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Обзор беспилотных авиационных систем доставки грузов

Е. В. Соломин[1*], А. С. Мартьянов[1], Х. Шахин[1],
Н. А. Пшениснов, С. К. Шерьязов[2]

[1]Южно-Уральский государственный университет (национальный исследовательский университет)
Российская Федерация, 454080, г. Челябинск, просп. Ленина, 76
[2]Южно-Уральский государственный аграрный университет, Институт агроинженерии
Российская Федерация, 454080, г. Челябинск, просп. Ленина, 75
[*]E-mail: nii-uralmet@mail.ru

Статья относится к беспилотной авиации и посвящена обзору беспилотных авиационных систем (БАС согласно ГОСТ Р 59517–2021, или в ряде публикаций – беспилотных летательных аппаратов или дронов), способных доставлять различные грузы. Приведены и кратко проанализированы варианты их применения в различных сферах, включая сельское и лесное хозяйство, рыболовство, защиту дикой природы, мониторинг качества воздуха, горные разработки, оборонное и гражданское использование, поисковые и спасательные операции. Целью исследования являлась демонстрация выявленных возможностей БАС в части доставки грузов различного назначения, а также наличия инфраструктур при получении груза для дальнейшей транспортировки и выдачи его в месте доставки. Приведена история развития технологий беспилотных аппаратов. Представлены соответствующие стандарты Российской Федерации, классификация и категоризация БАС в РФ и за рубежом. Описаны преимущества и недостатки БАС, а также проблемы доставок почтовых отправлений с помощью дронов. Сделаны выводы о стремлении разработчиков и тенденциях по созданию интеллектуальных, полностью автоматических роботизированных авиационных систем, однако отмечено, что полностью автоматических систем пока в мире не существует, следовательно, данное направление разработок является актуальным. Сделано заключение о необходимости проведения научно-технических разработок в части создания автоматической доставки почтовых и иных отправлений, особенно актуальной для мегаполисов, в которых сосредоточена наиболее крупная часть населения развитых стран. При этом очевидно, что система доставки должна состоять, как минимум, из трех этапов – складской сортировки, непосредственно полета и навигации, отправления груза в соответствующий постамат. Каждый этап является инфраструктурной концепцией со сложной системой и логистикой, требующей наличия искусственного интеллекта, роботизированных устройств и других элементов и атрибутов сложных систем, подлежащих всестороннему изучению в техническом, законодательном, юридическом и логистическом плане.

Ключевые слова: беспилотные авиационные системы, беспилотник, дрон, доставка грузов, авиационная техника.

Overview of unmanned aircraft cargo delivery systems

E. V. Solomin[1*], A. S. Martyanov[1], H. Shahin[1],
N. A. Pshenisnov[1], S. K. Sheryazov[2]

[1]South Ural State University (national research university)
76, Lenin Av., Chelyabinsk, 454080, Russian Federation
[2]South Ural State Agrarian University, Institute of Agricultural Engineering
75, Lenin Av., Chelyabinsk, 454080, Russian Federation
[*]E-mail: nii-uralmet@mail.ru

The article is devoted to an overview of unmanned aircraft systems (UAS according to GOST R 59517–2021, or in a number of publications – unmanned aerial vehicles or drones) capable of delivering various cargoes. The options for their application in various fields, including agriculture and forestry, fishing, wildlife protection, air quality monitoring, mining, defense and civilian use, search and rescue operations, are given and briefly analyzed. The purpose of the study was to demonstrate the identified capabilities of unmanned aircraft systems in terms of cargo delivery for various purposes, as well as the availability of infrastructures when receiving cargo for further transportation and its delivery at the place of delivery. The history of the development of unmanned vehicle technologies is given. The relevant standards of the Russian Federation, classification and categorization of UAS in the Russian Federation and abroad are presented. The advantages and disadvantages of UAS are described, as well as the problems of delivering mail using drones. Conclusions are drawn about the desire of developers and trends to create intelligent, fully automatic robotic aviation systems, however, it is noted that fully automatic systems do not yet exist in the world, therefore, this area of development is relevant. It is concluded that it is necessary to carry out scientific and technical developments in terms of creating automatic delivery of mail and other items, especially relevant for megacities in which the largest part of the population of developed countries is concentrated. At the same time, it is obvious that the delivery system should consist of at least three stages – warehouse sorting, direct flight and navigation, and cargo shipment to the appropriate post office. Each stage is an infrastructural concept with a complex system and logistics that requires artificial intelligence, robotic devices, and other elements and attributes of complex systems that are subject to comprehensive study in technical, legislative, legal, and logistical terms.

Keywords: unmanned aircraft aerial system vehicle, UAV, drone, cargo delivery, aviation equipment.

Introduction

Unmanned aircraft systems (UAS), or unmanned aerial vehicles (UAV), according to GOST R 59517–2021 [1], have been used as air transport for the delivery of mail and other goods relatively recently, due to the rapid development of this area in the 20s of the 21st century. UAS systems (or in everyday language ‘drones’) were initially used mainly in the military and in the police for monitoring and tracking objects of surveillance. Since 2016, Zipline unmanned vehicles have been adapted for the delivery of blood and plasma in Rwanda (Africa) [2], then since 2019 in Ghana, having covered a total of more than 1.8 million km. On December 18, 2018, a UAS quickly delivered a vaccine to a child for the first time in the remote island state of Vanuatu in the South Pacific [3]. InTanzania, drones have also been used since 2019 to deliver medicines to hard-to-reach places during the COVID-19 pandemic [4].

Since 2019, during the COVID-19 pandemic, UAS systems have been used to expedite the delivery of tests, vaccines, and medical supplies while minimizing human contact. Among the first drones to deliver medicines and personal protective equipment were also Zipline drones used at the Novant Health Medical Center in Charlotte, North Carolina, USA. In 2019–2020, these UAS delivered 1–2-kilogram packages over a distance of 30–40 km at a speed of 60 km/h.

Further development of the postal service has led to the use of Matternet M2 drones by American postal companies UPS and CVS since 2020 to deliver packages and medicines to special distributors. That same year, Alphabet'sWing inVirginia began delivering small packages, usually food products, to the recipient's door. After the publication of the postal use of drones, their use expanded significantly, penetrating into various areas: military intelligence, transport and logistics, communal and household, etc. Since 2020, leadership in the field of drone operation has gradually begun to shift to China. Postal companies have become especially active [5; 6].

Currently, each country in the world has developed special rules for the use of drones, since they can pose a danger to aircraft, urban infrastructure, as well as people and animals. Moreover, the system of operating unmanned vehicles has quickly developed into a large, including bureaucratic, network. Today, the following structures are involved in the drone delivery service in each country (Fig. 1):

– drone developers and manufacturers;
– creators of software and flight tasks;
– National Air Transport Agency (or other responsible government regulatory agency);
– Federal Air TransportA gency;
– registration and /or licensing agency (identification of aircraft, air traffic management, metrology, notification of new obstacles, permits and prohibitions for flights inspecial zones, etc.);
– investor(s);
– drone owners or delivery service providers;
– drone pilots;
– ground handling, loading and unloading team.

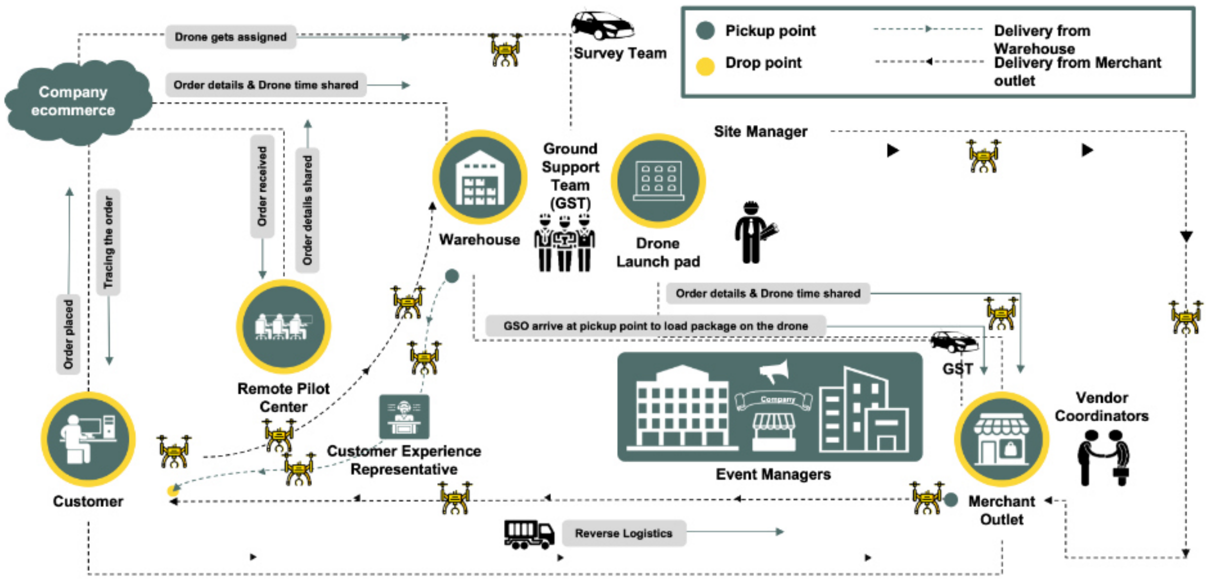

Рис. 1. Инфраструктура доставки отправлений дронами

Fig. 1. Drone delivery infrastructure

There are many laws that apply to drones in terms of prohibiting intrusion into airspace above 100-300 m and close to private property, depending on the country of operation, as well as the period of operation (both time of day and drone size), the weight of the unmanned vehicle, permitted navigation routes, etc. A corresponding license must be obtained to fly a drone. An FPV drone pilot must undergo extensive training and have an appropriate certificate or license to operate unmanned equipment (FPV – First PersonView, view from the perspective of the drone operator).

For the operation of unmanned, especially automatic, robotic vehicles, they require sites for testing, charging batteries (or refueling), navigation systems and maneuvering between buildings and structures, especially in urban areas, where there are many zones with a ban on flights for a number of reasons (Fig. 2).

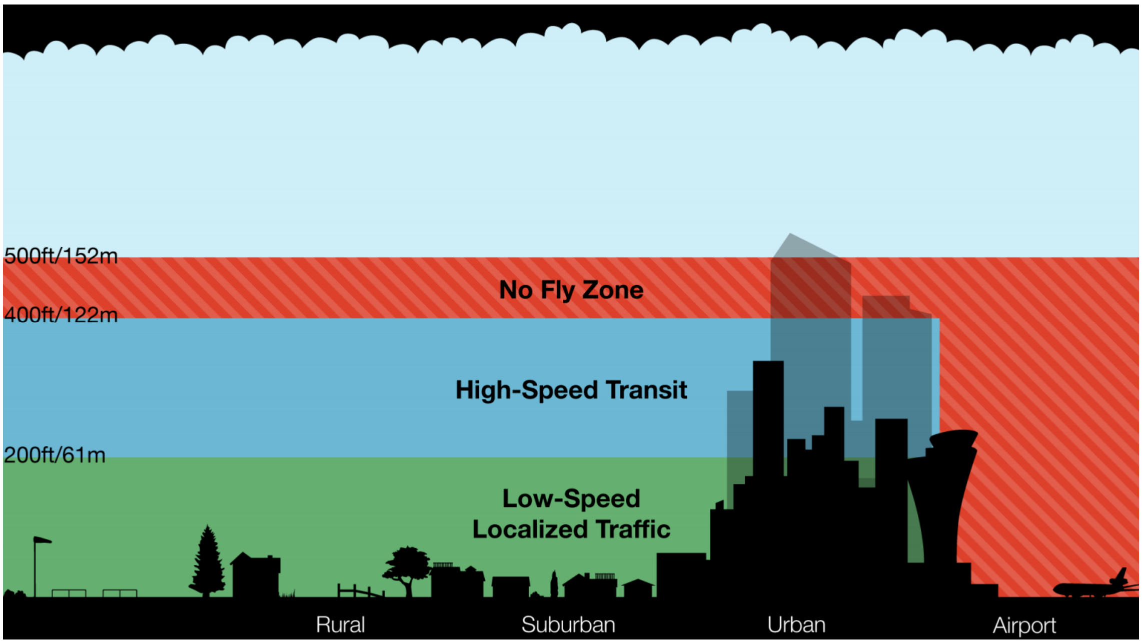

Рис. 2. Особенности воздушного пространства городской застройки

Fig. 2. Features of urban airspace

Weather conditions can seriously affect the behavior of a drone, since snow, rain, and wind can significantly change the route of the device, causing such undesirable consequences as damage to infrastructure or communications, intrusion into the airspace of no-fly zones, injury to people and animals, etc.

When delivering mail by drones, the disappearance and theft of items, accidental or intentional damage to elements of the device, and other circumstances leading to additional costs are possible.

As numerous studies show, the human community is not yet ready for the appearance of drones in the surrounding space due to the presence of noise, the emergence of danger, and most importantly, the invasion of human privacy. This topic is devoted to many publications [7], describing the risks and threats of using unmanned aerial vehicles, with the corresponding target functions [8].

Development of UAS technologies

Obviously, the described problems contribute to a significant increase in the cost of postal items by drones. In this regard, interested transport and logistics companies are striving to reduce costs in every possible way, while improving the quality of unmanned technologies in cooperation with drone manufacturers, programmers, cartographic and regulatory organizations. Due to these initiatives, the following development paths in this area have become more active at present (Fig. 3) [9]:

– development of unmanned aerial vehicle technologies (control of navigation devices and UAS mechanization, detection and avoidance of obstacles, interactive communications with basic systems and aircraft along the route). An important factor in the development of these technologies is the introduction of digital twins, local and global neural networks, artificial intelligence;

– expansion of automatic monitoring of both airspace and drone movement logistics and postal delivery;

– development of interactive intercommunication cartography with automatic application of newly discovered obstacles and exclusion of disappeared obstacles on maps, including popular browsers. Transition to geospatial 3D and 4D maps;

– attracting drone pilots (drone operators) of various types and their comprehensive training. Training of grounds upport operators;

– training students in the specialty “Developer of drones and related equipment”;

– conducting marketing and survey campaigns in order to analyze the development of the direction and accumulate system statistics and analytics of all components of development and transformation into the industry.

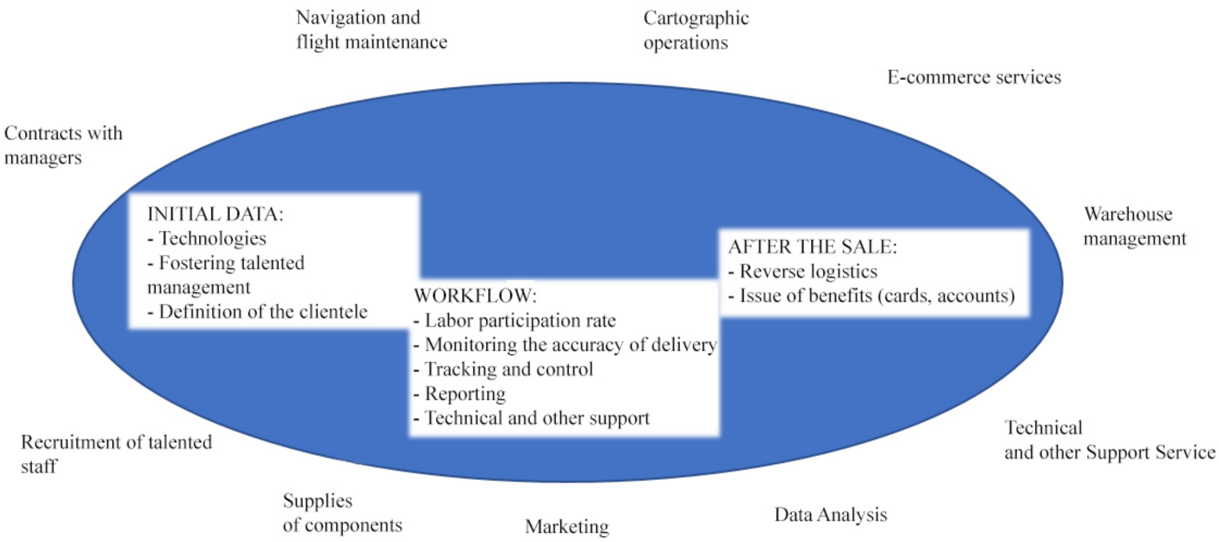

Рис. 3. Развитие направления и преобразование в отрасль

Fig. 3. Development of the direction and transformation into an industry

The advantages of using drones for postal delivery are:

– delivery speed due to straightening of routes;

– absence of difficult-to-reach places, such as off-road, thickets or jungles, impassable rivers and swamps, etc.;

– low operating costs compared to other types of transport;

– low carbon footprint compared to all other types of transport delivery;

– low accident rate compared to all known types of transport;

– high accuracy of cargo delivery, especially for drones with vertical takeoff and landing;

– wide possibilities of machine learning, use of geospatial maps, neural networks, artificial intelligence;

– possibility of contactless cargo transfer (during a pandemic).

As practice shows, the use of drones in the future is predetermined and will develop at a rapid pace. Unmanned technologies continue to improve, incorporating numerous achievements in the IT industry, the telephone industry, artificial intelligence technologies, aviation, etc. Investment amounts and patent activity are growing exponentially every year.

Application of drones

The use of unmanned aerial vehicles or drones is increasingly covering both civil and defense industries, bringing wide operational capabilities that are sometimes unique [10].

As a rule, drones are equipped with various sensors, cameras and other sensor devices for various purposes, allowing for such tasks as collecting information, identifying danger (collision, non-return, excessive distance), orientation on the ground and in space, etc. in day and night conditions, fog, snowfall, strong wind and other adverse weather conditions. At the same time, drones have already proven themselves to be very valuable tools in a wide range of industries, including postal delivery, agriculture, forestry, environmental protection, search and rescue, military affairs, as well as a wide range of scientific research. Moreover, drones in combination with living beings (for example, birds) can present unusual applications, such as controlling swarms of bees [11], flocks of birds [12], etc.

In accordance with the specifics of the application, drones are equipped with various sensors [13], allowing for the assessment of the danger posed by various objects and substances (biological, nuclear, chemical, etc.).

Agriculture. Modern agriculture is a complex mechanism of resource allocation, point and hybrid optimizations, temporal and spatial strategies. Numerous agricultural methodologies and techniques are based on systematic data collection, spatial-temporal mapping, results analysis, forecasting, decision-making, public information, etc. Remoted at a collection and processing technologies widely use aircraft systems, satellites and other unmanned technologies, examples of which are the OLI (Operational Land Imager) sensor systems on Lands at 8, MODIS (Moderate Resolution Imaging Spectroradiometer on Terra and Advanced very-high-resolution radiometer on NOAA-15) for remote monitoring of the earth's surface geolocations using satellites [14–18].

Satellite sensors have proven themselves to be very successful, however, in precision agriculture, which is a complex high-tech management system based on global positioning technologies using geographic information systems, yield assessment technology, variable rationing, etc., the use of satellite sensors is often difficult due to the presence of clouds. The solution to this problem was unmanned aerial systems with similar sensors [19].

The use of such sensors expands the capabilities of remote sensing with a resolution of 30 m in 11 spectral ranges of 435–12510 nm.

Remote monitoring technologies have revolutionized precision agriculture by studying the understanding of the impact of climatic fluctuations on crop growth [20], and the occurrence of periodic floods [21].

Based on the analysis of monitoring data, crop volume is forecasted [22–24], the water balance of agricultural crops and the frequency of field irrigation are managed [25; 26], monitoring forest growth [27].

Today, drones are mainly used to obtain high-quality, high-resolution photographs. An example is the use of the Microdrone MD4-200 microdrone, which has a CMOS camera (Complementary Metal Oxide Semiconductor), manufactured using special technology that requires very low power, with a resolution of 1200×1024 pixels. By analyzing such photographs, it was possible to quickly and accurately estimate the content of nitrogen residues in the soil and the volume of biomass in corn, alfalfa, and soybean crops [28; 29]. In some cases, drones are installed on helicopters for accelerated flights over agricultural lands. The drones themselves are equipped with multispectral and thermal cameras, allowing them to obtain photographs in the thermal spectrum with a resolution of 40 nm and a spectral range of 400–800 nm. This approach, due to the presence of multispectral and thermal sensors, made it possible to demarcate fluctuations in water distribution with ingrape fields and reduce dependence on rainfall [30].

Forestry, fisheries, wild life protection. Drones are now seriously competing with satellites due to their low cost, lack of need to be launched into low-Earth orbit, the ability to shoot in cloudy weather, controllability, etc. Using high-quality, high-resolution photographs, it is possible to measure the height of forest stands, update geographic maps, monitor the behavior of wild animals, conduct and adjust forestry activities, detect and monitor forest fires with automatic recognition and notification of the fireservice, and perform many other useful tasks [31]. For this, remotely controlled drones equipped with thermal and hyperspectral sensors are used. In combination with satellite data, this approach allows for the prompt identification of poaching cases, assessment of critical conditions for the existence of certain animals (for example, flooding, drought, or a strong snowcrust that is dangerous for ungulates), and also counting the number of certain populations [32]. These technologies have significantly reduced the loss of wild animals and increased the preservation of nature in its original form.

Air quality monitoring. This application covers an increasing number of public utilities due to the deterioration of air quality, especially in megacities, with critical levels due to vehicle emissions, smog and other gases.

Mining. During exploration and preliminary geological work, drones are used for research both above and below ground, in caves and other artificial and natural reservoirs, including those with a lack of oxygen and/or the presence of dust or suspension, where a person cannot be physically present. Aerial photography can be carried out both in the visible spectrum and in the infrared range.

Defense and military use. Drones were initially developed for military and defense purposes, including data collection, surveillance, reconnaissance, target identification (targeting), etc. However, in a short time, these devices gained demand in the civilian and logistics segments [33]. Today, the leading countries in the development and implementation of unmanned aircraft systems are the Russian Federation, the United States of America, the United Kingdom of Great Britain and Northern Ireland, Israel, and India. Military drones have been particularly rapidly developed since 2017 when performing pinpoint combat operations by small aircraft, including swarm drones, drones with a jet engine, and microdrones in hot spots such as Somalia, Yemen, and Afghanistan. With the start of Russia's special military operation in Ukraine, drone development not only increased exponentially, but also reached a fundamentally new level with the creation of special branches of the armed forces in Russia, the United States, and a number of other countries. India is also making a significant contribution to the development of military drones, creating advanced DRDO-type robotic manipulators in the category of medium-altitude (upto 800 m) long-term fligh tvehicles that can designate targets, launch and monitor missiles, dropbombs, and carry out strike missions [34; 35].

Civilian use. The transport and utilities businesses have shown significant interest in unmanned aerial vehicles. Today, there is a growing trend among power grid cooperators towards UAS or drones for inspecting high-voltage power lines. In a number of countries, these devices have been completely replacing human actions form annual inspection of power poles, removing ice, eliminating power outages, etc., for over 10 years [36; 37]. Drones are successfully used in rail transport to monitor and record rail defects, especially in regions with increased seismic activity. Such use of drones is invaluable especially in hard-to-reach places and areas with periodic climatic disasters. For the first time, drones were used by government agencies in India to compile operational 3D maps for monitoring railway corridors and national highways. After that, the Internet operator Amazon began using drones to deliver small shipments. Obviously, however, it can not yet be said that, firstly, drones have "taken root" in the delivery service, and secondly, that shipments can be delivered by drones in automatic mode. Nevertheless, drones are used in rescue services today in almost all countries to search for lost people or those involved in a disaster, to deliver water, medicines, as well as food and rescue products and materials. In addition, high-speed and high-flying drones are used to discover new, undiscovered spaces, assess tourist routes, identify defects in buildings, structures, wind turbine blades, etc.

Search and rescue operations. Drones sometimes play a decisive role in rescue operations (SAR – Search and Rescue), especially when there is a time factor [38].

They do not require long preparations and approvals from aviation authorities and in this regard are used as operational forms of communication for the delivery of various items – mobile phones, medicines, water, food and other essential products [39].

A number of developers, researchers and scientists have declared their readiness to fully develop this area with the improvement of unmanned aerial vehicles, especially in terms of rescue operations [40–42].

Today, drones are successfully used to protect natural resources, contribute to the survival of rare animals in various geographic latitudes, helping to overcome the effects of global warming both in terms of flood control and drought. Drones provide in valuable assistance almost every day in monitoring fires in the taiga, rainforests, mineral deposits, cities and small settlements [43; 44].

Mail and delivery. The ability to deliver mail and other items is an attractive business for many companies around the world. Well-known examples in this area are the delivery systems used by Amazon and Google in the US [45; 46] and DHL in Germany [47; 48], which deliver urgent items such as tests, medicines and other urgently needed items to customers. The vertical takeoff of UAS in the form of copters is a special advantage of these machines due to the possibility of point delivery of items.

Space drones. Space drones are not intended for transporting items on Earth, but they are promising, firstly, for sending various items to space stations, other planets and satellites, as well as for exploring cosmic bodies and space. At the same time, space drones occupy a rather advantageous position among other robotics due to their wide capabilities, which makes these devices indispensable for the examination of various space objects - asteroids, comets and other celestial bodies [49]. Moreover, several drone models have already been created for space missions and the exploration of other planets, in particular, Mars [50–52]. It is important to note that space and alien drones must undergo serious customization, i.e. parameter adjustment, have adaptive characteristics and be protected from various types of threats – radiation, harmful and toxic aggressive substances, extreme overloads, varying degrees of gravity and acceleration, etc. For example, on Mars, a 38.5% decrease in gravity will increase lift and maneuverability, which in turn will affect the operation of the control system in terms of speed [53].

Sea drones. Sea drones have not yet been considered as transport drones, but it is logical to assume that this type of transport may subsequently prove to be very effective in terms of prompt delivery of shipments to accident and disaster sites. Sea vehicles can serve as excellent and convenient devices for studying marine organisms, detecting oil and other emissions, and for other purposes [54–56].

In the future, according to a number of experts, interaction between sea and air drones, including combine dones, will be organized for the delivery of various shipments by sea and land. Obviously, sea delivery can be much more effective than air delivery, and the presence of a vertical takeoff drone on a sea drone expands the possibilities for cargo delivery. Today, sea drones are mainly used for underwater operations and delivery of airshipments by air drones based on underwater drones [57–63]. Such models include Scan Eagle, Volans, and Cormorant drones.

Land (road) drones. Road drones in the form of robotic cars have undergone a rapid development stage since 2019, when this direction was just beginning to emerge [64], and today they are already operating in a number of countries based on algorithms such as a “swarm of bees” or “colony of ants” [65].

Drones of general application. In addition to traditional use, UAS or drones are used in quite unusual ways, but with great benefit for various services. For example, the Tokyo Police Department has developed about a thousand options for protecting the city’s air space and flight corridors from unauthorized drones, which are sold generally without control, especially those with low weight. For this purpose, there are counter-drones that, in the event of disobedience of any aircraft, can carry out an attack to destroy a suspicious drone-intruder [66].

Drones can also perform unconventional tasks – for example, serving as air platforms for other drones [67]. Drones are also used to scare away or control the behavior of birds on airport runways [68].

They can be used to clean windows, drain pipes, wind turbine blades, solarpanels, and many other objects [69].

And, of course, drones can be used as video and photo cameras at leisure events, especially in extreme places [70].

Arctic development. A number of countries are developing the Arctic due to the presence of large mineral deposits under the Arctic ice. The shores of the Arctic seas can be successfully used for living and performing various tasks - fishing, protection and defense measures, observing the development of natural processes, archaeological excavations, etc. Drones are considered by researchers as systems for monitoring and recording various events.

Use of UAS in Russia. Domestic Russian UAS technologies have made strides in the past few years, both qualitatively and quantitatively. The Concept of Technological Development for the period up to 2030 [91] launched the national project 'Unmanned Aircraft Systems' [92], which defined the key priorities for the development of unmanned systems in the Russian Federation. According to this project, which has become one of the most critical for achieving technological sovereignty and leadership, the share of domestic UAS in the total market volume (including airplanes, helicopters, multirotors) should be at least 70.3 % by 2030. In quantitative terms (excluding educational UAS), this number is calculated as 46,230 units. The level of technological independence of the industry should reach 81.1 %. Russian companies in the field of unmanned aircraft construction are seriously engaged in logistics [1–3], delivery of various shipments [4] and products [5], as well as studying the economics of UAS systems [6]. The development of UAS in accordance with the concept of the National Technological Initiative [93] is carried out according to a four-level model of sky architecture: space (control); stratospheric (stability); logistic and economic. The St. Petersburg International Economic Forum 2024 highlighted common trends and challenges in relation to the development of the UAS market, which is becoming a branch of the economy:

– simplification of UAS operation processes;

– achieving the minimum required level of safety for UAS operation (not lower than the level of regular commercial transportation);

– development of digital flight rules;

– infrastructure unification and implementation of interoperability principles (in the future, it is extremely important to comply with the principles of interoperability when integrating drones of various environments into a single ecosystem);

– expansion of functional scenarios for the use of UAS;

– operation in an environment saturated with various objects (including the application of X2X principles);

– a radical reduction in the cost of services for the end user.

The special attitude of the Forum was designated to interoperability in terms of implementation at the hardware and software levels, with the exclusion of parallel financing of similar projects with different standardization, with the achievement of a high synergistic effect.

In terms of achieving technological leadership in Russia, since 2024 the Ministry of Education and Science has launched a federal project "Advanced Technologies for UAS" to carry out R&D, within the framework of which nine priority areas for the development of UAS are identified [95]:

– navigation technologies, radio navigation;

– computers, photonic integrated information systems;

– new production technologies and new materials for UAS;

– technologies for group interaction of unmanned aerial vehicles (UAV), decision-making and integrated UAV control systems;

– technologies and means for integrating unmanned aerial vehicles into a single air space;

– machine vision technologies for UAS;

– technologies, layouts and principles of UAV movement;

– technologies, methods and means of communication;

– power and power plants.

According to the objectives of the Project, it is necessary to lay a solid foundation for the development and production of fully autonomous UAS using artificial intelligence within a few years, with the formation of a single, seamless digital environment for the interaction of unmanned vehicles of various types and various environments. For example, so that one device performing monitoring, in the event of a certain signal situation on the railway tracks, would transmit a corresponding notification to a ground wheeled device for autonomous trouble shooting. Thus, the Project covers broad interdisciplinary tasks.

The UAS market of the commercial sector of the B2B economy (business sales) is growing by an average of 60 % per year [96]. In 2023, it amounted to 8 billion rubles, and by 2028 it should exceed 82 billion rubles. According to Rostelecom, an increase in investment in the emerging industry is expected from the logistics, agriculture, construction, and energy segments, as those most interested in the development of UAS technologies. The main advantages of UAS for the business segment are the ability to optimize and simplify processes, reduce labor costs, accelerated at a collection, and minimize the human factor. However, at the moment, the development of UAS is constrained by the complexities of legal and logistical regulation, under developed infrastructure, and limited information about already implemented cases of using drones for business purposes. According to the Aeronext Association, the unmanned drone market in 2023 was underutilized by 34 % of devices due to the remaining bans on UAS flights in many regions of Russia since autumn 2022.

According to various forecasts (Rostelecom, Aeronext, etc.), in Russia, as the largest country in terms of territory, postal drones will be primarily in demand for delivering orders from online stores such as Yandex, Ozon, WB and many others. IT Holding T1 is already testing the delivery of medicines by small drones weighing up to 30 kg in the Yamalo-Nenets Autonomous Okrug along the Naryan-Mar – Andeg – Naryan-Marroute. After receiving the air worthiness certificate under the simplified procedure, the Holding plans to develop, manufacture and operate drones weighing more than 30 kg [97]. Currently, the production of civilian UAS is mainly focused by the Holding on agriculture in terms of a separate device such as Rubin A50 (Fig. 4) with sensor systems for avoiding obstacles while following a route. The device facilitates the automation of agricultural processes and the efficient application of chemicals. The Holding manufactures 500–1500 units of devices with complex navigation systems per month.

Рис. 4. Агродрон «Рубин А50»

Fig. 4. Agro-drone “Rubin A50”

There are examples of UAS application in Russia:

– aerial monitoring of 50+ capital construction projects (PJSC Gazprom, since 2021);

– aerial monitoring during reconstruction and modernization of the Baikal-Amur Mainline (PJSC Russian Railways, since 2022);

– monitoring of city construction sites, control over the delivery of facilities (Department of Construction of the City of Moscow, since 2021);

– monitoring of the construction of the International Medical Cluster using online broadcasts (Skolkovo, since 2023);

– emergency recovery operations on overhead powerlines, inspection of lines after stormy weather conditions, study of power transmission lines up to 200 km/day (PJSC Rosseti, since 2021. Digital Transformation 2030 Program);

– geological exploration, pipeline inspections, gas (oil) leak detection, monitoring of construction sites, checking the condition of offshore and onshore platforms, checking the flare tower, fire safety monitoring (Neftegaz (Tatneft, Sibur, Gazprom) since 2019; technology development has been carried out using artificial intelligence since 2025;

– test delivery of parcels (Russian Post, Pony Express, etc. The pilot project began in 2023, final tests are planned for 2025–2026);

– temporary communication networks during mass events, natural disasters, or other emergencies (PJSC Rostelecom, since 2020);

– military reconnaissance missions (Kalashnikov Concern. SKAT 350M, Kub type devices (Fig. 5).

Promising technologies are offered by a number of educational institutions. Reshetnev Siberian State University of Science and Technology (Krasnoyarsk) plans to develop a hybrid communication system based on stratospheric (25–30 km) unmanned vehicles. Such technologies will significantly improve the quality and reduce the cost of mobile (satellite) communications [98].

Strike UAS were rapidly developed during the Special Operation in Donbass. Since 2015, in the context of the military operation in Syria, unmanned vehicles have proven their advantages, evolving from optical carriers to means of delivering light weapons. Moreover, both small reconnaissance UAVs and large strike UAVs have become widespread. Light UAVs such as the 'Inohodets' can carry small grenades and mines first using a make shift suspension, then with an industrial fastening system. FPV drones are usually used as light and maneuverable loitering munitions to hit various targets, including hidden ones. Kamikaze drones like the Lancet-3 with anti-laser protection are also actually loitering munitions and are used to hit mobile and stationary targets within a radius of up to 40 km or more with precise target destruction (Fig. 6). The Geran-2 long-range heavy-hitting (up to 200 kg) UAVs can hit targets within a radius of up to 2.500 km.

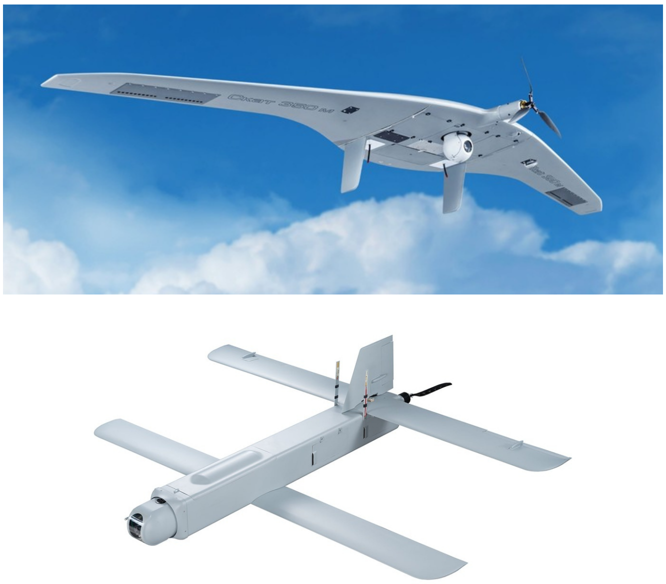

Рис. 5. БАС СКАТ 350М концерна «Калашников» и Куб-Э
(управляемый барражирующий боеприпас)

Fig. 5. Kalashnikov Concern SKAT 350M UAS and Kub-E
(guided barrage ammunition)

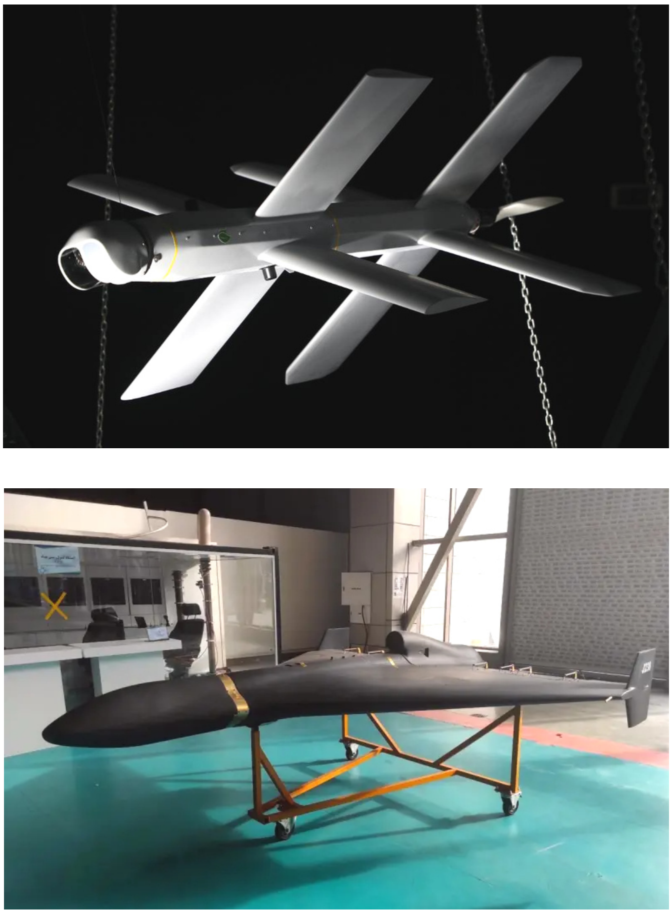

Рис. 6. БАС «Ланцет-3» и «Герань-2»

Fig. 6. UAV “Lancet-3” and “Geranium-2”

In recent years, vertical takeoff and landing (VTOL) UAS with a payload capacity of 15–300 kg are of great interest in Russia. These include drones such as the Phaeton (payload up to 15 kg, 5-hour flight, 500 km), the Burya-20 with compartments for FPV drones (payload 15 kg, 5-hour flight, 500 km), the R-75 convertiplane from Ecolibri (payload 25 kg, 7-hour flight, 750 km), the S-76 (MBS) (payload up to 50 kg, 4-hour flight, 400 km), and the S-76 from Sukhoi Design Bureau (payload up to 300 kg, 5–7-hour flight, 1.500 km).

When analyzing military drones, it becomes clear that UAS technologies have been greatly developed during the Special Military Operation due to the possibility of developing technologies without taking into account many existing flight restrictions. Moreover, it is also becoming obvious that the current GOSTs are seriously outdated, airspace regulation needs serious revision, and the technologies of unmanned vehicles themselves can be adapted in the civilian sector with enormous economic benefits.

Drone Design Methods

The process of developing a drone, regardless of its weight, functionality, topology, size, etc., can be formally divided into three main stages – concept development, preliminary design and detailing [77–80].

Each stage requires a comprehensive assessment of size, aerodynamics, aeroelasticity, strength, stability, control, reliability and performance [81–82].

The process of determining the size of a drone, as a rule, includes the following stages [83–87]:

– determination of mission parameters (remoteness, complexity, stealth, speed at various points of the route, the need for maneuvering);

– determination of the flight mode depending on the mission requirements;

– determining the wing configuration and aerodynamic quality using load modeling, ultimate loads, solving kinematic and dynamic systems of equations;

– overcoming design problems and contradictions; optimizing the aerodynamics of components and the entire apparatus as a whole;

– predicting the drone mass based on the data obtained during modeling;

– determining the engine power and battery capacity;

– achieving mission accuracy (precise takeoff, landing and drop locations);

– assessing the cost of R&D in comparison with the mission being performed and in accordance with the production culture, technological capabilities of the component manufacturer, availability of tooling, materials and components.

Drone classification

In Russia, drones (UAS) are classified and categorized by GOST 59517–2021. Unmanned aircraft systems. Classification and categorization [1].

According to this standard, UAS are classified as follows:

– by the maximum take-off weight of the UAS as part of a UAS: from 0.25 to 30 kg inclusive, from 30 kg and above;

– the kinetic energy achieved by the UAS in flight: 100 J or less, more than 100 J and above;

– by operational purpose: for personal purposes, for performing aerial work;

– by visibility conditions: direct radiovisibility, no direct radiovisibility.

UAS categories

Open category (A). UAS may be assigned to category A provided that it meets the following criteria: the maximum take-off weight of the UAS as part of UAS is not less than 0.25 kg and does not exceed 30 kg; the maximum kinetic energy achieved by the UAV during flight does not exceed 100 J (and the UAV as part of the UAS does not have rotating parts in its design that could cause serious bodily harm); the use of the UAV is only for personal purposes, while the performance of aerial work is not permitted; the flight of the UAV as part of the UAS is carried out under the following conditions: (altitude limitation up to 150 m; flights in BVLOS (Beyond Visual Line of Sightor IFR - Instrument Flight Rules) conditions; flights are carried out during day light hours; flights are carried out at a distance from buildings and people of at least 150 m or in airspace specially allocated for flights of unmanned aerial vehicles.

Special category (B). The UAV can be classified as category B if it meets the following criteria:

– the characteristics and design of the UAV exceed the limitations specified in the previous paragraph;

– the automatic control system, in the event of loss of communication, ensures the return of the UAV to the point of departure of the flight until the restoration of the operability of the command and control line or immediate flight termination;

– the UAV is supposed to be used to perform aerial work in the operational volume of the allocated airspace approved for this in accordance with [1], which establishes the procedure for using airspace.

Based on the Federal Aviation Rules "Certification aviation equipment, development and manufacturing organizations", Part 21, 2019, Category B UAS are allowed to fly subject to confirmation of compliance with ther equirements for a single aircraft as part of a UAS or the volume of air worthiness requirements for UAS with UAV of the corresponding type approved by the federal executive body in the field of civil aviation in the form of a type certificate or a type certificate of a limited category.

To prove the compliance of a Category B UAS with the expected operating conditions, the applicant may use the results of the risk assessment of special situations that may arise during or as a result of a UAS flight as part of a Category B UAS in accordance with the methods approved by the federal executive body in the field of civil aviation.

Certifiable category (C). UAS may be classified as category C if it is necessary to perform UAS flights as part of UAS in the declared class of non-segregated airspace according to visual flight rules and instrument flight rules.

Category C UAS are allowed to fly subject to confirmation of compliance with the approved volume by the federal executive body in the field of civil aviation with the requirements of the airworthiness standards of UAS with UAV of the corresponding type in the form of a type certificate or a type certificate of a limited category.

Operation of category C UAS must be carried out in accordance with the Federal Aviation Rules establishing the procedure for the use of airspace.

Classification of drones abroad

The classification of drones abroad (in the West) has taken various, rather vague, non-strict forms [88; 89]. In particular, the following parameters or characteristics are usually used for the classified objects:

– control methods: remotely piloted with control in two modes – manual and automated, and automatic with autopilot control along a predetermined trajectory at a given altitude with a given speed and with stabilization of orientation angles;

– design type: fixed-wing unmanned aerial vehicles with a direct push on a fixed wing to obtain lift and rotary wing unmanned aerial vehicles, which are divided into two types - single-rotor and multirotor (multicopter);

– by size and weight: super-heavy (take-off weight over 2 tons – X-45, Darkstar, Predator B and Global Hawk), heavy (weight from 200 to 2000 kg), medium weight (from 50 to 200 kg), light (from 5 to 50 kg) and micro (up to 5 kg);

– by flight altitude: low altitude (up to 1000 m – FPASS, Pointer, Dragon Eye), medium altitude (from 1000 to 10,000 m – most UASs or UAVs) and high altitude (more than 10,000 m – X-45, Predator B, Darkstar, Global Hawk). According to other classifications [90], drones are divided into categories such as micro or nano (Miniature, MAV, NAV Air Vehicles with low flight altitude up to 330 m and short flight time), vertical takeoff and low altitude flight (VTOL Vertical Take-Off & Landing do not require a runway. An example is shown in Fig. 7 – Convair XFY-1 Pogo), small UAS (LASE Low Altitude, Short-Endurance or sUAS – Small Unmanned Aircraft Systems with a mass of up to 2–5 kg), medium altitude up to 9000 m long-term flight (LALE Low Altitude, Long Endurance several hundred kilometers of flight), high altitude up to 20,000 m and above long-term flight (HALE High Altitude, Long Endurance over 30 hours of flight).

The latest developments are aimed at miniaturizing components, equipping them with the maximum set of sensors, improving navigation characteristics, and creating ground bases for stopping and refueling UAS.

Conclusion

As the review analysis shows, despite the existence of scattered attempts to create intelligent complexes for the delivery of small and large cargo, fully automatic systems (according to GOST 34.003–90) combining automatic interaction of the platform preparing for cargo collection, UAVs with manipulators (GOST R 57258–2016) and a parcel distributor do not yet exist.

Thus, despite the imaginary popularity of the idea of delivering postal items, as well as the wide experience of using UAVs to transport various items, the integrity and automation of the cargo deliv-

Рис. 7. БАС с вертикальным взлетом и горизонтальным полетом Convair XFY-1 Pogo

Fig. 7. Convair XFY-1 Pogo vertical takeoff and horizontal flight UAS

ery process is still absent. In no country in the world is there automatic sorting before cargo collection, there is no clear autonomous flight mission, there are not even concepts of cargo receivers and distributors in multi-story (multi-office) buildings. Nevertheless, with the growth of consumption of light small-scale cargo, delivery times to parcel terminals and pick-up points by delivery companies are steadily increasing. This problem is especially typical for mega cities, where there is an unstoppable growth in the number of parcel terminals and, accordingly, the number of city transport for delivering parcels. In addition, the problems of automatic flight around existing and newly erected obstacles that are not indicated in current cartographic documents - trees, scaffolding, masts, guylines, etc. – have not yet been solved. Thus, logistics (including the use of big data) at any stage of cargo delivery to the consumer (customer) has not yet been solved.

Nevertheless, trends towards the transition to semi-automatic and automatic systems for sorting, delivery and distribution of goods, and the expansion of the use of autonomous UAVs are becoming noticeable. Consequently, the opportunities for R & D in terms of postal delivery are quite broad.

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Соломин Евгений Викторович – доктор технических наук, профессор, профессор кафедры электрических станций, сетей и систем электроснабжения; Южно-Уральский государственный университет (национальный исследовательский университет). E-mail: nii-uralmet@mail.ru. https://orcid.org/0000-0002-4694-0490.

Мартьянов Андрей Сергеевич – кандидат технических наук, доцент, доцент кафедры электрических станций, сетей и систем электроснабжения; Южно-Уральский государственный университет (национальный исследовательский университет). E-mail: martyanov_andrey@mail.ru. https://orcid.org/0000-0002-9997-9989.

Шахин Ханна – аспирант кафедры электрических станций, сетей и систем электроснабжения; Южно-Уральский государственный университет (национальный исследовательский университет). E-mail: hannashahin9902@gmail.com. https://orcid.org/0009-0004-5670-8144.

Пшениснов Никита Анатольевич – кандидат технических наук, преподаватель кафедры промышленной теплоэнергетики; Южно-Уральский государственный университет (национальный исследовательский университет). E-mail: pshenisnovna@icloud.com. https://orcid.org/0009-0003-3734-9177.

Шерьязов Сакен Койшыбаевич – доктор технических наук, профессор, профессор кафедры энергообеспечения и автоматизации технологических процессов; Южно-Уральский государственный аграрный университет. E-mail: sakenu@yandex.ru. https://orcid.org/0000-0001-8795-5114.

Solomin Evgeny Viktorovich – Dr. Sc., Professor, Professor of Department of Electric Power Generation Stations, Network and Supply Systems; South Ural State University (national research university). E-mail: nii-uralmet@mail.ru. https://orcid.org/0000-0002-4694-0490.

Martyanov Andrey Sergeevich – Cand. Sc., Associated Professor, Associated Professor of Department of Electric Power Generation Stations, Network and Supply Systems; South Ural State University (national research university). E-mail: martyanov_andrey@mail.ru. https://orcid.org/0000-0002-9997-9989.

Shahin Hanna – Graduate student of Department of Electric Power Generation Stations, Network and Supply Systems; South Ural State University (national research university). E-mail: hannashahin9902@gmail.com. https://orcid.org/0009-0004-5670-8144.

Pshenisnov Nikita Anatolyevich – Cand. Sc., Associated Prof. of Department of Industrial Heat Power Engineering; South Ural State University (national research university). E-mail: pshenisnovna@icloud.com. https://orcid.org/0009-0003-3734-9177.

Sheryazov Saken Koishybaevich – Dr. Sc., Professor, Professor of Department of Electric drive, mechatronics and electromechanics; South Ural State Agrarian University, Institute of Agricultural Engineering E-mail: sakenu@yandex.ru. https://orcid.org/0000-0001-8795-5114.

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