry, experts (see https://russiandrone.ru/experts_opinion/) identify such areas of UAVs application as inventory of farmlands, including the high-precision field maps development; maps of inter-field roads and 3D terrain maps development, etc.; mapping of erosion processes in the territories of agricultural holdings; estimation of the vegetation index (NDVI) by the development phases of crops and soil moisture; remote determination of nutrients in the soil; counting of crops seedlings; weeds in the fields determination; crop yield forecast in the early phases of crop development; precision treatment of crops, plantations from pests and weeds; introduction of entomophages (biological plant protection products).

Another promising direction for the agricultural UAVs market in Russia may be spraying fields with their help [5]. Sensors on small UAVs already today identify fields that need agrochemical processing easily. But processing is often still carried out with ground sprayers or with the help of agricultural aviation. The carrying capacity of small UAVs for such operations is still insufficient, since they can lift no more than 200 kg of cargo.

The capabilities combining of UAVs and the technology of low-volume (LV) and ultra-low-volume (ULV) plants spraying will be a possible direction for solving this problem. Technologies and equipment for small-droplet spraying in Russia already exist [5, 17]. For example, “Zarya”, a small-droplet spraying device, that apply the principle of a rotating mesh drum. It crushes the liquid entering it into small uniform droplets. If one can find a solution that applies the capabilities of UAVs and low-volume spraying technologies, then the accuracy, efficiency and cost-effectiveness of applying agrochemicals or fertilizers will increase in several times. Perhaps it is exactly in Russia such a solution will appear that will transfer chemical treatment programs to a new technological and environmental level.

Some the Internet sources (see https://www.dairynews.ru) and the authors [7–9] note that, according to the information of 2017, UAVs were applied in the agricultural sphere only on 1-2% of farmlands in Russia. More often, Russian agricultural producers apply only small UAVs to collect information. But we have other examples. So, the Bonduelle Company applies 4 unmanned aerial vehicles on their fields, which cultivate 10,000 hectares in Krasnodar Krai. Moreover, agro-UAVs participate in tests for growing organic vegetables per 100 hectares; UAVs spray predator insects that destroy pests.

The authors note that the main restrictions for the widespread application of UAVs in Russian agriculture remain the new technologies cost, difficult weather conditions, scale of farmland and the relatively low carrying capacity of small UAVs. However, exactly in Russia specialists create new solutions that expand the capabilities of UAVs applications.

According to the “Aeronet” group, the “Aviaresheniya” company (Kazan) is completing the development of the “SKYF” heavy unmanned aerial vehicle. One of its main application areas is agriculture (for more details see DairyNews.ru). This project is the most complete one. The developed “SKYF” unmanned aerial vehicle is a project of heavy (cargo) unmanned aerial vehicles similar to the AN-2 manned aircraft [10]. Two models are being developed that are already undergoing flight tests. The take-off mass of the aircraft is 300-500 kg, the payload mass is 150-300 kg. For the agricultural sector the application of UAVs is plant protection products.

Among the tasks that developers should solve at the final stage is a choice of the optimal flight altitude, the force of the jet selection to irrigate the fields so that it does not damage plants, as well as some other characteristics.

It should be marked that one more area in the field of unmanned agricultural aviation is the manned aircraft conversion into unmanned aerial vehicles. Partially, it is due, to the fact that in agriculture one can observe two main directions of the production activity restructuring [11].

The first is the creation of large industrial-type enterprises specializing in the production of grain, milk, and meat. The second is the disaggregation of agricultural organizations with land transition to private sector and a significant reduction of arable land in each farm.

All this leads to the case that in the second case, the field areas and their size are significantly reduced. It practically excludes the possibility of using large agricultural aircrafts of the AN-2 type for processing crops. Therefore, more and more attention has recently been paid to the small aircraft application (motor hang gliders, monoplans, biplanes) in the crops processing, which are superior in terms of economic performance to ground vehicles and large agricultural aircraft like AN-2.

However, an unmanned version of the AN-2 type aircraft may be in demand in the case of the first direction implementation associated with the foundation of large agricultural enterprises of the industrial type. At the same time, in an unmanned version, this aircraft is an effective transport platform for goods transportation (up to 1,500 kg) in rural areas, i.e., in the absence of financially costly infrastructure of modern airfields and airstrips.

3. UAVs' efficiency in agro-technological processes

Some authors suggest considering a mathematical model of the biotechnological system of the technological process for processing crops with aircraft of various carrying capacities [10-12]. They pay special attention to the man-machine subsystems, which is important for both the manned aircraft and unmanned aerial vehicle alternatives of the aircraft [18-20].

The process of crops treatment with aircraft includes separate flights throughout the working day (repeated cycles of processing crops), and the treatment process itself also includes monotonously repeating stages T_{RS}, which is effectively supported by modern UAVs control technologies [11]:

$$T_{RS} = T_{SERV} + T_{POL} + T_{TR} + T_{TREAT} + T_{PHYS.N} \quad (1)$$

where T_{SERV} is time for maintenance and loading the aircraft with chemicals; T_{POL} is fueling time; T_{TR} is time of movement of the aircraft before and after the flight (ground movement), T_{TREAT} is time of crop treatment; $T_{PHYS.N}$ is time for the physical needs of a person (it should be noted that this term is absent in the case of the UAVs application).

At the same time, the time for crop treatment includes:

T_{TOL} is take-off and landing time (it varies depending on the type of the aircraft); T_{FL} is time of flight from the airfield of the cultivated field; $T_{F.TR}$ is field treatment time; T_{REV} –is time of reversal.

$$T_{TREAT} = T_{TOL} + 2T_{FL} + \Sigma T_{OF.TR} + \Sigma T_{REV}, \quad (2)$$

$$\text{hence } T_{RS} = T_{SERV} + T_{POL} + T_{TOL} + 2T_{FL} + \Sigma T_{F.TR} + \Sigma T_{REV} + T_{PHYS.N}, \quad (3)$$

where T_{TREAT} is effective production time of the mathematical model.

A number of flights in crop treatment by aircraft can reach 30 or more flights per working day. This shows that a production process has a pronounced cyclical nature. The analysis of time parameters is given in table 1.

Table 1. Time parameters of UAVs flight activities.

Aircrafts	T_{tol}	T_{serv}	T_{tr}	$2T_{fl}$	ΣT_{treat}	ΣT_{rev}	Total %
Agricultural aircrafts	4,2	13,4	5,3	19,7	7,2	40,2	100
Small UAVs (motor-hang gliders)	1,2	5,0	1.0	28.0	60,0	4,5	100

If we consider the manned aviation, it is known that, based on the peculiarities of the flight for crop treatment with an aircraft, the estimation of the optimal parameters for the crop treatment process play a significant role in increasing its efficiency (taking into account fuel consumption, training of flight and technical personnel, etc.). For UAVs, some parameters related to the preparation and financial and utility provision of flight crews may not be taken into account when building a model, thereby affecting the efficiency of the production process.

One of the components of the crop treatment is the preparation of the cultivated area, which determines the performance of aircraft and the costs of the crop treatment [18]. Crop fields for aerochemical operations vary in size, configuration, headland, distance from the airfield. Before flights start, the height of air obstacles is calculated, the optimal heading length in these specific conditions, the sequence and processing routes of fields. If we consider manned aircrafts, the location of signalmen at each section is determined, their movement plans, widths of the transitions to the next signal line, and the routes of flights are substantiated in specific conditions. The field treatment is carried out by sequential application of parallel bands of distributed substances from the air by shuttle, driven or non-standard methods.

The stages of crop treatment by aircrafts (manned or unmanned aircraft, motor hang gliders, etc.) differ slightly, due to only the characteristics of each type of aircraft. Taking all these into account, in modeling the field treatment process, a system of correction factors is introduced. It takes into account the application of one or another type (manned / unmanned, transport / small, etc.) of the aircraft.

The production flight is carried out at a low altitude and at a low flight speed. Therefore, the equation of the aircraft motion proposed in [11] can be considered with sufficient accuracy for modeling. The paper gives the equation of the aircraft motion in a general form (along three coordinate axes). Note that mathematical models of the technological process of crop treatment from diseases and pests by unmanned aerial vehicles even at the initial stage of organization help to highlight the features of their application, which are due to the influence of production, technological and economic factors in the aggregate, to predict objectively the costs of these operations.

The methods of rational production are widely introduced in agricultural aviation [12–20]. They include the increase in flight productivity due to of air route improvement, optimal methods of take-off and climb, selection of echelons and flight speeds, rational use of aviation petrol, oil and lubricants, service and culture improvement, etc.

It is important that the reserves in labor productivity are applied to the maximum extent possible at each airline, in each crew. And they exist. The proposed methods for increasing the aviation operations efficiency can reduce the cost of financial, material and labor costs for the implementation a unit of aircraft products and improve the production culture without attracting additional investment.

Obviously, the initiatives of specialists concerning the ways to further increase of the unmanned aerial systems application and the most complete and highest-quality satisfaction of the needs of the national economy sectors in aviation services are important.

It is known [1-3, 11] that one of the best ways from financial point of view to increase the efficiency of UAVs in aviation operations of the national economy without additional investment, is to optimize the parameters of aircraft operations. It helps to achieve either the highest UAVs performance in specific production conditions, or to minimize the expenditures of the national economy per a unit of aircraft production.

4. Loading optimization of cargo UAVs

The main tasks in terms of improving the efficiency of UAVs operations are [3, 10, 11]:

- increase flight performance in aviation and chemical works in agriculture;
- reduce of specific operating expenditures for the implementation of all types of aviation works;
- reduce in fuel consumption per a unit of aviation works;

- increase the flight safety.

It is obvious that increasing the productivity of flights in aviation operations helps to reduce the costs of material, financial and labor resources for their implementation. As it is known, the main economic indicator of the aircraft efficiency in aviation and chemical work is flight performance. The cost of aviation and chemical works and the operating time are directly dependent on its value.

The flight performance depends on a number of factors that can be divided into two types: uncontrollable factors that are unchanged in the specific conditions of aviation and chemical works (operating speed, turn time for the next run) and controlled factors, that can vary within certain limits (headland length, distance flight to the certain place, loading the aircraft with chemicals). Unlike uncontrollable factors, controlled ones can be optimized in order to achieve the maximum aircraft performance.

The maximum load with chemicals provides, all other things being equal, the maximum performance during the flight hour, but always contributes to the maximum performance in the working hour, since it is often necessary to refuel due to the small amount of fuel on board the aircraft. At the same time, greater productivity during the working hour helps to increase the annual aircraft application, i.e., to reduce the cost of one flight hour. Therefore, it is advisable to be loaded with chemicals lower than the maximum under certain conditions.

Currently, the aircraft loading is carried out as close as possible to the maximum. However, as the studies showed, the maximum load of the vehicle with chemicals almost always ensures (ceteris paribus) the performance below the maximum.

The optimizing task of the aircraft loading with chemicals should be considered for two technological schemes for organizing their refueling with aviation fuel. The first scheme is applicable when refueling is carried out at the airport, where the aircraft is loaded with chemicals; the second is carried out while refueling is at a temporary airfield (strong hold).

The concept of optimum has a specific content. The optimum is the minimum or maximum value of the optimality criterion within the given boundaries of the change in the parameters (variables) of the planned system. In our case, the criterion of the system optimality is the of the aircraft performance in both manned and unmanned alternatives.

The analysis showed [11] that, it is necessary to take productivity per working hour (an hour of cyclic time, taking into account the aircraft's flight cycle, steering, loading with chemicals, and refueling between flights) as an objective function (optimality criterion) in optimizing the mass of chemicals loaded into an aircraft. The productivity during a flight hour cannot be applied, since it does not take into account the time spent on the ground during the working day.

According to the analysis [11], the maximum performance during a flight hour as an objective function, occurs when the load with chemicals (G_x) is equal to

$$G_x = G_0 - gt_d, \tag{4}$$

where G_0 is the full aircraft load (chemicals and fuel), kg; g is minute aircraft fuel consumption, kg; t_d is duration of one flight, min.

This means that the aircraft refueling with aviation fuel must be done after each flight. However, in this case, the daily productivity in aviation and chemical works will be very low. This will have very bad consequences, as it will lead to a sharp decrease in the annual flight hours, i.e., to the increase in the cost of aviation and chemical works. Moreover, terms for the implementation of aviation and chemical works will be extended. It will lead to the decrease in the level of crop yields. Therefore, in order to reduce the cost of aviation chemical work while optimizing the mass of the chemical loaded into the aircraft, the criterion of flight productivity per working hour should be used.

This criterion is fully consistent with the optimization goal; it means to obtain the highest efficiency of aviation operations. It helps to solve two main problems: to reduce the agrotechnical time for the implementation of aviation and chemical works by increasing the shift productivity of flights and to increase the annual flight hours for the list of aircraft. The solution to the first task helps to increase the agricultural crops yield (in early spring feeding of winter crops during the snowmelt) or to save it (pests and diseases control). The solution of the second task, associated with the increase in the annual flight hours helps to increase the extensiveness of their application. It leads to the decrease in indirect costs for aviation and chemical works, i.e., to the reduction in their cost for both civil aviation and national economy.

5. Conclusion

So, the results of this investigation, taking into account the technological and economic efficiency of using aviation unmanned systems and the analysis presented in [9–11], showed that the mass of the chemical loaded into an aircraft largely depends on the distance to the area where chemicals are to be applied (with the increasing distance to the site the mass of chemicals decreases), the working width, the rut length of the treated area and the rate of application of chemicals. That is, the less these indicators, the less chemicals can be taken on board of the aircraft for the same distance to the area of its application.

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