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TECHNICAL ASPECTS OF AVIATION FIREFIGHTING IN ECOSYSTEMS: THE EXPERIENCE OF FOREIGN COUNTRIES

Abstract. The article examines the technical aspects of aviation firefighting in ecosystems based on the experience of leading countries around the world. The features of natural and man-made ecosystems in the plane of fire suppression are disclosed. It is specified conditionality of occurrence of requirement in aviation firefighting, first of all, by existing features of ecosystems, and also available level of technical development and possibilities of manned aviation on operative performance of tasks of firefighting in ecosystems. The state of fire aviation of the USA and Canada, European countries, China and other countries, as well as infrastructural peculiarities in organization of fire extinguishing from the air were investigated. According to the results of the study it is noted that the fleet of fire-fighting aviation or aviation involved in fire suppression consists of different types of aircrafts and helicopters, which are used depending on the ecosystem for rapid elimination of the fire occurred in the ecosystem. Attention is focused on the prospects of creating aviation firefighting means based on unmanned aviation, which develops in an avalanche-like manner and allows to optimize firefighting in different ecosystems. Attention is drawn to the direction of development, though not quite new, but useful, the essence of which is the use of aviation firefighting means in the form of special bombs on the example of Russia, China and Israel. The state of fire-fighting aviation fleet of Ukraine was analyzed. Proposals of technical and organizational character of the further development of fire extinguishing from air in Ukraine are investigated. The analysis of the given proposals showed that the direction connected with the development of unmanned aerial firefighting aircraft in natural and artificial ecosystems of Ukraine still remains at the level of ideas, though it requires further promotion in our country, which has a number of aviation enterprises, capable of successfully solving the following problems under the conditions of the necessary financing. The conclusions focus on the fact that the considered directions of development of fire aviation in Ukraine are mostly at the level of ideas, which should be, first of all, scientifically grounded. The directions of further research should be considered the development of the newest and scientifically justified technical solutions with their subsequent implementation in the infrastructure of aviation firefighting in Ukraine.

Keywords: ecosystem, fire, aviation firefighting, firefighting aircraft.

Formulation of the problem

An ecosystem is defined as a structural and functional unit of the biosphere, which includes both organisms and the biotic environment, which influence each other's properties and are necessary for life support.

There are two types of ecosystems - natural and artificial. A naturally occurring system develops through the constant interaction between biotic and abiotic environmental factors. A man-made artificial system consists of plants, animals, people, and technology for its own good [1].

Ecosystems occasionally experience fires:

forest fires,
steppe fires,
agricultural fields,
administrative or residential buildings,
civilian and military warehouses, etc.

Depending on the fire and the place of its origin, various means of extinguishing are used, including firefighting aviation.

Global innovations in the field of piloted fire (firefighting) aviation and the avalanche-like development of various unmanned aircraft systems (complexes), which gave impetus to the activation of the idea of using unmanned aerial vehicles (hereinafter referred to as UAVs) for extinguishing fires from the air both in a separate application and together with piloted

aviation, is the basis for the further development of aviation firefighting in ecosystems.

In 2018, the State Emergency Service of Ukraine (hereinafter referred to as the Emergency Situations Service of Ukraine), which has its arsenal of aerial firefighting - piloted An-32P aircraft - took the first step towards the introduction of unmanned aviation in the field of aerial monitoring of emergency situations (fires, floods, landslides, etc.) in the activities of its regional structures, which were represented by various types of quadcopters:

DJI Phantom 2;
DJI Phantom 2 Vision;
DJI Phantom 3 Professional, Hubsan H502S FPV;
DJI Matrice 100, DJI Matrice 200;
DJI Mavic Air;
DJI Mavic 2 Zoom;
Yuneec Typhoon H

and others [2, 3].

In Ukraine, there are also Mi-8MTV-1 firefighting helicopters from the fleet of the airline company "Ukrainian Helicopters" [4].

Analysis of recent research and publications

A number of domestic and foreign scientists and specialists dealt with some issues of research on the foreign experience of aviation firefighting and its development.

Thus, in the article "Monitoring forest fires with UAVs" (2019), attention is focused on the use of UAVs for timely solving the tasks of detecting fires and their extinguishing, as well as accompanying fire extinguishing measures [5]

Proposals for the use of copter-type UAVs for aerial firefighting are outlined in "How Firefighters Can Better Manage Emergency Situations Using Drones" (2019) [6].

The results of the analysis of the state of manned firefighting aviation in the world and in Ukraine, as well as problematic issues and some proposals for its further development are presented in the article "Proposals for the Development of Firefighting Aviation of Ukraine" (2020) [7].

The role of piloted aviation in extinguishing forest fires and the main tasks that must be solved in Ukraine to increase the effectiveness of extinguishing fires in natural ecosystems with the use of piloted aviation were disclosed by a team of authors in the article "Organizational aspects of the use of aviation forces for forest fire extinguishing" (2021) [8]

In the article "Unmanned aerial vehicles - a vital robotic tool of modern times" (2021), the author partially noted that according to the experience of the leading countries of the world, UAVs are considered a breakthrough technology in the field of robotics and are actively used in the field of civil defense not only for detecting and preventing fires, but also for their quenching in ecosystems [9].

The possibility of using UAVs for extinguishing fires with specific requirements for them is indicated in the material "Theory and Practice of Fire Firefighting and Eliminating Emergency Situations" (2021) [10].

In the work "Firefighter Drones 2022: Top Full Guide For You" (2022), the author focuses on the possibility of using copter-type UAVs for quick and effective delivery of water and other anti-permeants to the places of fire [11].

The conducted analysis showed that research is being conducted that sheds light on some issues regarding the directions of development of aviation firefighting in ecosystems. At the same time, the issue of systematization of foreign experience in Ukraine in the field of development of aviation firefighting in natural and artificial ecosystems remains problematic and requires research in order to determine possible directions for the development of firefighting aviation in Ukraine.

The purpose of the article

To systematize the foreign experience of aviation firefighting in ecosystems and directions of its development, as well as to substantiate proposals regarding possible directions of development of firefighting aviation in Ukraine.

Research methods

The method of theoretical research is used, the components of which are the following operations: analysis, synthesis, analogy, comparison, generalization, systematization, etc.

Presenting main material

Aviation firefighting has its own history. The idea of using aviation to detect fires in natural ecosystems first appeared in the USA in 1916 [12].

However, it could be put into practice only three years later, when the federal government transferred several firefighting planes to the U.S. Forest Service to monitor forest fires in California, Oregon, and Washington. In Canada, the aircraft for monitoring began to be used in 1921, and in the USSR - a few years later.

In the USSR, aerial fire monitoring was implemented later than in the USA and Canada. At the same time, the Soviet Union became the first country in the world to drop fire-fighting substances from the air, thereby opening the era of using aviation to extinguish fires.

This happened in 1933 when extinguishing a steppe fire on the territory of the grain farm of the North Caucasus branch of the VNDISH branch (dropping water from the U-2SP aircraft on the burning remains of the stalk 70-80 cm high after harvesting grain) [13].

Before the Second World War, aircraft were mainly involved in patrolling forests, monitoring the fire situation and landing firefighters to fight fires. Experiments were conducted with dropping water from the plane, but the small volumes of liquid for fire extinguishing and the lack of a unified system for fighting forest fires at the time made such a plane ineffective. In the USSR, Po-2 and R-5 aircraft were converted for this purpose. After the war, the situation changed radically. This is especially true in the US, where the bombers left in large numbers after the war were sold at low prices, and the government at the time began to show concern about the ever-increasing damage from forest fires. The bombers were converted to dump water, which became the basis for the creation of the 50s of the 20th century. In the USA and Canada, a powerful fleet of such aircraft:

B-17,
B-24,
B-26,
PB4Y,
Tigercat,
Avenger, etc. [14].

In 1969, the CL-215 amphibious aircraft, designed specifically for extinguishing forest fires from the air, made its first flight in Canada [15].

Two conclusions can be drawn from the historical analysis of aviation firefighting. The first is the conditioning of the need for aviation firefighting, first of all, by the existing features of natural ecosystems. The second is the level of technical development and capabilities of manned aviation for the prompt execution of firefighting tasks in natural ecosystems.

The development of humanity on the planet has led to the creation of artificial ecosystems for various purposes, which, like natural ones, have grounds for using manned aircraft to extinguish fires that occur in such artificial ecosystems as, for example, agricultural fields with cereal crops or fuel storage sites located on open areas.

In connection with the above, we will briefly consider the characteristics of natural and artificial ecosystems using the example of Ukraine, which determine the necessity and difficulty of using piloted aviation for extinguishing fires that occur in them. Terrestrial natural ecosystems of Ukraine include forests and steppes.

The forest zone is located in the north and west of the plain part of Ukraine. It occupies about 24% of the country's territory. Within its boundaries, two subzones are distinguished: mixed (17% of the area) and broad-leaved forests (7% of the area). The broad-leaved forest subzone occupies the western part of Ukraine. The steppes were preserved only in the system of protected objects on the area, which is about 0.6% of the territory of Ukraine [16].

Any ecosystem is characterized by its dimensions. Forests and steppes are considered to be long area objects of considerable size. This determines the possibility of using firefighting aircraft for extinguishing fires, under the conditions of their occurrence and coverage of the territory of ecosystems. For this, there are also necessary conditions to ensure the safety of manned aircraft flights.

The composition of artificial ecosystems includes cities and villages with their infrastructure, agricultural land, separate various civil and military infrastructures (fuel storage bases; separate large production enterprises; power plants, including nuclear ones; large warehouses of products; arsenals with ammunition; weapons storage bases and military equipment, etc.), in which or on which fires occasionally occur for various reasons.

On the territory of Ukraine there is a very dangerous artificial ecosystem "Chernobyl Exclusion Zone", which, in addition to its considerable size, has another characteristic - a different level of radiation pollution in its territory after the accident at the Chernobyl nuclear power plant in 1986.

For extinguishing fires, for example, on agricultural land, arsenals with ammunition, bases for storing weapons and military equipment, in the Chernobyl exclusion zone, as experience shows, piloted firefighting aircraft can be used. For extinguishing fires in the conditions of a city, especially a sufficiently urbanized one, such aviation can be used to a limited extent if there are, for example, square fires, due to the dangers and consequences for the ecosystem that may be associated with the occurrence of an aviation event and its negative consequences under the conditions falling on residential blocks.

At the same time, fire statistics in Ukraine show a significant number of local fires occurring within cities and towns: 57% and 42%, respectively, of the total number of fires. For comparison, fires in natural ecosystems do not occur so often and account for 0.2% of the total number of fires, but the consequences and damages from such fires are very impressive [17].

Scientific and technical progress has increased the possibilities for the further development of firefighting aviation and created conditions for the development and use of unmanned aviation not only in the interests of monitoring, but also for direct extinguishing of fires, including within such artificial ecosystems as cities and

villages, which is confirmed the experience of a number of foreign countries.

Piloted aviation, which is used for firefighting in ecosystems at the current stage, is divided into two groups: airplanes and helicopters. It should be emphasized that in most countries the number of helicopters regularly used for firefighting exceeds the number of specialized piloted firefighting aircraft. This is primarily due to the wider introduction of helicopters in the activities of rescue services and forestry, as well as the spread of various types of drainage devices for helicopters, which allows you to quickly modify any civilian or military helicopter into a firefighting one, if there is a suitable attachment and strength of the power installation allows you to lift the appropriate weight. Let's consider the technical aspects of firefighting from the air based on the experience of a number of countries around the world.

In the United States and Canada, modern firefighting aviation is represented by heavy manned aircraft based on wide-body civilian airliners and military transport aircraft. Mainly used are airplanes taking off from ground airfields. This is due to the fact that large tracts of industrially important forest are located in the western United States, where bodies of water suitable for landing seaplanes are quite rare. The large carrying capacity of airfield-based aircraft, compared to amphibious aircraft, allows to partially compensate for their low performance. Such planes, for example, include the world's largest firefighting plane, the Boeing 747ST Supertanker, capable of dropping about 72,000 liters of water or fire retardant immediately in one flight, or gradually in several places. DC-10 and BAe-146 firefighting aircraft are widely used [18]. Aviation firefighting is also represented by a fleet of such aircraft as: AT-802F, P2V, C-130H, MD-87, C-130Q, RJ85, C-130 H&J.

The firefighting aviation includes amphibious aircraft CL-215, CL-415, CL-515 and Air Tractor Fire Boss [19].

Helicopters in various configurations are actively used for firefighting in the US and Canadian ecosystems. The advantages of helicopters, despite the significant operating costs and limited carrying capacity, are considered to be the ability to fill water tanks in almost any reservoir, as well as greater efficiency due to the increased accuracy of dropping this water to the scene of the fire. It should be noted that until the early 1960s, helicopters were almost never used to protect forests from fires in the United States, as there were few commercial airlines and the military provided helicopters only in critical situations when wildfires became uncontrollable. After the so-called "helicopter boom" that began in the late 1960s, when affordable and reliable models appeared on the civilian market, the use of helicopters in forest protection became commonplace. Chinook CH-47, which can transport more than 11,000 liters of water [20], is considered one of the largest firefighting helicopters both in the USA and in the world.

The line of firefighting helicopters of the USA and Canada includes:

Sikorsky S-64,

Sikorsky S-70 [21],
Bell-212 HP [22],
Bell-412 [23], etc.

To ensure replenishment of water reserves for firefighting in 2020, a special fully automated platform 69 Bravo is connected to the structure of air extinguishing, which allows crews to refuel helicopters with water without even needing to land [20].

Helicopters are also used for extinguishing fires at individual objects due to the presence of open air space above them, which happened, for example, in 2020, when with the help of a helicopter as part of the fire department of the city of Los Angeles, a fire that threatened was quickly extinguished a large one-story residential building in Northridge [24].

More than 816,000 rescue operations are carried out in Europe every year, and the resources needed to fight fires are as diverse as the landscape. Thus, in Spain, the Babcock and Titan Aerial Firefighting firms are engaged in extinguishing fires from the air on the basis of contracts. Babcock's role in firefighting missions is twofold: providing real-time tactical information to the forward command post and fighting fires from the air. Babcock has a leased aircraft fleet of 57 firefighting aircraft, including helicopters (Bell-412, S-64) and airplanes (CL-215, CL-415, etc.). The Babcock aircraft park also includes UAVs for monitoring and targeting. Titan Aerial Firefighting operates in Spain with its own AT-802F firefighting aircraft [25].

In Italy, the Italian fire service deals with firefighting issues. Babcock also, as in Spain, performs on the territory of Italy on the basis of contracts a full range of tasks related to aerial firefighting, including water discharge, ground transportation of firefighters, coordination of missions and collection of video information in real time for transmission to command and control centers [25].

Portugal is another country where Babcock also provides aerial firefighting services. AT-802F amphibious aircraft are operated by the local company Agro-Montia.

The Swedish Emergency Management Agency (MSB) implements aviation firefighting capabilities through Saab on a contractual basis. Saab uses AT-802F firefighting aircraft to extinguish fires from the air [26].

Israel's aerial firefighting unit is part of the police force and helps firefighters on the ground detect and extinguish fires. The fire squadron is equipped with AT-802F aircraft and H-125 and H-145 helicopters for aerial firefighting. Firefighting helicopters use a strong and flexible Bambi Bucket to collect and deliver water to the firefighting site [27, 28].

Aviation firefighting in Greece is carried out by the 359th Air Support Squadron of the Public Services. The squadron includes firefighting aircraft:

PZL M.18 Dromaders,
PZL M.18BS Dromaders,
CL-215,
CL-415,
CL-515,
Bell-47,
Bell OH-13H helicopters.

If necessary, Greece rents firefighting aircraft in other countries, for example, the Be-200 amphibious aircraft from the Russian Federation [25, 29].

France, through the General Directorate of Civil Defense and Crisis Management, uses specialized aviation to fight fires from the air. Aircraft carry the inscription Securite Civilial on their board together with the international symbol of civil defence. The fleet of firefighting aircraft includes CL-415, Grumman S-2 Tracker, Dash-8 Q400 and Beechcraft King Air 200. The fleet of helicopters used, including for firefighting, consists of EC-145 helicopters [25, 30].

After the fire in the Notre-Dame Cathedral, when DJI Matrice-210 and Mavic Pro UAVs were used to optimize firefighting, the practice of further use of drones during firefighting is being implemented.

Germany currently uses only helicopters for aerial firefighting. For this purpose, they are equipped with external water tanks of various sizes. Smaller helicopters, such as the Airbus H-135, carry about 500 liters; Larger models, such as the Airbus Super Puma operated by the German Federal Police or the rather large Sikorsky C-53 operated by the German armed forces, carry 2,000 L and 5,000 L, respectively [31, 32].

In order to be prepared for any large-scale fires in forest ecosystems, the European Commission in 2021 created a European fleet of 11 firefighting aircraft and 6 helicopters deployed in Member States as part of the rescEU mechanism. The Commission also set out guidelines for Member States to strengthen their measures to prevent fires. The rescEU firefighting aviation consists of planes and helicopters from six EU member states:

2 firefighting planes from Croatia;
2 firefighting planes from Greece;
2 firefighting planes from Italy;
2 firefighting planes from Spain;
2 firefighting planes;
6 firefighting helicopters from Sweden;
one firefighting plane from France.

The EU provides a coordinated approach to prevent, prepare for and respond to forest fires when they exceed national firefighting capabilities. The capabilities of the rescEU system are also available to other European countries that can request assistance in using firefighting aircraft to fight forest fires.

In the near future, the rescEU air fleet will be expanded with optimization of its placement on the territory of Europe. The European Commission finances up to 90% of the costs of purchasing and maintaining new helicopters and airplanes. The EU also covers 75% of transport and deployment costs. An amount of about 200 million euros per year is allocated for this purpose. The aviation fleet of the rescEU system is planned to be increased and fully formed by 2025 [33, 34].

One of the most important tasks of the aviation of the Ministry of Emergency Situations of Russia is the implementation of special aviation operations to extinguish natural and man-made fires. Russia has one of the largest parks of fire-fighting state aviation, which includes aircraft (Be-12P-200, An-32P, Il-76TDP, Be-200, Be-200ChS [35]) and helicopters (Mi-6P, Mi-

6PZh2, Mi-8 LT, Mi-14 Eliminator, Mi-26TP, Ka-32A [36]. In 2020, the AVIC AG600 amphibious aircraft made its first flight, which still has no analogues in the world and surpassed the Japanese US-2 and the Russian Be-200 in terms of its characteristics. In the official characteristics of the aircraft, it is indicated that it can take in 12 tons of water in 20 seconds, as well as extinguish an area of 4,000 m² with one discharge of water [37, 38].

On the basis of the conducted analysis, it is possible to draw a conclusion about the state of aviation firefighting in the countries of the world. It should be noted that the fleet of firefighting aviation or aviation used for extinguishing fires consists of various types of aircraft and helicopters, which are used depending on the ecosystem for the prompt elimination of fires arising in ecosystems for various reasons.

New technical possibilities for aerial firefighting in various ecosystems, including artificial ecosystems, have appeared in parallel with the development of unmanned aircraft. Thus, fire services in a number of American cities send UAVs to the scene of a fire, using them as scouts. The French fire service actively uses drones to monitor fires. After UAVs appeared in the arsenal of firefighting teams in Germany, they began to perform aerial monitoring of fires and other emergency situations in various ecosystems [39]. Drones help to coordinate the work of all rescuers and to cope with the fire in a shorter time, and also, which is very important, to save water. With traditional extinguishing methods, it is used in much larger volumes [40].

In addition to a number of useful functions [41] that rely over time on unmanned aviation in the field of civil protection, a fire extinguishing function has been added. This direction is actively developing in China, where UAVs are considered a key component of modern firefighting arsenals. Solving the problem of fire extinguishing in apartments or offices located in high-rise buildings has found its solution by using UAVs to raise fire hoses into the air to the required height. So, firefighters in the Chinese city of Chongqing used an unmanned aerial vehicle and extinguished a 10-story building in 15 minutes. At the same time, drones have a battery life of 20 minutes. With the help of several helicopter-type UAVs, fire hoses were raised to the top of the flame, which allowed it to be gradually extinguished [41, 42].

The Chinese company EHang, which specializes in the development of drones, presented the EHang 216F copter-type UAV, capable of flying for 1-2 minutes. raise to a height of 600 m up to 150 l of water (foam) or foam and act as a powerful fire extinguisher. A long gun barrel is installed on board the UAV, and there is a six-charge launcher above the cockpit. The incendiary bombs fired from this device are capable of piercing the glass of a building with a special hard alloy tip. The drone has a laser pointer and a camera. It is designed for semi-autonomous operation - the process of fighting fire is managed by the pilot-operator, while the UAV stays in position independently according to the program. The drone is capable of operating at heights of up to 600 m [43].

Extinguishing fires from the air in forest ecosystems is a very difficult and dangerous operation. This is due to the fact that smoke from a fire greatly impairs visibility, and hot air from a fire impairs controllability of an airplane or helicopter and can disrupt the operation of engines. At the same time, pilots must fly over the fire as low as possible to effectively dump the water (solution). To extinguish forest fires, the Chinese company QilingUAV has developed a helicopter-type UAV JS260. The device can carry two containers filled with fire extinguishing liquid weighing up to 100 liters. According to the developers, the volume of each tank is enough to extinguish 50 m³ of forest area [44].

In 2017, the Spanish company Singular Aircraft began production of Flyox Mark I and Mark II heavy unmanned seaplanes. The Flyox Mark II seaplane can be used for firefighting. It is equipped with a capacity of 2 tons of water, and is also able to receive water in the container in the gliding mode, and then dump the water at the site of the fire [45].

Another direction in the development of aerial firefighting, although not entirely new, is the use of special aviation means of firefighting - bombs. Thus, during the USSR at the end of the 80s of the 20th century. such a tool was developed - ASP-500 - a bomb in a plastic case containing 400 kg of a water mixture for extinguishing a fire. Upon hitting the surface, a special charge sprays a mixture that instantly extinguishes the flame on an area of about 1,000 m². The use of such bombs even in urban ecosystems was envisaged. It is important to note that firefighting specialists have developed a combined fire extinguishing technology using ASP-500. At first, the bombers were supposed to practice, which with the help of ASP-500 were supposed to shoot down the flames, and after them the Il-76 and Be-200 planes were supposed to drop water (solution) on this area. And, finally, the Mi-26TP, Mi-8LT and KA-32P helicopters were to finally eliminate the remains of the fire by spot dropping water (solution). Under conditions of good organization, according to experts, even with several echelons of such carpet fire extinguishing, which gives a 100% result, according to calculations, it would be possible to quickly extinguish fires in large-scale ecosystems [46].

In 2021, a bomb for aerial firefighting was tested in China. The weight of such a bomb is 200 kg. The bomb was successfully dropped on the training ground from a height exceeding 2,000 m with the TB-001 UAV, which is capable of lifting a payload of up to 1 ton. According to experts, one such bomb is capable of extinguishing a fire in an area of up to 450 m² [47].

At the end of 2019, the Israeli company Elbit Systems conducted tests of a new means of extinguishing fires, thanks to which aircraft will be able to extinguish fires on the surface of the earth from a greater height and in night conditions. The Israeli development is thin-walled bags filled with water, foam or fire retardant. The new fire extinguisher can be used on any aircraft or helicopter equipped with a water tank and a discharge system [45].

The above technical aspects of modern firefighting from the air provide grounds for a comparative analysis

of the situation with aviation firefighting that takes place in Ukraine.

The firefighting aviation of the State Emergency Service is represented by the Special Aviation Detachment of the Operational Rescue Service of the State Emergency Service, which is stationed at the airfield near the city of Nizhyn in the Chernihiv region, which is equipped with specialized firefighting aircraft An-32P (the weight of the fire-fighting mixture is 8 thousand kg) and a number of modifications of helicopters We-8 of Soviet production, which can use special equipment for extinguishing fires. The results of the involvement of An-32P firefighting aircraft for the elimination of forest fires in the "Chernobyl Exclusion Zone" ecosystem in 2020, as well as the elimination of large-scale fires in forest ecosystems on the territory of Ukraine in the past years, testify to the insufficient number of firefighting aircraft in the composition of the State Emergency Service for operational and effective solution of firefighting tasks from the air [48].

In Ukraine, the private aviation company "Ukrainian Helicopters" operates, which leases Mi-8MTV-1 helicopters and can participate in aerial firefighting, as happened during the fire in Turkey in 2021 [49].

There are a number of proposals for the development of firefighting aviation in Ukraine. One of them is to develop systems similar to the Russian VAP/VAP-2, for their possible installation on Il-76 type aircraft, which are in service with the Air Force of the Armed Forces of Ukraine. This path is problematic, which is due to the small remaining resource of Il-76 aircraft existing in Ukraine - within 5-8 years [48].

As another way, it is proposed to start work on the creation of a heavy firefighting aircraft based on the An-70/77. According to projected figures, the cost of such an aircraft may reach \$160-170 million US [48], which requires significant foreign investment. At present, countries usually purchase ready-made firefighting aircraft.

So, for example, one CL-415 amphibious firefighting aircraft purchased for the European rescEU system costs up to 40 million euros [33]. In this regard, it is very difficult to expect investment in Ukraine in the interest of creating a new firefighting aircraft.

The essence of another proposal lies in the organizational plane - the creation of a general system of management of available aviation resources when extinguishing fires in forest ecosystems of Ukraine, including various departmental affiliations [8].

The paper [50] gives an idea regarding the prospective use of airships for aerial firefighting with a proposal to conduct scientific research to substantiate the implementation of such an approach in Ukraine.

The proposal for the creation of an international association of fire aviation with the participation of Ukraine, which could become a coordinating body for the management of fire aviation units of different countries in the interests of joint work in countries where large-scale fires have occurred, is set out in [48]. This, according to the authors, could contribute to obtaining an order for Ukraine for the production of heavy firefighting aircraft, taking into account the fact that our country is one of the few countries in the world where heavy and super heavy transport aircraft can be created. This proposal echoes the position of the Ministry of Internal Affairs of Ukraine regarding the creation of a European hub of aviation security, for which it is necessary to "increase the aircraft fleet of the State Emergency Service, namely to double the number of AN-32P aircraft" [51].

Considering the creation of the rescEU system on the territory of the EU, it makes sense for Ukraine to join it, which, in our opinion, will strengthen our country's efforts towards European integration.

The analysis of the given proposals shows that the direction related to the development of unmanned aviation in the interests of aerial firefighting in natural and artificial ecosystems still remains at the level of ideas, although it requires active promotion in Ukraine [52], which has a number of aviation enterprises [53], able to solve such tasks under financing conditions.

Conclusions

Analysis of the technical aspects of aviation firefighting in ecosystems based on the experience of a number of foreign countries showed that there is a problem of protecting both natural and artificial ecosystems from fires that arise both as a result of natural factors and as a result of human activity. In parallel with the mentioned problem, there is the problem of aviation firefighting, especially in forest ecosystems in conditions of coverage of large areas by fires.

The experience of foreign countries indicates the need for the active development of aviation firefighting by creating an aviation triad:

manned aircraft,

helicopters and unmanned aircraft,

creating joint aviation structures to optimize the processes of firefighting from the air,

as well as by searching for and using the latest technologies.

Prospects for further research

The directions of further research should be the development of the latest and scientifically based technical solutions with their further implementation in the infrastructure of aviation firefighting in Ukraine.

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Технічні аспекти авіаційного гасіння пожеж в екосистемах: досвід зарубіжних країн

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Анотація. У статті розглянуто технічні аспекти авіаційного гасіння пожеж в екосистемах на основі досвіду провідних країн світу. Розкрито особливості природних і техногенних екосистем у площині гасіння пожеж. Уточнюється обумовленість виникнення потреби в авіаційному пожежогасінні, перш за все, існуючими особливостями екосистем, а також наявним рівнем технічного розвитку та можливостями пілотованої авіації щодо оперативного виконання завдань пожежогасіння в екосистемах. Досліджено стан пожежної авіації США та Канади, країн Європи, Китаю та інших країн, а також інфраструктурні особливості організації гасіння пожеж з повітря. За результатами дослідження зазначено, що парк пожежної авіації або авіації, яка залучається до гасіння пожежі, складається з різних типів літаків і вертольотів, які використовуються в залежності від екосистем для швидкої ліквідації пожежі, що виникла в екосистемі. Акцентовано увагу на перспективах створення авіаційних засобів пожежогасіння на базі безпілотної авіації, яка розвивається лавиноподібно та дозволяє оптимізувати пожежогасіння в різних екосистемах. Привертає увагу напрямок розробки, хоч і не зовсім новий, але корисний, суть якого полягає у використанні авіаційних засобів пожежогасіння у вигляді спеціальних бомб на прикладі Росії, Китаю та Ізраїлю. Проаналізовано стан протипожежного авіаційного флоту України. Досліджено пропозиції технічного та організаційного характеру подальшого розвитку пожежогасіння з повітря в Україні. Аналіз наданих пропозицій показав, що напрямок, пов'язаний із розвитком безпілотної літальної апаратури пожежогасіння в природних та штучних екосистемах України, поки що залишається на рівні ідей, але потребує подальшого просування в нашій країні, яка має низку авіаційних підприємств, здатних за умов необхідного фінансування успішно вирішувати наступні завдання. У висновках акцентується увага на тому, що розглянуті напрями розвитку пожежної авіації в Україні здебільшого знаходяться на рівні ідей, які мають бути, насамперед, науково обґрунтованими. Напрямами подальших досліджень слід вважати розробку новітніх та науково обґрунтованих технічних рішень з подальшим їх впровадженням в інфраструктуру авіаційного пожежогасіння України.

Ключові слова: екосистема, пожежа, авіаційне пожежогасіння, пожежна авіація.