https://doi.org/10.26552/aer.C.2019.2.3

THE ADVANTAGES OF PLANT PROTECTION BY USING UAV OF AIRCRAFT CONFIGURATION AND ULV TECHNOLOGY

Gennadiy Yun
National Aviation University
Kyiv 03680
Ukraine
yungennadiy2021@gmail.com

Yuri Pederiy
AeroDrone
Franztr 10, Munich
Germany

Andrei Gnashuk
National Aviation University
Kyiv 03680
Ukraine

Abstract

The article deals with the design of agricultural UAVs. In recent years, various agricultural UAVs (mainly the copter configuration) have been developed for processing small fields using the method of ultra-low-volume spraying. The proposed project of an agricultural UAV aircraft configuration has several advantages especially when used on large fields. Due to the high flight speed, high payload and the duration of flight time without refuelling, this aircraft has a fairly high performance in the process of protecting plants from diseases and pests. In addition, a relatively simple infrastructure, based on the years of experience in the use of manned aircraft in agriculture, allows, by analogy, to develop an unmanned aviation system for agricultural purposes. Flights are currently underway to test UAV control systems when manoeuvring at low altitudes near obstacles.

Keywords

UAV, agricultural UAV, ultra-low volume (ULV), aircraft, copter, airplane configuration

1. Introduction

According to the revised data from FAO, UN WFP, UNICEF and WHO, the number of hungry people in the world is growing, reaching 821 million in 2017. This means that every ninth person on the planet has been affected by hunger, according to the report published in "The State of Food Security and Nutrition in the World - 2018 " (FAO, 2018). The world is moving towards a long period of conflict related to increasing food prices and an acute shortage of food. Hunger is no less dangerous than terrorism, because, together with poverty, it creates a threat to world security.

One of the ways out of this situation is the so-called "Second Green Revolution", based on the introduction of new technologies (Schröder, 1998 & Carvalho et al., 2011). This article discusses the private aspect of choosing effective plant protection technologies based on the latest advances in mechatronics and aeronautics - agricultural unmanned aerial vehicles (UAVs).

2. Prospective technologies in the agricultural sector

What are the ways to increase the yield of the field? As can be seen in Fig. 1 a large role in this agro-technological cycle to achieve the ultimate goal is assigned to plant protection. The introduction of appropriate plant protection products would raise field yield by up to 50%. Currently, these are ground transportation, manned aircraft and UAVs. In the same sequence, we consider the comparative levels of each of these assets development, their advantages and disadvantages, as well as the immediate prospects for their implementation in the agricultural sector.

Figure 1: Agro-technological production cycle. Source: Authors.

3. Level of development

3.1. Ground transportation

There are countries where, for reasons of environmental safety and the concept of precision farming, even today only ground equipment is used to protect plants or, in some cases, in combination with agricultural aviation. Ground-based equipment, of course, has its advantages over aircraft (LA), which (especially airplanes) are limited to navigation and environmental requirements. Nevertheless, by a large number of criteria, ground transportation is inferior to aviation, although recently there has been a trend towards automation of managerial functions for existing tractors, for example, Magnum, JohnDeer (CaseIH and CNHIndustrial's Innovation Group, 2016 & Yun et al., 2018) and others. Recently, CaseIH (USA) specialists have created a completely new type of tractor (Fig. 2) on autopilot and have high hopes for it (Schröder, 1998). The car was equipped with a variety of sensors that help navigate in space. The "brain" of the tractor analyzes the signals coming from both the sensors and the person, if necessary, and signals the operator about emergency situations. The unmanned tractor is controlled by means of a tablet or computer. Indeed, using the software of the devise allows operating it fully autonomously.

Soon, unmanned tractors, apparently, will make a real competition to manned agricultural aviation.

Figure 2: Unmanned tractor company of CaseIH. Source: (CaseIH and CNH Industrial's Innovation Group, 2016).

3.2. Piloted aircraft

Manned agricultural aircraft have a long history. Thus, the An-2 aircraft designed at O. Antonov Design Bureau in 1947 has continued performing a large amount of work in agriculture in many countries worldwide. Fig. 3 shows Russia's new recently manned agricultural aircraft Su-38L. This fact proves that it is still too early to write off manned agricultural aircraft, especially where there are trained personnel, infrastructure and deep-rooted traditions of using manned aircraft in agriculture.

Figure 3: Manned aircraft of Sukhoi company. Source: (Sukhoi, 2017).

3.3. Unmanned Aerial Vehicles

Why did the agricultural UAVs of copter and aircraft configurations appear, even in a compromise hybrid design? The unmanned helicopter can be considered as a kind of copter that deserves a separate study and publication. In this article we will conduct a comparative analysis of two UAVs configuration: copter and aircraft. UAVs have a long list of advantages compared with manned aircraft:

- The main advantage of the UAV is a significantly lower cost of their creation and operation, provided that the tasks performed are equally effective;
- Fuel economy when using internal combustion engines;
- Low weight allowing the use of electric motors;
- Due to the weight of the pilot and his/her workplace, it is possible to increase the payload, that is, to place on board more working material or fuel;
- Significant reduction in take-off and landing space;
- High operational efficiency;
- Improved field processing performance;
- Lack of pilots reduces the risk of personnel and financial losses for training;
- No problem with pilot fatigue;
- A UAV can operate at night when there is less wind, less demolition of the working material.

In addition to purely technical advantages, it is worth noting the main economic benefits of UAV application for plant protection:

- 60-percent reduction in plant protection operating costs;
- 30-percent yield increase in the farms which have not been previously engaged in plant protection;
- 3-fold increase in field processing performance;
- 5-fold reduction in fuel consumption.
- However, it is necessary to recognize the fact that the UAV of the aircraft configuration is not without many serious drawbacks as compared with helicopters:
- The need for a runway;
- Difficulties in accurate processing around the perimeter of the field can lead to the violation of environmental legislation – the need to introduce sanitary buffer zones along the field borders;
- Limited field processing with difficult mountainous terrain.

3.3.1. Copters

In the last decade, a large number of copters (quadcopters, octocopters, multicopter), developed even far in non-aviation countries, have appeared. Their developers offer them as an inexpensive and easy-to-use plant protection product similar in design and flight-technical and commercial characteristics to copters (Kabra et al., 2017 & Yun et al., 2014 & Hunt et al., 2018).

Fig. 4 shows a typical sample of an agricultural UAV Copter vehicle (DJI Agros MG-1, 2017). This Chinese DJI Agros MG-1 drone sprayer is designed for field protection with a predominantly flat terrain. As seen from above, the device is of a star-shaped structure with a block of equipment in the center (battery, navigation equipment with GPS radio transmitter), as well as a removable plastic tank for working chemical solutions attached by strips.

On each "beam" of this star there is a propeller with a drive from an electric motor and a nozzle for spraying the working fluid. The device is controlled from a telephone or mobile computer, it starts vertically from the ground. You can control the flight manually or automatically, denoting the starting and landing points on the computer screen, as well as the trajectory and speed. The device is controlled from the keyboard of a mobile computer. The time spent in the air is up to 24 minutes, the maximum speed of 79 km / h within a radius is of up to 5 km from the operator.

The proposed design has several advantages:

- stability in static modes (hovering), which facilitates control and turns in out;
- a significant reduction in construction costs and weight due to the absence of the fuselage;
- an increase in power supply due to the use of an electric drive instead of an internal combustion engine, which has lower efficiency, and the absence of converters of mechanical moments.

Figure 4: Agricultural UAV of copter configuration. Source: (DJI Agros MG-1, 2017).

As a rule, the main parameters of modern agricultural copters are in a narrow range of values: flight time over the field within 20-30 minutes, and payload weight of 10-20 kg. The bottleneck of the copters is the power sources of electric motors, on-board equipment and avionics. The capacity of a modern battery limits a copter flight time before replacing or recharging it with 40-50 minutes. Therefore, these parameters effect the economic efficiency of copter performance (Kedariet et al., 2016 & Rendl et al., 2014). To reduce the specific energy consumption and improve aerodynamic parameters, some UAV developers chose the path of motorists, that is, create a hybrid vehicle, combining the advantages of aircraft and copter in its design.

3.3.2. Multirotor quadcopter

In Ukraine, the company has chosen this path (Kray Technologies 2017). Its brainchild Kray is a hybrid of a copter and an aircraft (Fig.5). Eight propellers provide a vertical take-off, and traction propeller and wing provide flight at the speed of up to 110 km/h at a vista of 1 m above the plant, considering the relief and obstacles. Productivity is 300-500 hectares of land per day.

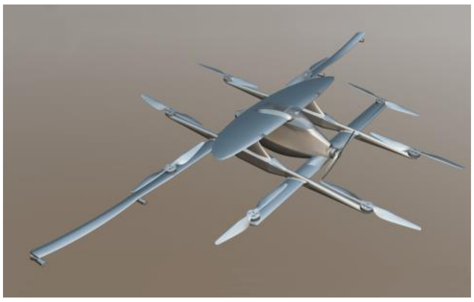

Figure 5: Multirotor Quadcopter Kray. Source: (Kray Technoilogies, 2017).

The prototype design includes two folding rods and 5-meter-disperse sprayers. In addition, it is equipped with the terrain recognition system and rotary atomizers which ensure the accurate introduction of concentrated protective equipment, while the rotor will fly over the field of 1 meter in height. The copter operates on promising concentrated products using ULV technology, as well as well as for making leaf fertilizers or chemicals in the fields.

The Ukrainian Kray drone has several competitors on the market, including the above DJI Agros MG-1. The latter has already appeared on sale in online stores. It is more compact in size, simple in programming tasks, and the price cheaper by almost three times - $ 15,000 but is not capable of developing such a high speed as it is equipped with the tank that is half as large in volume.

3.3.3. UAV of Aircraft Configuration

Against the background of numerous varieties and sometimes simply exotic copter designs, the aircraft UAV configurations may seem rather conservative (Yun et al., 2017 & Pederiy et al., 2015 & Giles et al., 2015). However, in plant protection technologies, there are situations when the aircraft configuration is clearly superior to the engine one. Firstly, there are countries, such as Ukraine, Kazakhstan, the USA, Canada, Australia and others, where the fields have even relief and without obstacles in the form of power lines, buildings, structures, antennas, etc. In this case, the aircraft can handle large areas per flight. To do this, it must have a large tank for both fuel and working material, as well as high speed on the rut. Secondly, as seen on Table 1, some chemicals, especially fertilizers, are applied to the soil with a high consumption rate, which again places high demands on aircraft performance and tank capacity.

Table 1. Consumption rates of plant protection products. Source: Authors.

Chemicals	Herbicides	Fungicides	Insecticides and Acaricides	Regulators Growth	Liquid Fertilizer “ Aydar”	Ammonium Nitrate	Ureaa
Norm, l/ha, kg/ha	0.08-6.0	0.2- 2.5	0.1-3.0	2.0-3.0	6.0-9.0	150-250	100-200

Given the above, a group of Aero Drone company's employees under the direction of Y. Pederiy designed, manufactured and got ready for mass production of DR-60 UAVs of the aircraft configuration. Below is a brief description of this UAV.

Purpose

The DR-60 UAV is one of the largest UAVs in Ukraine today, specifically designed for use in the agricultural field to protect plants by spraying fields with a payload capacity of up to 60 kg, which allows for manual flight within the visibility zone under operator's control. The UAV development was carried out according to civil standards for the development of aircraft. The DR-60 allows ULVT fields to be processed at an application rate in the range of 1 to 3 litres per hectare. While spraying it uses standard rotating nozzles (similar to Micronair) with a droplet size of at least 100 micrometres and a flow rate of up to 1 litre per minute. Sprays, chemical tanks and pumping equipment are not included in the DR-60 UAV configuration.

UAV components:

- Technological panel for UAV pre-flight inspection and control
- UAV battery charger
- A set of spare parts and accessories for minor repairs in the field
- Operation manual.

General view of the UAV

Fig. 6 shows a general view of the DR-60 UAV, which is an aircraft LA with an overhead wing, pulling propeller and an internal combustion engine. UAV is equipped with the main chassis on the front spring and a rear wheel. Onboard equipment is powered by two high-capacity lithium-ion batteries and an onboard generator. The wing, fuselage and engine of the UAV are made of metal, which significantly increases the aircraft strength, and also provides its maintenance and repair.

Figure 6: UAV general view

1 – aileron, 2 – horizontal tail, 3– fin, 4 –rudder, 5– wing, 6 – fuselage (with equipment), 7– chassis, 8– engine,9 – propeller, 10 – chemical tanks, 11 – rotating nozzles

The on-board equipment consists of that for aircraft monitoring and control (OCULA), electrical equipment (ET) and replaceable attachments (HO) for carrying out plant protection works. ET includes a set of Li-Ion batteries, 9V (2 pcs.) for powering all OKULA and Li-Po 7.5V, 4A batteries for powering FUTABA BLS 175, HITEC HSB-9380TH servo drives.

OKULA has a Taranis X9D receiver for receiving signals from a ground transmitter that is controlled by a ground operator. The control signals are transmitted to the receiver through a channel at a frequency of 2.4 GHz, using FASST technology. OKULA provides in manual mode:

- UAV take-off and landing
- Flying within sight
- Switching on / off pumps that supply liquid to rotating nozzles

Remote control FUTABA 14MZ

The control panel TARANIS of the X9D brand, the standard remote-control model of radio models, is designed to control the UAV. The rules for operating the remote control are described in the "Operation Manual" of this product. The control of the UAV remote control is carried out in manual mode. The console is not equipped with a receiver of video signals and is intended only to control the UAV within sight of the operator. The control panel is designed to perform the following functions:

- Flap control
- Aileron control
- Gas damper control
- Steering wheel height
- Steering rudder
- Brake control

An additional purpose of the technological panel is to check the condition of the electromechanical control devices of the UAV, as well as to check the condition of the power plant.

Charger

The charger is used to charge the batteries. Rules for working with a charger and charging batteries are described in the "Charger Handbook".

Technical specifications

The main flight characteristics of the UAV are given in Table 2.

Table 2: Technical specifications. Source: Authors.

Maximum airspeed	100 km/h
Cruising flight speed	80 km/h
Flap speed without flaps	50 km/h
Landing speed	65 km/h
Maximum flight altitude	3 km
Maximum flight time (depends on weather conditions)	1.5 h
The working range of the radio control UAV	3 km

Control range	In the line of sight, up to 1 km
Engine type Hirth F33	Two-stroke ICE
Maximum payload weight	60 kg
Maximum take-off weight	150 kg
Length	4 m
Wingspan	6.5 m
Aerodynamic quality	10
Operating temperature range	-20… +450 C

Preparation of the UAV to work

The first stage - determining the place of take-off and landing - includes the study of the terrain at the proposed starting point. It is desirable to consider:

- the starting point should be chosen as high as possible relative to the intended route with the minimum distance from the fields in order to increase the useful time and to achieve maximum results;
- it is preferable to choose a launch pad with a low grass cover. The size of the site must be at least 150x20 m provided that there are no objects in the surrounding area that would prevent the normal mode of take-off, landing and the search for UAVs (rivers, lakes, ravines, buildings, masts, towers, etc.) within a radius of 400 m.

At the first stage it is also necessary to:

- determine the position of the cardinal points.
- determine the direction and speed of the wind (the direction and speed of the wind at the surface of the earth and at the working height may differ).
- determine the direction of the route relative to the take-off point and make sure that there are no obstacles in this direction to ensure direct visibility.
- determine the direction of the launch and make sure there are no obstacles in this direction.
- ensure that there are no obstacles in the landing zone.

It should be noted that the landing machine comes against the wind. For a safe launch and landing of a UAV, there must be no obstacles: buildings, masts, towers, factory pipes with a height of more than 50 meters.

The landing site is selected near the starting point from the consideration of the possibility of UAV operator’s visual inspection by approach and landing. To land a UAV, a flat terrain with a size of 150x50 m is selected. There should be no objects on the ground that could be damaged by landing UAV, namely bushes and trees, stumps and stones, poles and power lines, buildings and structures, water bodies. When landing in manual mode, the landing point is determined by the operator based on current weather conditions, size, location and features of the landing site. To carry out inspections of specific objects, the flyby mode of a given object with a given flyby radius is used (Fig. 7). This mode is widely applicable when object coordinates are known, and its state needs to be clarified.

The second stage is flight preparation, which includes setting up the operator’s workplace, namely: turning on the on-power toggle switch of the servo drives; turning on the UAV manual control transmitter; check the installation of communication transmitter with an onboard receiver, rejecting the control knobs on the transmitter and tracking the development of control rudders on the UAV. Now the UAV is on and ready to go.

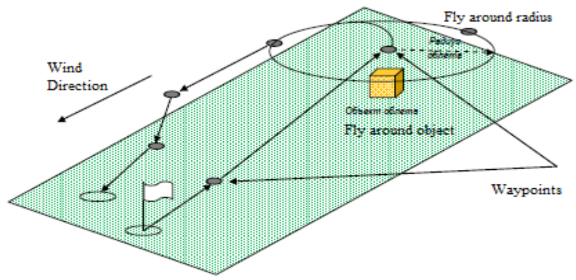

Figure 7: Circling a given object. Source: Authors.

4. Conclusion

In world practice, thousands of different types of aircraft are used annually to protect plants, with the help of which millions of hectares of agricultural and forest lands are treated with chemical and biological preparations. According to large analytical companies (PWC, Goldman Sachs, Markets and Markets, IDTech Exlheubt, 2017), the agricultural sector will be the largest in terms of civilian use of drones by the size of the segments in the next 5 years and the potential size of the agricultural market will increase from $ 32.4 billion up more than $ 150 billion.

Despite the high efficiency, the main economic benefits from the use of UAVs for plant protection in comparison with terrestrial methods of protection are: increase in yield by 30% in the farms which have not been previously engaged in plant protection; 60-percent reduction in plant protection operating costs; 4-fold increase in field processing performance; 5-fold reduction in fuel consumption compared with manned aircraft.

ULV technology, the need to make chemicals with a high rate of consumption is not removed from the agenda. Therefore, at present, in Ukraine, at the National Aviation University, the assembly of a prototype agricultural UAV of an aircraft circuit with a 300-liter tank capacity is already being designed and is being completed. It is obvious that in the near future unmanned agricultural aircraft with a carrying capacity of the An-2 aircraft, that is 1500 kg, will appear.

If we compare the UAV of vertical take-off and landing (copters and unmanned helicopters) with the UAV of an aircraft circuit, then, undoubtedly, the latter lose by take-off and landing parameters. For example, the DR-60 UAV requires a 150x20 m platform. Although in countries where previously piloted agricultural aircraft were used or are used, it is possible to organize the operation of an UAV aircraft configuration. In Ukraine and the countries of the former USSR, a sufficiently developed network of such airfields remained.

The authors of the article do not consider Copter and aircraft agricultural UAVs only as competing NLA. It is more profitable to consider them as complementary, using the advantages of each configuration (Marintseva et al., 2019). In small areas, especially in mountainous areas with a complex perimeter geometry, it is more expedient to use helicopter or cruiser

UAVs, and on large fields with a flat profile - airplane UAVs. But even large fields are not always a rectangle without any obstacles that it is almost impossible to accurately fly around an aircraft UAV. This job of cleaning up small “patches” will be better done by a copter or ground vehicle.

Another direction of the rapid development of the fleet of agricultural UAVs is the conversion (Belan et al., 2018 & Marintseva, 2014) of existing manned general-purpose aircraft into agricultural ones. Here you can win not only in the rate of fleet growth, but also in cost savings.

Obviously, any aircraft, including unmanned, originally designed to solve specific problems, will be functionally more efficient than a modernized, re-equipped manned aircraft or a helicopter. But we must not forget that with a successful choice of a manned prototype, an unmanned transformation may be preferable to the originally developed version, which meets all technical and economic requirements of the customer. This approach to creating a new UAV has several advantages, such as cost savings in the design, production and testing phases; availability and logistics of spare parts; the possibility of using the existing service base; shortening the project development time frame and launching the mass production of UAVs. The term "conversion" refers to the process of converting light and ultralight manned aircraft into unmanned aerial vehicles for their subsequent economically and technically efficient use in various sectors of the economy. The effectiveness of such a UAV will largely depend on how well the above-mentioned transformation will be performed. To solve the conversion problem, we need the appropriate theoretical foundations, a certain set of algorithmic and software tools, as well as technical tools that provide the full cycle of testing UAV control systems in all flight modes.

References

Belan, V., Yun, G., Gnashuk, A. 2018. Problem of manned aircraft conversion into unmanned aerial vehicles. In Proceedings of the National Aviation University, N 2, pp. 57-61.

Carvalho, W. P. A., Antuniassi, U. R., Araújo, E. C., Schroder, E. P. 2011. Techología de aplica9äo por via aérea In: Tecnología de aplica9äo paraculturasanuais.led. Passo Fundo: Aldeia Norte/ FEPAF, v. 1, pp. 143-188.

Case IH and CNH Industrial’s Innovations Group, 2016. Available at: https://www.caseih.com/apac/ru-ru/news/pages/2016-case-ih-premieres-concept-vehicle-at-farm-progress-show.aspx.

DJI Agros MG-1, 2017. Available at: https://www.dji.com/mg-1https://www.dji.com/mg-1

FAO, IFAD, UNICEF, WFP and WHO, 2018. The state of food security and nutrition in the world - 2018.Improving resilience to climate for food security and nutrition. Rome, FAO. License: CC BY-NC-SA 3.0 IGO, 2016. Available at: https://www.youtube.com/watch?v=XrqMVzFfAjY.

Giles D. K., Billing R. C. 2015. Deployment and Performance of a UAV for Crop Spraying. Chemical Engineering Transactions, 44, pp. 307-322.

grotóxicos. Santa Maria: Departamento de DefesaFitossanitária; Sociedade de Agronomia de Santa Maria, pp. 87-94.

Hunt J. R., Raymond E., Daughtry, Craig S. T. 2018. What good are unmanned aircraft systems for agricultural remote sensing and precision agriculture? International Journal of Remote Sensing, Volume 39, Issue 15-16. Published Online: 03 Dec 2017

Kabra T. S., Kardile A. V., Deeksha M. G., Mane D. B., Bhosale P. R., Belekar A. M. 2017. Design, Development & Optimization of a Quadcopter for Agricultural Applications. International Research Journal of Engineering and Technology (IRJET), 04 (07).

Kedari S., Lohagaonkar P., Nimbokar M., Palve G., Yevale P. 2016. Quadcopter-A Smarter Way of Pesticide Spraying. Imperial Journal of Interdisciplinary Research, 2 (6).

KrayTechnoilogies, 2017. Available at: https://kray.technology/.

Marintseva, K. 2014. Methodological aspects of the interconnection of exploration of aviation transport systems and airborne industry. Scientific journal "Knowledge-based technologies", N3 (23), pp. 341-344.

Marintseva, K., Yun G., Vasilenko I. 2019. Delivery of Special Cargoes Using the Unmanned Aerial Vehicles. Chapter 2 In book Kille Tarryn, Paul R. Bates and Seung Yong Lee. "Unmanned Aerial Vehicles in Civilian Logistics and Supply Chain Management." IGI Global, 1-374.

Pederi, Y. A., Cheporniuk, H. S. 2015. Unmanned Aerial Vehicles and new technological methods of monitoring and crop protection in precision agriculture. Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD), 2015 IEEE International Conference, pp. 298-301.

PWC, Goldman Sachs, Markets and Markets, IDTech Exlheubt. 2017. Available at: https://startupnetwork.ru/startups/355927.html

Randal U, Biard T. 2014. Small unmanned aerial vehicles. Theory and practice. M.: Radar MMC, pp. 184.

Sukhoi, 2017. Available at: https://ru-aviation.livejournal.com/3851494.html.

Yun G. N, Mazur M., Pederiy Y. 2017. Role of unmanned aerial vehicles in precisions farming Journal. Proceedings of the National Aviation University, pp. 106-112.

Yun G. N., Marintseva K.V. 2018. Unmanned aerial system for agriculture. The Eighth World Congress AVIATION IN THE XXI-st CENTURY, proceedings of the NAU.

Yun G. N., Shariphov F. A., Kandyba Jr. 2014. Optimization of routes of aircraft engaged in agro-aviation works. Scientific journal "Science based Technology", N3 (23), pp. 319-325.