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Monograph

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The monograph outlines the main provisions on modern aspects of the use and development of Unmanned Aerial Vehicles. The general provisions of flight operation of Unmanned Aerial Vehicles when performing tasks in new areas of application are considered. A separate section is devoted to the peculiarities and directions of development of avionics of modern Unmanned Aerial Vehicles and the structures of their electrified complexes.

Thus, the monograph will be useful for specialists and scientists in the field of 173 – "Avionics" and 272 – "Aviation transport" and other related specialties.

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## *Appeal to Readers…*

*The given monograph is logical extension of "Modern acpects of application and development of Unmanned Aerial Vehicles" by T. Shmelova, S. Boiko, O. Kotov, O. Burlaka, M. Nozhnova, Yu. Bershadska, L. Chyzhova, D. Hinosian, V. Zhurid, V. Yemets, Yu. Oliinyk, and V. Moskalyk.*

*Monograph. Not the first. This is a continuation of the ongoing research in the field of aircraft avionics, namely helicopters. The authors of this monograph are scientists from the National Aviation University, Kryvyi Rih National University, Kharkiv National University of Internal Affairs and Kremenchug Flight College of Kharkiv National University of Internal Affairs, my colleagues, like-minded people and friends who are directly involved in training aviation technicians pilots and operator s of Unmanned Aerial Vehicles.*

*What is the purpose of writing this monograph? What is the target audience? We did not consider these issues while working on this monograph. The monograph is aimed at a wide range of specialists - pilots, operator s of Unmanned Aerial Vehicles, avionics, students, cadets, graduate students, researches workers and more.*

*We also hope to be satisfied with the work done and will be happy if someone finds this work useful. Of course, readers can either praise or criticize him. In any case, we hope that our readers will appreciate our efforts.*

*Special thanks to the reviewers DSc. (Engineering), Prof.,* ***Yu. Denisov****, (National University «Chernigiv Polytechnic», Chernihiv) and DSc. (Engineering), Prof.,* ***O. Sablin,*** *(Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Dnipro).*

*T. Shmelova, S. Boiko, O. Kotov, and team of authors*

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## LIST OF ABBREVIATIONS

AC – aircraft;
ASS – air signal system;
AV – avionics;
ATM – Air Traffic Management
CC – control cell;
CL – code link;
CWS – critical warning system;
CDM – Collaborative Decision Making
DME – rangefinder;
DDSS – Distributed Decision Support System
ECK – engine control knob;
EGPWS – Enhanced Ground Proximity Warning System;
EIS – electronic indication system;
ESD – external storage device;
FOCL – fiber optic communication line;
FF-ICE – Flight & Flow Information for a Collaborative Environment
GPWS – ground proximity warning system;
HMDS – helmet-mounted display system;
HSC – heading station corner;
RPA – Remote piloted aircraft
RPS – remote piloting station
ICRT – indicator on a cathode ray tube;
TCCS – traction control computer system;
UAVs – Unmanned Aerial Vehicles;
WRS – weather radar station.

# INTRODUCTION

Unmanned Aerial Vehicles and their implementation in various fields today are a very relevant topic for research. The development of the functionality of Unmanned Aerial Vehicles provides them with additional capabilities during operation and improves their flight characteristics. Meanwhile, depending on the areas of implementation of Unmanned Aerial Vehicles and the tasks set before them, their tactical and technical characteristics also depend. Given the various tasks and specifics of the conditions of use of Unmanned Aerial Vehicles in different areas of application, there is a need to take into account the features and specifics of flight operation of certain types of Unmanned Aerial Vehicles when performing tasks in new applications.

The monograph outlines the main provisions on modern aspects of the use and development of Unmanned Aerial Vehicles. The general provisions of flight operation of Unmanned Aerial Vehicles when performing tasks in new areas of application are considered. A separate section is devoted to the peculiarities and directions of development of avionics of modern Unmanned Aerial Vehicles and the structures of their electrified complexes.

Thus, the monograph will be useful for specialists and scientists in the field of 173 - "Avionics" and 272 - "Aviation transport" and other related specialties.

# CHAPTER 1
# CURRENT WORLD TRENDS IN THE DEVELOPMENT OF UNMANNED VEHICLES

### *1.1 Features of unmanned vehicles operation*

With the advent of commercial aerospace surveys, a market for geoinformatics data was formed. Modern geoinformatics provides users with a powerful tool for visualization, analysis, systematization, storage of geospatial data. GIS is used not only by government agencies (for example, for cadastral accounting), but there are numerous corporate GIS applications that provide sound decision-making in complex projects for the use of natural resources, construction, agriculture and others. The question of information content of GIS, their updating is solved, proceeding from available means. Mostly now - it's space aerial data. However, despite the continuous improvement of aerospace remote sensing tools, such imaging has known methodological limitations, which are determined primarily by the inability to capture at any time anywhere due to weather conditions and given the geometry of the orbits of satellites. UAVs are far superior to spacecraft in terms of shooting efficiency. For monitoring of long objects, which are main pipelines, power lines, sea and land borders, railways and highways [1].

Let's list the main advantages of UAVs: first, they are on average an order of magnitude cheaper than manned aircraft, which need to be equipped with life support systems, have a less effective scattering surface and less vulnerability to enemy air defense fire. They need to finally train pilots (and it costs a lot of money). In UAV systems, if the aircraft is controlled from the ground, one pilot can control several vehicles. As a result, the absence of a crew on board significantly reduces the cost of performing a task [2-4].

Second, light (compared to manned aircraft) Unmanned Aerial Vehicles consume less fuel.

Third, unlike manned aircraft, unmanned vehicles do not need concrete-covered airfields. It is enough to build a ground runway with a length of only about 600 m. ("Drones" take off with a catapult, and land "by plane" as fighters on aircraft carriers or parachutes). This is a very serious argument, as 70% of airfields in Ukraine need reconstruction, and the pace of repair today is one airfield per year [5].

Fourth, modern manned aerial reconnaissance, for all its detection and analysis capabilities, is limited by the range and angle of elevation at which the earth's surface is surveyed. With a decrease in the angle of elevation (up to 1 ° and less) and as the range increases sharply, the effect of shading targets due to the influence of terrain. As the experience of regional armed conflicts in recent years has shown, the impact of the shadowing effect on targets in different theaters of operations is different. In the Middle East, which is characterized by a predominance of desert terrain, it is close to minimal, and in the mountainous Balkans seriously reduces the effectiveness of reconnaissance aircraft, for which at least 50% of reconnaissance areas fall into invisibility zones. Reconnaissance UAVs, in addition to monitoring such areas, as well as searching for the area of visibility, which is inspected by onboard means of manned reconnaissance aircraft, which is for reconnaissance 150 km, radar - 250 km, radio and radio technical - up to 300 km (these values should be reduced by 50... 100 km due to the need to safely remove patrol routes from the front line), provide many angles of various-scale observations of hidden enemy objects, being far beyond the front line [6].

The advantages and specific qualities of UAVs complexes determine their role as a highly mobile and combat-ready component of the VIS, capable in a short time not only to collect reliable intelligence about the enemy in large areas and at great depths, but also to target high-precision weapons VIS, Navy and ground forces, to strike at the most important objects of the enemy, to act flexibly in the conditions of intensive counteraction of air defense according to a changing situation. These qualities determine the growing role of UAV complexes, which can be used in combat operations in the tactical and operational levels (in the long run - and in the strategic level), as well as to solve economic problems.

### *1.2 The composition of the onboard equipment of modern UAVs*

To ensure the tasks of monitoring the underlying surface in real time during the flight and digital photography of selected areas, including hard-to-reach areas, as well as determining the coordinates of the studied areas, the UAVs payload [7-10] should include:

- Devices for obtaining image information:
- Satellite navigation system (GLONASS / GPS);
- Radio devices of image and telemetry information;
- Devices of command-navigation radio line with antenna-feeder device;
- Device for exchanging command information;
- Device of information exchange;
- Onboard digital computer (on-board computer);
- Image information storage device.

Modern television (TV) cameras provide the operator with a real-time view of the terrain in the format closest to the characteristics of the human visual system, which allows to navigate freely in the area and, if necessary, to perform UAV piloting. Capabilities for detection and recognition of objects are determined by the characteristics of the photodetector and optical system of the television camera. The main disadvantage of modern television cameras is their limited sensitivity, which does not provide round-the-clock use. The use of thermal imaging (MS) cameras allows to ensure round-the-clock use of UAVs. The most promising is the use of combined tele-thermal imaging systems. The operator is given a synthesized image containing the most informative parts, inherent in the infrared wavelength range, which can significantly improve the tactical and technical characteristics of the surveillance system. However, such systems are technically complex and quite expensive. The use of radar allows to receive information around the clock and in adverse weather conditions, when TV and solid waste channels do not provide information. The use of replaceable modules reduces the cost and reconfiguration of the onboard equipment to solve the problem in specific conditions of use. Consider the composition of the onboard equipment of the mini-UAV.

The observation course instrument is fixed at a certain angle to the formation axis of the aircraft, which provides the necessary area of capture on the ground. The observation course instrument may include a television camera (TC) with a wide-field lens (WFL). Depending on the tasks to be solved, it can be promptly replaced or supplemented by a thermal imaging camera (TIC), digital camera (DC) or radar.

The device of detailed inspection with the rotary device consists of TC of the detailed inspection with a narrow-field lens (NFL) and the three-coordinate rotary device providing turn of the camera on a course, a roll and a pitch on commands of the operator for detailed analysis of a concrete site. To ensure operation in low light TC can be supplemented by a thermal imaging camera (TIC) on a microbolometric matrix with a narrow-field lens. It is also possible to replace TC with DC. Such a solution will allow the use of UAVs for aerial photography when turning the optical axis of the DC in nadir [11-15].

Radio devices of image and telemetry information (transmitter and antenna-feeder device) must ensure the transmission of image and telemetry information in real or near real time on the CB within radio visibility.

Command and navigation radio line devices (receiver and antenna-feeder device) must provide reception within the radio visibility of UAV piloting commands and control of its equipment.

The command information exchange device provides distribution of command and navigation information to consumers on board the UAV.

The information exchange device provides the distribution of image information between the onboard sources of image information, the transmitter of the radio line of image information and the onboard device for storing image information. This device also provides information exchange between all functional devices that are part of the target load of the UAV on the selected interface (for example, RS-232). Through the external port of this device before the takeoff of the UAV is the introduction of the flight task and pre-launch automated built-in control over the operation of the main components and systems of the UAV [15-18].

The satellite navigation system provides the binding of the coordinates of the UAV and the observed objects on the signals of the global satellite navigation system GLONASS (GPS). The satellite navigation system consists of one or two receivers (GLONASS / GPS) with antenna systems. The use of two receivers, the antennas of which are spaced along the construction axis of the UAV, allows to determine in addition to the coordinates of the UAV values of its course angle.

The onboard digital computer (OBDC) provides control of the onboard UAV complex.

The device for storing image information ensures the accumulation of the image information selected by the operator (or in accordance with the flight task) until the moment of landing the UAV. This device can be removable or stationary. In the latter case, a channel must be provided to remove the accumulated information in the external device after landing the UAV. The information read from the device for storing image information allows for a more detailed analysis when decoding the flight information obtained in the UAV flight.

The built-in power supply unit provides coordination on voltage and currents of consumption of the onboard power supply and the devices which are part of payload, and also operative protection against short circuits and overloads in the power supply network. Depending on the UAV class, the payload can be supplemented by different types of radars, environmental, radiation and chemical monitoring sensors. UAV control complex is a complicated, multilevel structure, the main task of which is to ensure the withdrawal of UAVs in a given area and operations in accordance with the flight task, as well as to ensure the delivery of information received by UAVs to the control point [19].

### *1.3 Classification Unmanned Aerial Vehicles of Unmanned Aerial Complex*

1. By classes of UAVs UACs are classified as [20]:

1) Class I "Lungs" (take-off mass up to 150 kg), which includes:

– micro (tactical) UAVs UACs with a take-off mass of less than 2 kg, range up to 5 km;

– mini (tactical battlefields) UAVs UACs, with a takeoff weight of 2 to 15 kg, range more than 5 km;

– small (tactical) UAVs UACs with a take-off mass of more than 15 kg, range of more than 25 km. Class I UAVs are launched from the hand, using a catapult or mobile launchers or using the runway;

2) Class II "Medium" (takeoff weight from 150 to 600 kg), which includes tactical (operational-tactical) UAVs UACs with a range of more than 50 km. Class II UAVs are launched by means of a catapult, mobile launchers or use a runway;

3) Class III "Heavy" (take-off mass over 600 kg), which includes:

– operational UAVs UACs (medium altitude long endurance - MALE, medium altitude, long duration), used at altitudes up to 13,700 m (45,000 feet) and having a range of more than 200 km;

– strategic high-altitude long endurance (HALE) UAVs used at altitudes up to 1,800 m (65,000 ft) and with a range of more than 200 km. Class III UAVs require RWY with artificial turf.

2. According to the purpose UAVs UACs are classified as:

1) combat UAVs UACs - designed to perform combat missions, which include:

– reconnaissance UAVs UACs;

– UAV UACs intelligence and target-indication;

– UAV UACs radio electronic warfare;

– strike UAVs;

– UAVs - interceptors of aircraft. Combat UAVs UACs can have a combined purpose;

2) special UAVs UACs - designed to perform special tasks as repeaters and targets, as well as for observation and monitoring of objects, territories, etc.

3. By type, location, method of takeoff and landing, type of flight control system UAVs UACs are divided into the following:

1) by type of aircraft:

– aircraft type;

– helicopter type;

– multirotor;
2) at the place of base:
– ground based;
– river (sea) base;
– air base;
3) by method of take-off:
– by plane (from the start);
– by helicopter (from a place);
– with the help of launchers (catapult, launcher);
– out of hand;
– universal (combined);
4) by method of landing:
– by plane (with mileage);
– by helicopter (without mileage);
– by means of landing means (parachute, brake device, etc.);
5) by type of flight control system:
– autonomous UAVs UACs that fly according to the previously entered program and may have an emergency mode of bringing the UAV to the landing point or the mode of emergency termination of flight;
– manned UAVs UACs, which include:
– UAV UACs with manual piloting;
– Autopilot UAVs;
– UAVs UACs, piloted by waypoints;
– UAV UACs with a combined control system.
4. Consolidated classification of UAVs UACs by main features [21]

| Class | Level of application | Combat radius | Category UAVs UACs of NATO member states |
|---|---|---|---|
| I Class < 150 kg | micro (tactical) take-off weight <2 kg | up to 5 km (line of sight) | micro |
| | mini (tactical battlefields) 2 kg ≤ take-off weight ≤ 15 kg | more than 5 km (line of sight) | mini |
| | small (tactical) take-off weight> 15 kg | more than 25 km (line of sight) | small |

| | | | |
|---|---|---|---|
| II Class 150-600 kg | tactical (operational and tactical) | more than 50 km (line of sight) | tactical |
| III Class > 600 kg | operational | more than 200 km (out of line of sight) | MALE |
| | strategic | more than 200 km (out of line of sight) | HALE |

Given the "Rules of flight of Unmanned Aerial Vehicles of state aviation of Ukraine", "Requirements for the basic qualification level of the operator of Unmanned Aerial Vehicles" and analysis of UAV operation by special units of the Ministry of Internal Affairs of Ukraine, including during the ATO, it is necessary to state in-depth training of UAV operators.

Namely, among other equally important skills should be singled out.

UAC operators must undergo full theoretical training, equivalent to the training of manned aircraft crews, which includes obtaining basic knowledge, namely:

1) the structure and procedure for the use of airspace of Ukraine;
2) the order of ATC and flight rules;
3) aerodynamics (practical aerodynamics);
4) the design of UAC;
5) flight and technical operation of UAC;
6) air navigation;
7) aviation meteorology;
8) the procedure for conducting radio communication (including aviation English in ICAO);
9) performance of special tasks;
10) flight safety.

Also, UAC operators must undergo a full program of practical flight training, which consists of flight training at UAC and training at the training and modeling complex UAC. Flight training provides UAC operators with the opportunity to demonstrate skills and abilities in UAC control (UAV, RCP) in the entire range of its altitudes and speeds at any stage of the flight.

In addition, it is worth considering the classification of civil UAVs that are used in various sectors of the economy.

The classification of UAVs has been developed according to classic target tasks, tactical and technical characteristics of UAVs such as cargo capacity, flight range, construction, ways of take-off and landing; the number of UAVs in the flight. By the purpose, the UAV classified as agricultural, forest, and town works; surveillance and monitoring for situations such as natural, technical, and social ordinary/emergency situations; organization of search and rescue; organization and controlling of traffic road; organization and improve performance logistics, and communications, urban planning; dynamic management and urban planning (Table 1).

The analysis, systematization, and coding of UAVs according to classifications is carried out (Table 1). There are the following classifications of UAVs [1; 2; 3; 4]:

– by target;
– on takeoff mass;
– flight range;
– flight altitude;
– by flight duration;
– by type of construction, etc.

According to the type of UAV, designs are divided into devices made of aircraft (fixed - wing) and helicopter (rotary - wing) schemes, as well as devices with a fluttering wing [2].

By type of takeoff, UAVs are divided into aircraft with takeoff from the runway and with vertical takeoff (usually used depending on the target task) [1].

Unmanned Aerial Vehicles are classified according to the method of take-off and landing: aerodrome and non-aerodrome, ie take-off from the runway or by catapult; landing on the runway or on a parachute or with the help of nets [1].

By target task, UAVs are classified as agricultural, surveillance, search, and rescue, cargo, and communication repeaters, etc.

Recently, the scope of application of UAVs is significantly expanding: trade operations, forestry and fishing, and others. According to the number of applications, they are classified as single and multiple applications.

As a rule, such UAVs are used in forest fire monitoring and search and rescue operations, where there is a high probability of aircraft loss [2].

According to the duration of the flight, UAVs are classified as short-range aircraft (up to 1 hour), medium-term flight (1 to 6 hours), early flight (6 hours) [20]. Given the rather large variety of UAVs, they are also classified by weight. Micro to 1 kg., Small 1 - 100 kg., Light 100 - 500 kg., Average 500 - 5000 kg., Heavy 5000 - 15000 kg., Superheavy 15000 kg and more. All of the above types of UAVs by weight are classified depending on the flight range and maximum takeoff mass [1].

In terms of the number of UAVs used to carry out target missions, there can be single and group flights [22]. The use of group UAVs flights increases the efficiency of target tasks to perform many tasks that were previously difficult to solve such as observation and monitoring missions in hard-to-reach places (forest, mountains, sea, rivers, lakes, big parks); monitoring forest fires; search and rescue operations; alternative performance of a difficult agricultural activity (aviation chemical work); relaying of communication signals in places where antenna coverage cannot be set because of terrain; for first aid to people in various life situations [23].

The efficiency of group UAV flights in some operations more preferable such as monitoring forest fires, search and rescue operations, agriculture in crop processing, communication relay, and cargo movement. The main advantage of using UAVs is areas with extra high risks to humans or large and inaccessible areas with the necessity in control using single or group UAVs flights in cities or agricultural terrain.

The use of a single-operating or a group of UAVs is opening a big variety and a principally new level of complexity of target tasks and missions lowering the presence of a human itself while task execution of smart governance in the future cities as smart-cities8]. So, the disadvantages of UAV include the limited capacity due to the small size of UAV that can be satisfied with the group flight usage [25-28]. For the control of the UAV are using the next schemes of UAV control (group and single):

– Operator - single UAV;
– Group of operators – group of UAVs;
– Operator – Central Drone Repeater (CDR) – group of UAVs.

The UAV control classified according to degrees of autonomy and control of UAV flight [28]:

– under remote control by an operator;
– autonomously by onboard computers;
– piloted by an autonomous robot.

Table 1.1 shows the analysis, systematization, and coding of UAV types according to existing classifications.

Table 1.1 – Classification of UAV types [20-29]

| № | Class | Classification | Subclass | Code |
|---|---|---|---|---|
| 1 | A | UAV classification by purposes | Surveillance | $A_1$ |
| | | | City works | $A_2$ |
| | | | Other works (agricultural, forest, sea, river, steppe, etc.) | $A_3$ |
| | | | Dynamics management and urban planning | $A_4$ |
| | | | Relays communications | $A_5$ |
| | | | Logistic | $A_6$ |
| | | | Search and rescue operations; | $A_7$ |

| | | | | |
|---|---|---|---|---|
| | | | Organization of traffic, controlling traffic road, traffic problems | $A_8$ |
| | | | Aerial photography | $A_9$ |
| | | | First aid to people | $A_{10}$ |
| | | | Noise and landscape pollution | $A_{11}$ |
| | | | Monitoring nature emergency situation (forest fires, floods, earthquakes) | $A_{12}$ |
| | | | Monitoring the social situations in the town (social behavior, criminal situations, social emergency situations, demonstrations, show on holidays, etc.) | $A_{13}$ |
| | | | Monitoring the technical emergency situation | $A_{14}$ |
| 2 | B | UAV classification by duration of the flight | UAV of a short flight (1 hour) | $B_1$ |
| | | | Medium-flight UAV's (from 1 to 6 hours) | $B_2$ |
| | | | Long flight UAV's (more 6 hours) | $B_3$ |
| | | | Distant flight UAV's (more 30 hours) | $B_4$ |
| 3 | C | UAV classification by weight | Micro UAVs (to 1 kg). | $C_1$ |
| | | | Small 1 - 100 kg. | $C_2$ |
| | | | Lightweight 100 - 500 kg. | $C_3$ |
| | | | Medium 500 - 5000kg. | $C_4$ |
| | | | Heavy 5000 - 15000 kg. | $C_5$ |
| | | | Super heavy 15000 kg or more | $C_6$ |
| 4 | D | UAV classification by the type of aircraft | UAVs airplane (fixed-wing) | $D_1$ |
| | | | UAVs helicopters (rotary-wing) | $D_2$ |
| | | | UAVs with flapping wings | $D_3$ |
| 5 | E | UAV classification by way of take-off | Airfield take off UAV | $E_1$ |
| | | | Non-airfield UAV taking off from a catapult; | $E_2$ |
| | | | Non-airfield UAV taking off from hands | $E_3$ |
| 7 | F | UAV classification by landing way | Airfield landing UAV | $F_1$ |
| | | | Non-airfield UAV landing with the help of parachute; | $F_2$ |
| | | | Non-airfield UAV landing with the help of snares; | $F_3$ |
| 8 | G | UAVs classification by the number of applications | UAV of single applications | $G_1$ |
| | | | UAV of repeated applications | $G_2$ |
| 9 | H | UAVs classification by | UAV of single flight | $H_1$ |
| | | | UAV of group flight | $H_2$ |

| | | | | |
|---|---|---|---|---|
| | | number of UAVs in flight | | |
| 10 | I | UAVs classification by schemes of UAV control: group and single | UAV operator - single UAV | $I_1$ |
| | | | Group of operators of UAV – group of UAVs; | $I_2$ |
| | | | UAV operator – Central Drone Repeater (CDR) – group of UAVs. | $I_3$ |
| 11 | J | UAVs classification by method of control of UAVs flight | UAV under remote control by an operator | $J_1$ |
| | | | UAV autonomously by onboard computers | $J_2$ |
| | | | UAV piloted by an autonomous robot | $J_3$ |

## List of references for chapter 1

1. Glotov V., Tserklevich A. Analysis and prospects of airship from an Unmanned Aerial Vehicle // Bulletin of the National University "Lviv Polytechnic". Sir: Modern achievements in geodetic science and production. Lviv: View of the Lviv Polytechnic National University. 2014 Wipes And (27). P. 131-136.
2. Dementiev D.O. Combat aircraft complexes as part of a single information-reconnaissance and navigational shock system / Dementiev D.O. // Sb. sciences Ave Military Institute of Kyiv National University. Taras Shevchenko. K.: VIKNU, 2015. №27. P. 74-77.
3. Zinchenko O.N. Unmanned Aerial Vehicle: Application for Erophotography for Cartography Access mode: http://www.racurs.ru/?page=681.
4. Angular O.P. Trends in the development of Unmanned Aerial Vehicles. Science and Armament 2014. No. 4. P. 39 - 47.
5. Lutsky M.G. Development of international regulation and normative base for the use of Unmanned Aerial Vehicles / M.G. Lutsky, VP Kharchenko, D.O. Bugayko // Bulletin of the NAU. 2015 No. 4. P. 5-14.
6. Moiseev V. S. Applied theory of control of Unmanned Aerial Vehicles: monograph / V. S. Moiseev. Kazan: State Audit Office "Republican Center for Monitoring the Quality of Education" (Series "Modern Applied Mathematics and Informatics"), 2013. p. 768.
7. Rostopchin V.V. Unmanned Aviation Systems: Basic Concepts / VV Rostopchin, IE Burund / ELECTRONICS: Science, Technology, Business. 2016 №7. P. 82-88.
8. U.P. Analysis of technical characteristics and capabilities of unmanned aviation complexes of operational tactical and tactical radius of armies of developed countries / Yu.P. Salnik, IV Matala // Military and Technical

Ass. 2013. № 7 P. 70-74.

9. The strategy of development of domestic aviation industry for the period till 2020: [approved by the order of the Cabinet of Ministers of Ukraine dated December 27, 2008. N 1656-p] [Electronic resource] // The Verkhovna Rada of Ukraine: [site]. Mode of access: http://zakon4.rada.gov.ua/ laws / shows / 1656-2008-% D1% 80.
10. Kharchenko O.V. Classification and trends of the creation of Unmanned Aerial Vehicles for military use / O.V. Kharchenko, VV Kuleshin, Yu.V. Kotsurenko // Science and defense. 2015 No. 6 P. 47-54.
11. Korchenko A. G., Ilyash O. S. Generalized classification of Unmanned Aerial Vehicles // Collection of Scientific Papers. Kharkov Air Force University. 2012. No. 4 (33). pp. 27–36.
12. Koucheryavy A. E., Vladyko A. G., Kirichek R. V. Flying Sensor Networks – New Application of the Internet of Things // IV International Scientific-Technical and Scientific-Methodical Conference «Actual Problems of Education in Science and Education». 2015. T. 1. pp. 17–22.
13. Koucheryavy A. E., Vladyko A. G., Kirichek R. V., Paramonov A. I., Prokopiev A. V., Bogdanov I. A., Dort-Goltz A. A. Flying Sensor Networks // Electrosvyaz’. 2014. No. 9. pp. 2–5.
14. Koucheryavy A., Vladyko A., Kirichek R. State of the Art and Research Challenges for Public Flying Ubiquitous Sensor Networks // Lecture Notes in Computer Science. 2015. Vol. 9247. pp. 299–308. DOI: 10.1007/978-3-319-23126-6_27.
15. Koucheryavy A. E., Vladyko A. G., Kirichek R. V. Theoretical and Practical Research Trends in the Field of Flying Ubiquitous Sensor Networks // Electrosvyaz’. 2015. No. 7. pp. 9-11.
16. Koucheryavy A. E., Vladyko A. G., Kirichek R. V., Makolkina, M. A., Paramonov, A. I., Vybornova, A. I., Pirmagomedov, R. Ya.: The Prospects for Research in the Field of Communications Networks on the 2017-2020 Years // Telecom IT. 2016. Vol. 4. No. 3. pp. 1-14. URL: http://www.sut.ru/doci/nauka/review/20163/1-14.pdf
17. Kirichek, R., Kulik V. Long-Range Data Transmission on Flying Ubiquitous Sensor Networks (FUSN) by Using LPWAN Protocols // Communications in Computer and Information Science. 2016. Vol. 678. pp. 442-453. DOI: 10.1007/978-3-319-51917-3_39.
18. Kirichek R., Paramonov A., Koucheryavy A. Flying Ubiquitous Sensor Networks as a Queuing System // 17th International Conference on Advanced Communication Technology (ICACT). 2015. pp. 127-132. DOI: 10.1109/ICACT.2015.7224771.
19. Kirichek R., Paramonov, A., Vareldzhyan K. Optimization of the UAV-

P's Motion Trajectory in Public Flying Ubiquitous Sensor Networks (FUSN-P) // Lecture Notes in Computer Science. 2015. Vol. 9247. pp. 352–366. DOI: 10.1007/978-3-319-23126-6_32.

20. Gupta L., Jain R., Vaszkun G. Survey of Important Issues in UAV Communication Networks // IEEE Communications Surveys & Tutorials. 2016. Vol. 18 (2). pp. 1123–1152.
21. Kirichek R. V., Kuleshov A. A., Koucheryavy A. E. Methods for Detection of Unmanned Aerial Vehicles Based on the Analysis of Network // Trudy uchebnykh zavedenii svyazi. 2016. No. 1. pp. 77-82.
22. Villasenor J. "Drones" and the Future of Domestic Aviation // Proceedings of the IEEE. 2014. Vol. 102. No. 3. pp. 235-238. DOI: 10.1109/JPROC.2014.2302875.
23. Ganin S.M. Bespilotnyye letatel'nyye apparaty / S.M. Ganin, A.V.Karpenko Sankt-Peterburg 1999 - 160s.
24. Inozemtsev D.P. Bespilotnyye letatel'nyye apparaty: teoriya i praktika / D.P. Inozemtsev // Sankt-Peterburg 2014 – 50 s.
25. Unmanned Aerial Vehicles in Civilian Logistics and Supply Chain Management. Chapter 5 Automated System of Controlling Unmanned Aerial Vehicles Group Flight /Tetiana Shmelova, Dmitriy Bondarev - International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. – November, 2019. – P. 167-204
26. Unmanned Aerial Vehicles: Breakthroughs in Research and Practice. Information Resources Management Association (USA)/ Chapter 8 Applications of Decision Support Systems in Socio-Technical Systems / Tetiana Shmelova, Yuliya Sikirda, International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. IRMA 2019. P.182-214
27. Kucherov D.P., Kozub A.N. Group Behaviour of UAVs in obstacle presence. Proceeding IEEE 4th International Conference "Methods and Systems of Navigation and Motion Control (MSNMC)", Kyiv, Ukraine, pp.51-54 (2016)
28. Shmelova T Geometry-modeling based flight optimization for autonomous groups of UAVs/ T. Shmelova, Yu. Kovalyov, S.Dolgikh, O.Burlaka Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD). 2019 IEEE 5d International Conference. Kyiv, 2019.: Proceeding. P. 79-82
29. Shmelova T. Optimization of flows and flexible redistribution of autonomous UAV routes in multilevel airspace / T. Shmelova, A. Sterenharz, O. Burlaka // 2019 IEEE Proceedings of the 15th International Conference on ICT in Education, Research and Industrial

Applications. Integration, Harmonization and Knowledge Transfer; 5th International Workshop on Theory of Reliability and Markov Modelling for Information Technologies (TheRMIT 2019) Volume IV: Workshops, Kherson, Ukraine, June 12-15, 2019. P. 703-714

# CHAPTER 2
# MODERN ASPECTS OF THE UNMANNED AIRCRAFT IMPLEMENTATION

## *2.1 Problems of flight operation of Unmanned Aerial Vehicles depending on the implementation field*

Unmanned Aerial Vehicles (UAVs) and their implementation in various fields today are a very relevant topic for research [1].

UAVs are currently used in such fields as archeology, architecture, agriculture, urban planning, aerotaxi, cartography, filming, etc. Currently, UAVs are being developed for spaceflight, for work in aggressive environments and on other planets [2]. UAVs are actively used for military purposes. UAVs are effective when used for environmental monitoring. UAVs are also used to ensure law and order by units of the Ministry of Internal Affairs of Ukraine and other countries.

The development of UAV functionality provides with additional capabilities during operation and improves flight characteristics. Meanwhile, depending on the areas of implementation of UAVs and the tasks, their tactical and technical characteristics also depend. Given the various tasks and specifics of the conditions of application of UAVs in different areas of application, there is a need to take into account the features and specifics of flight operation of certain types of UAVs when performing tasks in new areas of application [3].

Meanwhile, it should be noted that a certain role in the flight operation of UAVs is played by the human factor, which should also be taken into account.

Most research is aimed at improving the flight characteristics of existing UAVs by improving the design of the device or making changes to the UAV control system [1-10].

UAVs are used not only for research purposes, but also for transport, military, rescue needs. In many respects the type of UAV depends on the purpose of its application. [1-13].

Of course, UAVs have a number of advantages over manned aircraft. Among them, first of all, absence of crew, relatively low cost and low operating costs.

The variety of UAVs types facilitates their implementation in various fields to perform more and more new tasks.

However, compared to manned aircraft, UAVs have a number of disadvantages. Among other UAVs are characterized by less autonomy of application, modern software is not able to functionally fully compensate for the absence of crew on board [6].

Taking into account above disadvantages of the UAV, it should be noted that in the further application there are a number of aspects that make it impossible to solve such tasks as [7]:

- passenger transport, which requires increased reliability and unconditional presence on board a crew capable of operating the appropriate type of aircraft in manual pilot mode and in emergency situations is able to take actions to rescue the aircraft;
- performing high-precision and selective visual observation of transient ground conditions in difficult situations is impossible without making non-standard decisions by the aircraft pilot;
- using an aircraft in emergencies, instant decision-making by pilots, often non-standard, plays an important role in piloting.

Meanwhile, UAVs are relevant for use in solving problems inaccessible to the manned analogue of the aircraft, which include the following [8]:

- long flight duration, which the crew is not physically able to perform;
- high-speed flight, characterized by long-term effects of various long-term overloads on the pilot's body;
- maneuvers during the operation of the aircraft, characterized by angular velocities exceeding the limits that can withstand the pilot's body;
- operation of equipment on board the aircraft that adversely affects the health of the pilot;
- performance of dangerous tasks, subject to possible damage of the aircraft;
- operation of the aircraft in conditions of biological, chemical or radioactive contamination.

The main areas where UAVs are used are [9]:

1. Spectroscopic survey.
2. Aerial photography of the area.
3. Monitoring of oil and gas pipelines.
4. Monitoring of the state of environmental pollution.
5. Protection of large areas with difficult terrain during the day and night.
6. Monitoring the state of natural resources.
7. Monitoring the condition of overhead power lines.
8. Monitoring the condition of buildings.
9. Monitoring of the road situation, detection of traffic jams and accidents.

10. Protection of law and order in large areas with difficult terrain.
11. Use to control the border area.
12. Application in law enforcement agencies.
13. Service field.
14. Use to search and rescue people.

And this is not a complete list of areas for UAV implementation.

This diversity is due to the manufacturability of UAVs, which is characterized by features that determine the types of these aircraft, and the increase in the field of their use certainly generates an increase in the number of these features. Modern classifications are not complete enough, as they do not consider all types of UAVs that exist today, due to the dynamic development of this technology [10].

Meanwhile, pre-flight training plays a very important role in the performance of flights. Aircraft crews must be provided with the various information necessary to decide on the departure and safe performance of the flight. The responsibility for providing pre-flight information and providing recommendations for further flight is assigned to the flight controllers who provide flights at each modern airline. Very often no less important information received by the flight controller is dynamic and the time for its perception and analysis becomes much less. Therefore, it is advisable to develop a decision support system for the flight controller during the preparation of pre-flight information [11].

Statistics show that almost 50% of aviation accidents occurred due to violations of national aviation rules, operating manuals, instructions and pre-flight training requirements. In some cases, temporary economic benefits take precedence and flight safety is at high risk.

Sometimes, due to lack of time, the flight crew prepares for the flight during the insufficient period, which leads to uncertainty of situations, and worst of all - to aviation events. The nature, content and complexity of information vary, so it is important to provide information so that pilots can easily understand it [12].

There is an opportunity to increase the efficiency of pre-flight information preparation with the help of information support of the flight operations officer when providing recommendations to flight crews on the possibility of helicopter departure. Such programs help to create optimal operational flight plans with high accuracy in terms of wind, temperature, accept weather charts and reports, graphical images of the route and flight profile and other related information provided by the flight. Each helicopter operator chooses own flight planning system that is suitable for the purposes, strategy and requirements of flight operations.

When planning flights and preparing pre-flight information, the aeronautical information specialist faces a number of difficulties, for example, the computer calculates only the shortest route, not taking into account the specifics of the operation of the aircraft (restrictions related to technical status) or ATS areas. In addition, such systems do not allow the output of partial information when it is necessary to support the flight crew in the decision-making process [13].

Therefore, it is necessary to develop information support to make the right, safe decisions and to provide in such a dynamic environment, accurate, complete and biased information to assess all factors that may affect the decision to depart and the intention to continue a safe flight.

In accordance with ICAO flight planning requirements, automated pre-flight information systems for briefing and flight planning should be able to:

a) ensure constant and timely updating of the system database and monitoring of the validity and integrity of information stored before the flight;

b) allow access to the system by operators and flight crew members, as well as other interested users of air navigation by appropriate means of communication;

c) use access procedures and polls based on abbreviated plain language based on the user interface, controlled menu, or other appropriate mechanisms;

d) provide a rapid response to user requests for information.

The system must have two modes of operation [14]:

- pre-flight information mode;
- mode of support for the decision to leave.

In the pre-flight information mode, the output data is set:

- departure aerodrome [13];
- flight route;
- destination aerodrome;
- alternative aerodrome;
- type ACFT.

Information taken from the database is collected and distributed in information blocks according to the established initial data (DEP AD (departure aerodrome), DES AD (destination aerodrome), FLT ROUTE (flight route), ALT AD (alternative aerodrome), ACFT (operational information by type ACFT) [14].

In the departure decision support mode, the system analyzes the possibility of the aircraft departure in relation to the actual conditions. To analyze the possibility of departure, the system takes information from selected information blocks and input data and places in the decision support module. Upon request by the dispatcher, the database collects the data needed to evaluate each factor, obtains and compares the result of each with the approved conditions. According to the assessment of cumulative factors, the system issues recommendations on the possibility of departure of the aircraft and, in case of a negative answer, reports which factor is not satisfactory. At this stage, the system for the preparation of pre-flight information performs the following tasks [15-17]:

- analysis of the suitability of sending the heliport according to the established standards of actual meteorological conditions;
- analysis of predicted dangerous weather phenomena on the flight route;
- analysis of actual and forecasted meteorological conditions for the heliport;
- analysis of the technical condition of the departure heliport and destination;
- analysis of the air situation;
- selection of an alternative heliport;
- flight crew readiness analysis;
- analysis of technical readiness and airworthiness of the aircraft;
- verification of the submitted and confirmed flight plan;
- checking the presence of restrictions on the weight of the aircraft.

Thus, the results of the analysis showed that despite the flight operation of UAVs without pilots on board, a significant role in their operation is played by the operator. And the variety of field of UAVs application, a large number of their types with different characteristics, confirms the need for careful study of the flight operation of Unmanned Aerial Vehicles, depending on the type and field of implementation.

### *2.2 Relevance of the use of decision support systems when controlling Unmanned Aerial Vehicles*

Currently, Unmanned Aerial Vehicles are one of the most dynamically developing types of aircraft and are actively used in solving a wide range of problems. This is due to the fact that UAVs are much cheaper than manned vehicles, easier to maintain.

However, even in the case of Unmanned Aerial Vehicles, emergencies occur that are undesirable due to the destruction of the Unmanned Aerial Vehicle itself and the damage caused by a collision with an obstacle. And such situations require immediate and correct decisions from the Unmanned Aerial Vehicle operator.

Currently, the control of an Unmanned Aerial Vehicle is mainly conducted by the operator by transmitting the information received on board. The decision to adopt the required algorithm of actions to prevent a collision or crash of an Unmanned Aerial Vehicle and further actions is taken by the operator.

The disadvantages of the technology of direct participation of the operator in the process of piloting an Unmanned Aerial Vehicle in real time include: difficult working conditions that lead to an increase in the number of errors in decision-making on further action; the impossibility of effective control of more than one Unmanned Aerial Vehicle due to large volumes of circulating information, reduced productivity of a given job, solving the problem when changing conditions, the need for appropriate qualifications and experience of the operator for operational decision-making. [18] Also, when considering the manual method of piloting an Unmanned Aerial Vehicle, it is necessary to take into account the human factor, which will have a very negative impact on the final decision.

The combination of these disadvantages can lead to collisions, falls, etc. Unmanned Aerial Vehicle even if this could have been avoided by making the right decision.

Thus, the creation of methods for providing recommendations to the operator for the timely adoption of correct decisions by the operator when operating an Unmanned Aerial Vehicle is an urgent problem in the field of operation of Unmanned Aerial Vehicles.

According to research, to solve this problem it is necessary to operate with a larger range of input data than a person is capable of. So a person may not necessarily consider some parameters, which will critically affect the Unmanned Aerial Vehicle.

Therefore, the best solution would be to remove the person from the operator's decision support process. One of the areas that can significantly increase the efficiency of solving the above tasks is the use of decision support systems in the control of Unmanned Aerial Vehicles, which allows timely decisions by the operator in conditions of uncertainty, inconsistency of input information, complex situation with obstacles, significant parameters many of which are impossible for a person to process on their own. The knowledge of experts will allow to form uniform rules on control of Unmanned Aerial Vehicles at the decision of various problems in the conditions of uncertainty.

### *2.3 Development of Unmanned Aerial Vehicles for implementation as part of special units of the Ministry of Internal Affairs of Ukraine*

The current state of equipping law enforcement agencies of special units of the Ministry of Internal Affairs (MIA) of Ukraine with robotic and unmanned equipment is generally insufficient. First of all, police units need to be equipped with Unmanned Aerial Vehicles in order to prevent, detect or record an offense; protection of public safety and property; ensuring the safety of persons; ensuring public safety and order.

At the present stage of development of unmanned technologies in Ukraine the most promising direction is the introduction of unmanned systems and, first of all, Unmanned Aerial Vehicles [19].

As practice shows, at the present stage of development of Ukrainian Unmanned Aerial Vehicles within the Ministry of Internal Affairs, Unmanned Aerial Vehicles are also used by environmental protection forces. Thus, the Ministry of Internal Affairs allowed the police to use Unmanned Aerial Vehicles to ensure law and order and prevent crimes by an order that came into force on February 8, 2018. And this actually means that this industry is incredibly young in Ukraine and needs more detailed consideration and study. However, the experience of using Unmanned Aerial Vehicles by European countries in their own Ministry of Internal Affairs shows their incredible benefits and effectiveness.

In general, for the purpose of their appointment can be divided into 2 main areas: spot observation and planar supervision. For spot observation in the city, a constructive scheme of a multicopter is best suited for monitoring crowds, ensuring public safety, order, etc. A representative of the second type is a fixed wing. The field of this type implementation is search operations.

In order to ensure the proper performance of the monitoring tasks, the Unmanned Aerial Vehicle must have the best possible flight duration indicators and have satisfactory indicators of resistance to radio electronic control.

Thus, taking into account these circumstances, we propose to focus efforts on the development of domestic Unmanned Aerial Vehicles that would satisfy the special units of the Ministry of Internal Affairs of Ukraine with their tactical and technical characteristics.

### *2.4 Analysis of the expedience of unmanned aircraft use in the fight against air smuggling*

Elimination of smuggling is one of the most important tasks of the state in protecting its economic interests. A significant percentage of Ukraine's import and export flows have been smuggled for three decades. Both the interests of Ukrainian enterprises and the state budget as a whole suffer. Illegal import of goods reduces the demand for Ukrainian products, which leads to the decline of production, reducing the competitiveness of Ukrainian producers and significant economic losses in general.

This issue needs a comprehensive solution both in terms of direct fight against smuggling and its direct prevention. In this case, if the prevention of smuggling is provided by law, the fight is carried out using a range of methods, including technical.

After analyzing the thematic literature, it was found that one of the biggest sources of damage is small-scale smuggling in border areas, which is the most numerous type of illegal movement of goods and other valuables. In particular, it was determined that such offenses are committed with the use of transport with a tendency to increase the percentage of light manned aircraft, such as hang gliders. This is where the disadvantages of traditional methods come into play, as they are unable to provide sufficient control over the airspace of borders.

In the course of our research, we determined that the most effective way to prevent smuggling, including by air, is the use of Unmanned Aerial Vehicles.

The advantages of using Unmanned Aerial Vehicles are:

- does not require training of highly qualified personnel;
- does not need airfields;
- cheapness in production;
- cheapness in operation;

However, there is a problem of low surveillance area of one Unmanned Aerial Vehicle, which needs to be addressed immediately. At the same time, we do not consider it expedient to increase the number of Unmanned Aerial Vehicles, which is an extensive method of industry development.

We propose to use Unmanned Aerial Vehicles of the "mini" class [20] as this type provides the most satisfactory correlation between such parameters as cost, payload and complexity of development.

In order to reduce the number of required units of equipment, we decided to use the payload to install an onboard radar station.

This will allow you to quickly find and effectively track both illegal ground movements and, with even greater efficiency, illegal flights to transport goods without tax.

Thus, it will be possible through minimal investment to ensure the highest quality control over the border and prevent its illegal crossing by various vehicles, including aircraft and hang gliders.

### *2.5 The use of Unmanned Aerial Vehicles for the purpose of diagnostics and monitoring of the state of remote power facilities*

The economic situation that has developed in recent years in the energy sector of our country forces us to take measures aimed at increasing the life of various electrical equipment. Solving the problem of assessing the technical state of electrical equipment and electrical networks is largely associated with the introduction of effective methods of instrumental control and technical diagnostics. In addition, it is necessary and obligatory for the safe and reliable operation of electrical equipment [21]. The main goal of technical diagnostics, first of all, is to recognize the state of a technical system in conditions of limited information, and as a result, to increase reliability and assess the residual life of the equipment. At the same time, on the balance sheet of mining enterprises (MEs) there is a large length of electrical networks with a voltage of 0.4–35 kV, and the total capacity of transformer substations is tens and hundreds of megawatts.

As the analysis showed [22], in the last decade, Unmanned Aerial Vehicles (UAVs) have gained immense popularity, especially in the most developed countries of the world. The UAVs' implementation field is quite wide. The use of UAVs has great potential in the energy sector, especially in operational activities (monitoring the technical condition of power lines or cables, checking wind turbines and blades at wind farms, checking the technical condition of solar power plants, etc.).

Among the main tasks solved with the help of UAVs in the field of energy, the following can be distinguished: detection of violations of the technical state of the object (ruptures, cracks, corrosive zones, damage, detection of wire slack), visual assessment of the technical condition of supports, wires, phase separators, dampers, detection overheating elements of power transmission lines, routine diagnostics of the technical condition of the facility, etc.

Thus, the use of UAVs will make it possible quickly detect sources of energy losses in the distribution network, find damage in power lines in a short time, as well as monitor high-rise inaccessible objects.

### *2.6 The use of Unmanned Aerial Vehicles in Smart Grid systems*

The concept of "Smart City" is characterized, first of all, by the use of the latest achievements in the field of Internet technologies in order to monitor the state of urban infrastructure facilities, their control, as well as, based on the data obtained as a result of monitoring, the optimal allocation of resources and ensuring the safety of citizens. Such objects include: bridges and tunnels, roads and railways, communication systems, water supply and sewerage systems, power supply systems, as well as various large industrial facilities, airports, railway stations, seaports, etc. In addition, it should be noted that existing automated information systems (AIS) allow citizens to monitor the state of the city economy and the operation of utilities through the applications available on the AIS portals, and social networks allow organizing local Internet communities using specialized services that can be used to monitor urban infrastructure and their service.

The need to solve the above problems raises the question of the need to design and develop a more complex structure of sensor networks. So the FSN (flying sensor network), being a type of PSN (pervasive sensor network), includes two segments of the sensor network at once - the ground segment of the sensor network (GSN) based on stationary or autonomous sensor nodes and the air segment based on Unmanned Aerial Vehicles (UAVs) equipped with autonomous communication nodes [23].

This approach to the construction of PSN makes it possible to solve several tasks at once within the frame of a "smart city": monitoring of urban infrastructure objects that are dangerous to human health and life, installation and maintenance of network nodes in hard-to-reach places [24], increasing the life cycle of a sensor networks (in the case of using autonomous nodes) [25], effective collection of information by optimizing the trajectory of UAV movement [25] when solving problems of monitoring the urban environment, etc.

### *2.7 The use of Unmanned Aerial Vehicles for the delivery of goods*

Today, an increased demand for the use of UAVs is presented by the agricultural industry due to the need for aerial photography to solve the arising problems in assessing the state of the field from the ground plane during sowing of agricultural crops, as well as to monitor the state of air and soil moisture, the concentration of minerals and fertilizers in the soil, etc. Also, UAVs are in demand in the field of environmental protection and ensuring environmental safety due to the need to control the level of air pollution.

According to the latest research and forecasts of a number of leading analytical agencies, by 2020 small UAVs will become one of the main means for the delivery of various goods: mail delivery, transportation of small-sized cargo, food delivery, etc. [26]. Today, lightweight UAVs weighing up to 30 kg are used mainly for entertainment and competitive competitions. In this regard, the issues of using small UAVs for commercial operation, as well as regulating the movement of UAVs in airspace, are acutely faced by the regulatory bodies of various states [27].

### *2.8 The use of Unmanned Aerial Vehicles to monitor weather conditions*

Expansion of the range of tasks solved by state aviation and the scale of its application determines the need for intensive implementation of modern information technologies for flight and flight support. This fully applies to the meteorological support of state aviation, in particular, in terms of increasing the objectivity, accuracy, visibility and efficiency of information on the actual state of meteorological conditions of flights in the areas where aviation units are based and use. The most objective information about the actual characteristics of the atmosphere, which determine the meteorological conditions of flights, comes only directly during the flight. But in the presence of dangerous weather phenomena, if the meteorological conditions do not correspond to the level of crew training, it is impossible to determine the weather conditions directly in the environment for performing flight tasks. And in this regard, it is advisable to pay attention to the use of unmanned aircraft for solving problems of weather monitoring [28].

Currently, Unmanned Aerial Vehicles are widely used in many areas of economic activity and state security. The use of Unmanned Aerial Vehicles in the meteorological support of aviation will make it possible to promptly, with lower economic costs, receive such important meteorological data for aviation and other types and branches of the armed forces as the height of the cloud base and top, flight visibility, the spatial distribution of meteorological values.

This combination of advantages makes it possible to consider unmanned aircraft as a promising source of obtaining and processing meteorological information (as a carrier of meteorological target load) [29].

The considered examples of the use of a specific type of UAV for monitoring weather conditions, firstly, shows the feasibility of using these technologies in solving problems of hydrometeorological support, and secondly, it indicates the need for a detailed analysis of the capabilities of existing unmanned systems in relation to the tasks of meteorological (hydro-meteorological) service.

In principle, any UAVs with their standard equipment are applicable to obtain data on the state of the atmosphere - in parallel with the performance of the main task. The aforementioned applies to both heavy shock systems and miniature vehicles weighing several kilograms and with a range of 10-15 km. But to obtain regular meteorological information or weather data in a specific area at the required time or at a given time interval, it is required to use specially created (modified) or, at least, aircraft selected according to special criteria.

Based on the results of the analysis, the requirements for UAVs were formulated for effective monitoring of weather conditions from the air: route length - at least 200 km, flight time - at least 2 hours, cruising speed - at least 200 km / h. The practical ceiling of the UAV should allow determining the upper boundary of meteorological objects, which in many cases exceeds 10 km. However, even during manned aircraft flights, it is far from always possible to rise to the top of the clouds: this applies to transport and, above all, army aviation. In these cases, the determination of parameters, for example, the upper cloud limit, can be carried out by onboard remote sensing facilities. As practical experience shows, for most tasks of atmospheric monitoring, a short-term ascent of the aircraft to an altitude of 5-7 km is sufficient [30].

It is advisable to use a helicopter-type UAV directly in the process of performing aviation tasks for duty in weather-hazardous directions. It is rational to carry out this watch at ranges equal to the critical values for limiting and stopping flights in the event of dangerous weather phenomena: as a rule, 50 and 30 km, respectively. In this case, sufficient flight characteristics for a helicopter-type UAV are the flight time commensurate with the time of the aviation task (during flights - up to 6–7 hours). When performing a task in weather-hazardous directions with two or more vehicles, the flight time is limited by the time it takes to approach the airfield and back, and the time spent preparing the vehicle for a second flight. The maximum flight altitude is not essential for the detection of SNP - the ability to climb up to 2.5–3 km is quite enough to detect the approach of meteorological targets in the entire range of possible altitudes. Despite the preference for more high-speed UAVs, to solve the described problem, a UAV speed of 100 km / h is sufficient.

All other characteristics of the UAV can be attributed to secondary. Of course, the size and performance of the UAV play a role. Compact dimensions and low weight are preferred, as well as the possibility of operation in autonomous conditions (mobile and portable version).

**List of references for chapter 2**

1. Vasilin N.Ya. Unmanned Aerial Vehicles. Minsk. "Popourri", 2017. 272 pp.
2. Aviation safety / V.P. Babak, V.P. Kharchenko, V.O. Maximov and others. K.: Technique, 2004. 584 pp.
3. Kozeychuk E.Yu. The state of modern design of drones, drone control systems, copters' designs, copters' elements, solidworks / Automation and development of electronic devices added 2019. Pp. 64-66.
4. Tsymbalistova O.A. Development of the market of services of Unmanned Aerial Vehicles as the main direction of innovative progress of modern aviation Economic analysis: collection. Science. works / Ternopil National University of Economics. Ternopil: Publishing and Printing Center of Ternopil National Economic University "Economic Thought", 2015. Volume 19. 19. 1. Pp. 116-122.
5. Moiseev V.S. Applied theory of control of Unmanned Aerial Vehicles: monograph. Kazan: State Budgetary Institution "Republican Center for Monitoring the Quality of Education" (Series "Modern Applied Mathematics and Informatics"), 2013. 768 p.
6. Petrov A.M. Application of drones in agriculture / Young scientist. 2014. No. 2. Pp. 182-184.
7. Glotov V., Tserklevych A. Analysis and prospects of aerial photography from Unmanned Aerial Vehicles // Bulletin of the National University "Lviv Polytechnic". Ser.: Modern achievements of geodetic science and production. Lviv: Lviv Polytechnic National University Publishing House. 2014. Ed. (27). Pp. 131-136.
8. Angular O.P. Trends in the development of Unmanned Aerial Vehicles. Science and armaments 2014. № 4. Pp. 39 - 47.
9. Lutsky M.G. Development of international regulation and regulatory framework for the use of Unmanned Aerial Vehicles / M.G. Lutsky, V.P. Kharchenko, D.O. Bugayko // Bulletin of NAU. 2015. № 4. Pp. 5–14.
10. Kharchenko O.V. Classification and tendencies of creation of Unmanned Aerial Vehicles of military purpose / О.В. Харченко, B.B. Kuleshin, Yu.V. Kotsurenko // Science and Defense. 2015. № 6 Pp. 47–54.

11. Timochko O.I. Classification of Unmanned Aerial Vehicles / O.I. Timochko, D.Yu. Golubnichy, V.F. Tretyak, I.V. Ruban // Weapons systems and military equipment. 2007. Ed. 1 (9) P. 61.
12. Rostopchin V.V. Unmanned aerial systems: basic concepts / V.V. Rostopchin, I.E. Burdun / Electronics: Science, Technology, Business. 2016. № 7. Pp. 82–88.
13. Priymak A.V. Analysis of the feasibility of creating and using multifunctional Unmanned Aerial Vehicles for civil purposes / A.V. Priymak, Ya.V. Darin, D.M. Striuk, A.A. Slobodyanyuk / Weapons systems and military equipment. 2010. № 3 (23). Pp. 142–145.
14. Reg Austin, Unmanned aircraft systems: UAVS design, development and deployment / 2010 John Wiley & Sons Ltd.
15. Models of Decision Making Operators of Socio-Technical System /Tetiana Shmelova, Yuliya Sikirda, - International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania, 2018. Pp. 33-75.
16. Analysis of the Development Situation and Forecasting of Development of Emergency Situation in Socio-Technical Systems / Yuliya Sikirda, Tetiana Shmelova, - International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania, 2018. Pp. 76 -107.
17. Komarova O.V. Study of ways to increase the capacity of negative electrodes of lithium-ion batteries [Text] / O.V. Komarova - dissertation, 2004
18. Samsung newsroom [Electronic sourse]. Available at: https://news.samsung.com/global/samsung-presents-groundbreaking-all-solid-state-battery-technology-to-nature-energy
19. Korolyuk N.A., Єremenko S.N. Intelligent decision support system for control of Unmanned Aerial Vehicles at the ground control post. Information processing systems, 2015, issue 8 (133), 31 p.
20. Yu. G. Danyk, I.V. Puleko, R.M. Osadchuk, D.A. Ishchenko Features of the use of Unmanned Aerial Vehicles in the interests of units of the tactical unit of the ground forces: Information Systems, 2015, Pp.37-41.
21. Tymochko O. Classification of Unmanned Aerial Vehicles. / Weapons systems and military equipment, vol. 1, Pp. 61–67, 2007.
22. Kirichek R. V., Vladyko A. G., Zakharov M. V., Kucheryavyy A. E. Model networks for the Internet of things and programmable networks // Information technologies and telecommunications. 2015. No. 3 (11). Pp. 17-26. URL: http://www.sut.ru/doci/nauka/review/3-15.pdf
23. Vyrelkin A. D., Kucheryavyy A. E., Prokopyev A. V. Investigation of the possibility of using an Unmanned Aerial Vehicle as a temporary head node of clusters of a ground sensor network // Information Technologies

and Telecommunications. 2015. No. 1 (9). Pp. 27–34. URL: http://www.sut.ru/doci/nauka/review/1-15.pdf

24. Dinh Ch. Z., Kirichek R.V. Study of the installation of wireless sensor nodes from Unmanned Aerial Vehicles of various types // V International scientific-technical and scientific-methodical conference "Actual problems of information telecommunications in science and education." 2016. Pp. 344–348.
25. Kirichek R.V., Grishin I.V., Khundonugbo E.F., Dumin D.I. Positioning of sensor network elements using Unmanned Aerial Vehicles // Information technologies and telecommunications. 2016. Vol. 4. No. 2. P. 26–32. URL: http://www.sut.ru/doci/nauka/review/20162/26-32.pdf
26. Vyrelkin A.D., Vyornova A.I., Kucheryavyi A.E. Study of the possibility of using UAVs as a mobile gateway of a flying sensor network for ground-based autonomous sensor networks // Information Technologies and Telecommunications. 2016. vol. 4. No. 1. Pp. 29–36. URL: http://www.sut.ru/doci/nauka/review/20161/29-36.pdf
27. Vareldzhyan K.S., Paramonov A.I., Kirichek R.V. Optimization of UAV trajectory in flying sensor networks // Electrosvyaz. 2015. No. 7. Pp. 20–25.
28. Kirichek R., Makolkina M., Sene J., Takhtuev V. Estimation quality parameters of transferring image and voice data over zigbee in transparent mode // Communications in computer and information science. 2016. Pp. 260–267.
29. Kucheryavy A.E., Vladyko A.G., Kirichek R.V., Paramonov A.I., Prokopyev A.V., Bogdanov A.I., Dorg-Golts A.A. Flying sensor networks // Elektrosvyaz. 2014. No. 9. Pp. 2–5.
30. Kucheryavy A.E., Vladyko A.G., Kirichek R.V. Flying sensor networks - a new application of the Internet of things // IV International scientific-technical and scientific-methodological conference "Actual problems of information telecommunications in science and education." 2015. Pp. 17–-22.

# CHAPTER 3
# COMPLEX OF UNMANNED AERIAL VEHICLES POWER SUPPLY USING ALTERNATIVE ENERGY SOURCES

## *3.1 Review of the current state of development of power systems for Unmanned Aerial Vehicles*

Ukraine possesses a full cycle of aviation engineering and occupies a significant place in the global aviation market in the transport and regional passenger aircraft sector, which allows the development and production of aviation technology in areas such as aircraft engineering, on-board radio equipment, focused on the use of satellite communication systems, navigation and observation, ultralight and light aircraft, helicopter construction, Unmanned Aerial Vehicles. Unmanned Aerial Vehicles (UAVs) are no exception. Today, this technology is applied in many areas of activity and has extremely high prospects for other areas. Unmanned Aerial Vehicles (UAVs) are currently used to address a wide range of tasks, such as border patrols, reconnaissance, transportation and armed attacks. This diversity is due to the fact that UAVs are very technological, which explains their widespread use. Modern technologies of UAV energy supply have not yet reached the proper level, due to the dynamic development of this technology. Therefore, the purpose of the work is to develop a variant of the power supply system of the UAV using, in addition, alternative power sources and control system of the proposed grid [1-3].

The main components of the UAV are: an airplane with a special landing system, a power plant, a power supply for it, a power supply system, on-board radio electronic equipment (on-board control equipment and electronic elements of the target load). The UAV scheme in NATO countries is presented in Figure 3.1.

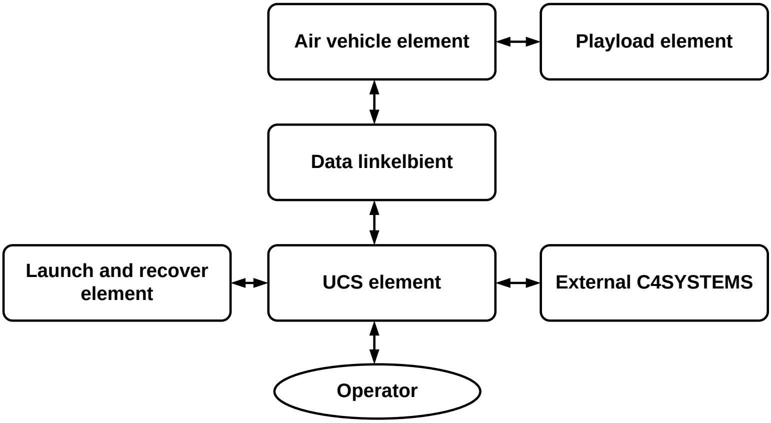



Figure 3.1 – Energy supply system for Unmanned Aerial Vehicles

The UAV should consist of three main elements: air vehicle element, payload element and control system (UAV air component). To analyze the possibility of external influence it is expedient to consider elements that can interact with other components using a wireless communication line (radio, optical, acoustic). In this case it may be a control system and a target load.

UAVs are characterized by the following advantages over manned aeronautics, such as: the lack of a need for crew and systems for its life support, in aerodromes; relatively low cost and low costs for their creation, production and operation; relatively small weight and dimensions in combination with high reliability, significant length and range of flight, maneuverability and a list of target equipment that can be placed on board, etc [4].

The type of control system determines the type of UAV.

**Remotely manned aircraft** are guided directly by the operator within the visibility through the ground station. They are equipped with a digital data channel that can be transmitted to the ground in real-time through direct line of sight or through a satellite channel up to 50 Mb/s.

**Remotely controled** operate autonomously, but can be driven by a pilot that uses only feedback through other control subsystems. Such aircraft include analog and digital channels, the first one providing a stable transmission of information up to 40 km and the other one up to 15 km.

**Automatic aircraft** perform pre-programmed actions. At UAVs of this type there are integrated systems of automatic piloting with GPS receivers, gyroscopes, accelerometers, various sensors, which allows working in real time and transmitting data through a communication channel with a frequency of 1 MHz Remotely controlled aviation systems are controlled by embedded systems, such as the UAS Analyzer.

The Unmanned Aerial Vehicle control system has the following functional architecture:

- engine, maneuvering and flying support (air vehicle / AV);
- operation controller for AV (VSM);
- operator interface (HCI);
- core (core USC);
- launch and recovery system;
- agrees target load unit (CCISM);
- external connecting c4I systems can be target load (c4I system).

The height of the flight significantly affects the work of the whole complex of electrical equipment and other airborne equipment of the aircraft.

External influences on electrical installations can lead to various types of damage, for example, to breakage of wires and windings, especially in the places where they are soldered, until cracks and damage to electrical insulating materials, accelerated wear of the axes and bearings in actuators, deviations from normal operation of spring and moving elements of mechanical systems.

The tactical and technical requirements for aircraft equipment, developed taking into account the conditions of operation of the electrical equipment and its purpose, include the following indicators: reliability and faultiness, requirements for mass and dimensions, strength of electrical equipment, chemical resistance of electrical equipment, ease of operation and repair of electrical equipment, economic requirements.

From the onboard generators all the electronics are emitted on board the aircraft, so the failure of generators will lead to the discharging of all onboard equipment. In this case, in some types of aircraft, manufacturers install retractable wind power units (RWPUs) that produce current due to the fact that the wind wheel is spinning under the influence of the counterflow of air on the blade, which makes it possible at least to keep track of critical technical indicators of the state of airborne equipment and aircraft systems.

At present, solar batteries (SBs) are one of the most promising alternative sources of electric energy in aircraft. Taking into account the fact that the SBs have been used in cosmonautics, which occupy a dominant position among other sources of autonomous power supply, we can talk about the further active their implementation in the system of primary emergency power supply aircraft systems, as additional sources of electrical energy.

Therefore, in view of the urgency of the problem of increasing the reliability of the operation of the entire complex of aircraft equipment, in order to increase the safety of operation, it is expedient to consider the issues of modernization of the airborne power supply aircraft, including renewable energy sources.

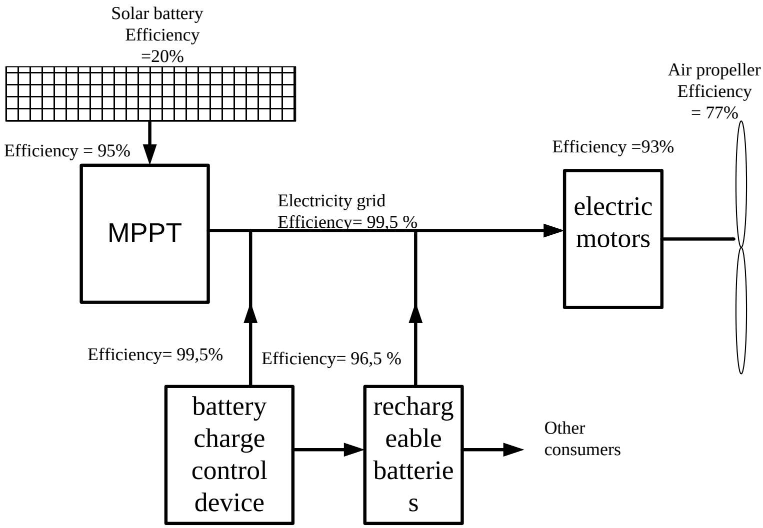



Figure 3.2 – Principle diagram of power plant for Unmanned Aerial Vehicles using solar energy

### *3.2 Development of energy supply system for Unmanned Aerial Vehicles using alternative energy sources*

Taking into account the features of modern aircraft, the authors recommend the structure of the power supply system of the aircraft (Fig. 3.3), which contains: RES1 and RES2 - renewable energy sources, BP - battery pack, BMU- battery monitoring unit, CS - control system, EMC1 and EMC2 - electromechanical complexes of the power system of electric motors based on asynchronous motors with short-circuited rotor, G1 and G2 - generators, E1 and E2 - aviation engines of internal combustion.

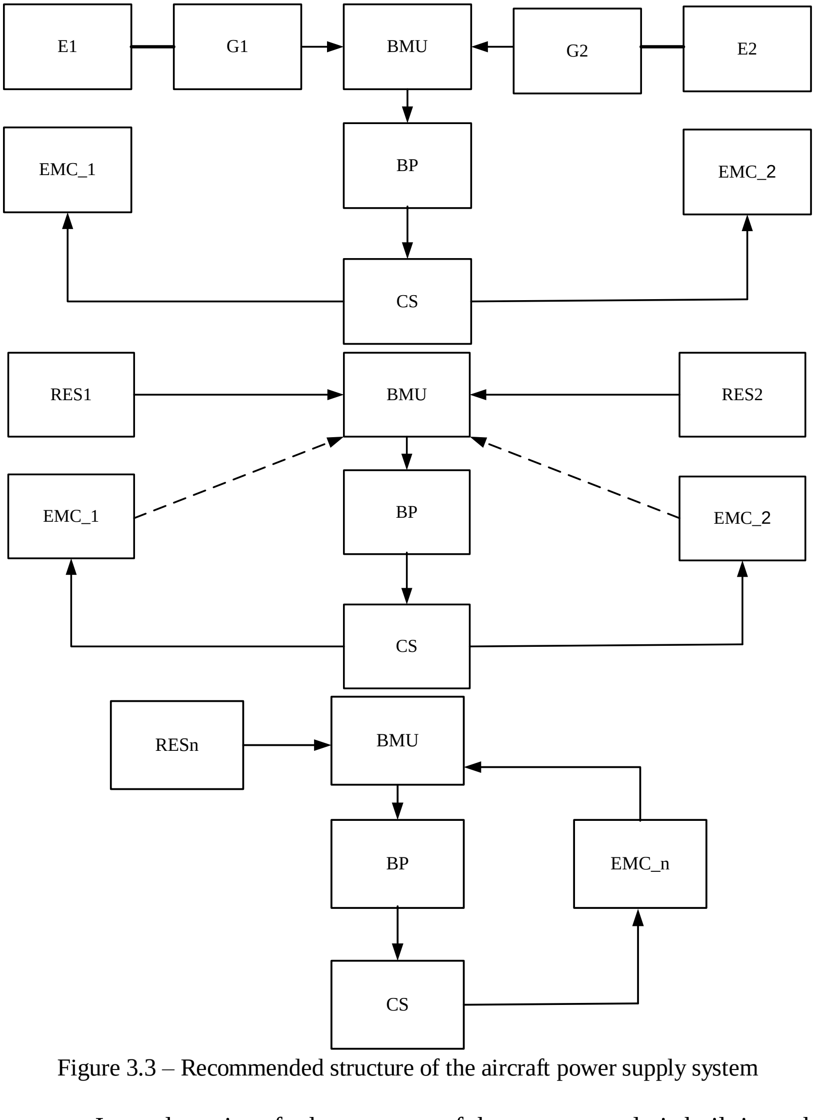



Figure 3.3 – Recommended structure of the aircraft power supply system

In modern aircraft, the structure of the power supply is built in such a way that the main sources of electric energy (EE) are generators, whose work is directly connected with the operation of the internal combustion engines (aircraft engines). In case of failure of internal combustion engines, aircraft in-flight power system is powered solely from the batteries, which is the emergency source EE onboard. Meanwhile, the emergency power supply system on the basis of batteries designed to supply electro starter and equipment ignition when starting the aircraft engines, it is vitally important to consumers during the flight. The lifetime is an important characteristic for battery and depends on many internal and external factors [8]. Complicated specific operating conditions dictate the necessity of monitoring the status of aircraft onboard batteries. The authors propose to implement condition monitoring onboard batteries in the BMU unit (see Fig.3.3). Meanwhile, the unit BMU battery will perform the functions of the charger. It is also proposed in addition to aircraft engines, is standard on the aircraft, in parallel to set the motors and as an additional source of the primary side of the power supply system, renewable energy sources. Given the basic tendencies of development of aircraft in the world today, among the major indicators of the Autonomous aircraft power systems is their energy efficiency, reliability and manageability. Thus, we will consider each indicator separately. The main factors that shape the features of the application of additional electrical power sources of low power onboard include minimizing weight and size characteristics and the need for interim energy storage with a specialized charge-discharge controller. The recommended option of the aircraft power supply system the battery pack has a capacity sufficient to supply in an emergency situation during the flight is not only responsible consumers (controls and navigation), but also the supply of electromechanical complexes power system motors (EM).

Although in the generator mode, the short-circuit induction motor (AMSCR) is rarely used due to the presence of an external cool-down characteristic and imperfect condenser excitation, but such application has a number of undeniable advantages over synchronous generators [5] such as: simplicity and reliability of the design; small weight and dimensions; low cost; easy installation and maintenance.

Taking into account the possibility of EE, including AMSCR, to work both in power and in generator mode, and optimum weight and weight indices, AMSCR is the optimal option for the implementation of additional power sources of low power on board the aircraft.

The energy efficiency of the on-board power supply system can be expressed as the ratio of the difference between the energy produced $W_{ps}$ and the energy losses in the converters $\Delta W_p$ and rechargeable batteries $\Delta W_b$:

$$k_e = (W_{ps} - \Delta W_p - \Delta W_b) / W_{ps\_\max} . \quad (3.1)$$

From the analysis of formula (2.1) it can be seen that the energy efficiency of the airborne power supply complex-electric power consumption of the aircraft depends on its structure and the coefficients of the usefulness of the transforming devices. An integrated approach to building a power supply system-power consumption of the aircraft will reduce losses in the distribution board network [5-10].

Next we will consider the reliability index, which is closely related to the reservation. Since in case of general reservation, the failure of the on-board electrical equipment of the aircraft will come with the refusal of all backup and one main, then with a separate reservation and in the presence of backup chains probability of failure of aircraft on-board electrical equipment will be equal to the product of the probability of failure of the main $Q_{осн}$ and backup $Q_{резі}$ chains:

$$Q(t) = Q_{осн}(t)\prod_{i=1}^{m} Q_{резі}(t) = \prod_{i=1}^{m+1} Q_i(t) \quad (3.2)$$

In the case of a separate reservation, if each main element has m backup elements, the probability of failure of the on-board electrical equipment of the aircraft due to the failure of elements of the i-th type is equal to the product of the probabilities of failures of the i-th element $q_i$ and all its reserving elements, i.e.:

$$Q_i(t) = \prod_{i=1}^{m+1} q_i = \prod_{i=1}^{m+1} (1 - p_i(t)), \quad (3.3)$$

Where $p_i(t)$ is the probability of failure-free operation of the i-th element and all its reserve ones:

$$p_i^{'}(t) = 1 - \prod_{i=1}^{m+1} (1 - p_i(t)) \quad (3.4)$$

As can be seen from formulas (2.2-2.4), when connecting additional power sources to the on-board power supply system of the aircraft using backup chains, the probability of the failure of on-board electrical equipment will decrease, which will increase the reliability of the electrical supply system of the onboard assembly.

Moreover, the probability of failure-free operation of the power supply system of the airborne complex in the general reservation was 0.98, and in the scheme of the previous connection 0.85.

The modern concept of aircraft development sets forth the requirements related to the miniaturization of on-board power and electronics systems, as well as requirements for the use of advanced technologies for manufacturing aircraft designs. Given the application of nanotechnology in the production of SB, there is a prospect of increasing the efficiency of their functioning and at the same time, a significant reduction in their cost. The implementation, if possible, of such implementation (depending on the design of the aircraft) as additional sources of the main electrical power supply system, the retractable wind power installations and the use as power systems of electric motors to install asynchronous motors with a short-circuited rotor, with the possibility of their use in generator mode, is also relevant.

### *3.3 On the application of emergency parachute systems for Unmanned Aerial Vehicles*

All Unmanned Aerial Vehicles have one major disadvantage - low reliability. This causes frequent accidents with their participation. Each such situation can lead to damage of varying complexity: from propeller failure to complete failure of the Unmanned Aerial Vehicle with or without the possibility of recovery. And despite their relatively low cost, even minimal damage is not desirable.

In recent years, sales of Unmanned Aerial Vehicles in Ukraine, including expensive ones worth $ 500, have reached more than $ 8.8 million per year (according to Drone.UA co-founder Valery Yakovenko) [6], however, their popularity is only growing. And most importantly - the growing popularity of Unmanned Aerial Vehicles in the field of photography and video, which often takes place over large crowds of people. This leads to the risk of injury due to the fall of Unmanned Aerial Vehicles.

Thus, the popular quadcopter DJI Phantom 4 weighs 1400 g, the material is shot at different heights, often up to 20 meters, and the speed of each of its four propellers is about 28,000 rpm and in addition they are sharp. There are many cases of humans' injuries of varying severity as a result of the fall of Unmanned Aerial Vehicles in some developed countries.

In the world practice of using Unmanned Aerial Vehicles in order to safely operate them and reduce the financial consequences of accidents, emergency parachute systems are introduced [7].

We propose to use universal emergency parachute systems in the form of external or internal modules for the design of Unmanned Aerial Vehicles.

The system consists of a body, controller, pyrocartridge, parachute, exit hatch with half-slots for easier rip in case of actuating. Power is supplied from the standard battery of the onboard network of the unmanned aircraft. There are two concepts of controlling an emergency parachute system: manual (occurs through an additional channel on the control panel or with an additional remote control in the absence of free channels) and automatic. With the automatic method of controlling the operation of the parachute system is carried out by a regular flight controller, which uses an onboard accelerometer receives information about the uncontrolled fall of the Unmanned Aerial Vehicle and at a certain height creates a potential difference at the terminals of the pyrocartridge which causes the detonation and release of the parachute, which removes the propeller slings of the drones of the Unmanned Aerial Vehicle, which protects them from damage, as well as reduces the rate of its reduction to the allowable speed at which neither it nor people will receive any damage. Reuse of the device is possible after replacement of a cover, a pyrocartridge, repeated insertion of a parachute cloth. Estimated weight of the device: 100-150 grams. Since all Unmanned Aerial Vehicles are not structurally designed for the installation of such systems, the solution is to mount an emergency parachute system from the outside. Due to this external suspension, the aerodynamic characteristics of Unmanned Aerial Vehicles can potentially suffer. To solve this disadvantage is possible by embedding the device under the casing of the fuselage of aircraft Unmanned Aerial Vehicles.

Thus, parachute emergency systems installed on Unmanned Aerial Vehicles make it possible to significantly reduce the degree of damage and eliminate injuries to people due to its fall.

### *3.4 The control system rtructure of the Unmanned Aerial Vehicles*

Modern Unmanned Aerial Vehicles (UAVs) are piloted using remote controls. During such piloting, there are a number of problems associated with special training of operators [8]. Most UAV accidents occur due to operator errors and mechanical failures [9].

UAVs are widely used for entertainment and photography, as well as in the civil sector, agriculture, police and other law enforcement agencies. In this aspect, the question arises about the design of UAV control systems for the safe control of ground facilities.

To perform the tasks of monitoring the Earth's surface in real time during the flight and video shooting of selected areas, as well as determining the coordinates of the studied areas of the UAV must contain [10]:

- navigation system unit;
- piloting control system unit;
- power supply system unit;
- block of video surveillance system.

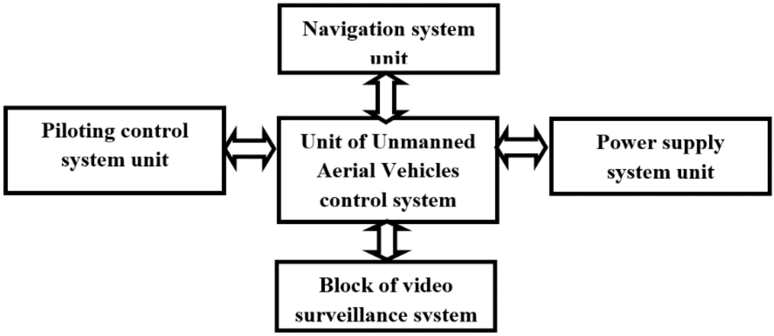



Figure 3.4 – Structure of the Unmanned Aerial Vehicles control system

The proposed structure of the control system of the Unmanned Aerial Vehicle (Fig. 3.4), in condition of its implementation will allow to control the UAV both manually, by remote control, and automatically, using autopilot.

### *3.5 The use of batteries new types in the field of UAV`s*

From one year to another, the market of Unmanned Aerial Vehicles grows, more and more new researches and developments in this field appear. This is due to a range of advantages of Unmanned Aerial Vehicles over other types of aviation. In particular, the main advantage is their low price, while the main disadvantage is the low flight duration.

After analyzing this issue, we found a huge amount of thematic literature, which in one way or another considers the issue of increasing the duration of the flight. Thus, some authors propose to reduce the weight of the aircraft to achieve this goal, and in general, this path is extensive, because it is impossible to constantly develop the field using outdated technologies. Others for the immediate creation and implementation of new technologies.

Currently, the most common type of batteries used in the purest and as a power source for Unmanned Aerial Vehicles with electric motors are lithium-ion and their modification - lithium-polymer batteries. A modern version of the lithium-ion battery with a graphite anode and a cathode of lithium cobalt was invented in 1991 by Akira Yosino. This means that there have been no major changes in the field of portable energy sources over the last almost 30 years.

Lithium-ion batteries and their modifications have a number of advantages over other types of power supply, namely: high energy density, wide range of operating temperatures, lightness, ductility, etc. However, there is a significant disadvantage: high flammability.

As a result of research conducted in the 80s to create lithium batteries, it was found that an accidental short circuit leads to an explosion of batteries. The temperature rapidly approaches the melting point of lithium, which leads to oxidation reactions of lithium with the release of large amounts of heat. [11]. The situation has not changed so far: the scandalous model of the Samsung Galaxy Note 7 cell phone, which constantly exploded or ignited. On the morning of September 2, 2016, sales of the model were suspended due to the inability to promptly resolve the issue.

Therefore, from the collected data it can be concluded that lithium-ion batteries are potentially dangerous and can cause an accident on an Unmanned Aerial Vehicle.

As an option to solve this problem, reputable scientists already present a wide range of proposals. One of them is the most competitive. Compared to lithium-ion batteries, which use liquid electrolyte, fully solid-state batteries can increase the amount of energy stored per unit weight, which in turn allows to create batteries of higher capacity and use solid electrolytes, which are significantly safer than liquid.

In London, researchers from the Samsung Advanced Institute of Technology (SAIT) and the Samsung Research Institute in Japan (SRJ) presented their study of the following battery: high-performance, fully solid-state, long-lasting and highly reliable and this has twice the volume of lithium-ion. [12]

Therefore, the installation of solid-state batteries on Unmanned Aerial Vehicles will significantly reduce the level of danger coming from the batteries, extend the flight time and at the same time improve the weight and dimensions of Unmanned Aerial Vehicles.

## List of references for chapter 3

1. Bocharnikov V.P.; Bocharnikov I.V. 2010. Discrete fuzzy filter of UAV flight parameters. Proceedings of the NAU. N 3 (44): 30-39.
2. Bocharnikov V.P. Fuzzy Technology: Mathematical Foundations. Modeling Practice in Economics. St. Petersburg: Science of the RAS, 2000. 328 pp.
3. Fuzzy sets in control models and artificial intelligence / ed. D.A. Pospelov M.: Science, 1986. 396 pp.
4. Dubois D., Prad A. Theory of Opportunities. Appendices to the representation of knowledge in computer science / per. fr fr M.: Radio and communication, 1990. 288 pp.

5. Touat M.A.; Bocharnikov I.V.; Bodnar L.S. Parametric optimization of multivariable robust control using genetic algorithm. - IX International Scientific Conference of graduates and young scientists "Polit": Proceeding of abstracts. Kyiv NAU-Druk: 215-216.
6. Asai K.; Watada D.; Ivay S., and other. Applied fuzzy systems / translared from Japaneese by T. Terano, K. Asai, M. Sueno. - M.: Mir, 1993. - 386 pp.
7. Holovenskiy V. V., Shmelova T. F., Shmelev Y. M., Boiko S. M., Khebda A. S., Chyzhova L. I. Unmanned Aerial Vehicles. Perspectives. Management. Power supply. Multi-authored monograph / Science Editor DSc. (Engineering), Prof. T. F. Shmelova 2019. 110 pp.
8. UBR.UA, Ukrainian business resource [Electronic resource]. – Access mode: https://gordonua.com/news/worldnews/v-yaponii-dron-upal-v-tolpu-video-216467.html
9. V.M. Alekseev, O.V. Korolyova "PARACHUTE SYSTEMS FOR UNMANNED AIRCRAFT". Development and modernization of OCT, 2015. - Pp. 3-6.
10. Richard V.N. OFDM wireless multimedia communication / V.N. Richard, R. Prasad // Artech House Boston London. 2010. P. 260.
11. Büchi R. Faszination Quadrokopter. 1. Auflage. Verlag für Technik und Handwerk / R. Büchi., Verlag f.Technik / Handwerk, 2010. 72 p.
12. Haas E. Aeronautical channel modeling. IEEE Transactions on Vehicular Technology. 2012. V. 51. № 2. P. 254-264.

# CHAPTER 4
# PSYCHOLOGICAL ANALYSIS OF ERROR ACTIONS OF UAV OPERATORS

It is well known that every three out of four accidents are the result of a malfunction in human performance, which means that any improvement in this area will significantly contribute to the improvement of aviation safety.

This fact was recognized by the ICAO Assembly, which in 1986 adopted Resolution A26-9 on flight safety and human factors. In development of this resolution. The Air Navigation Commission has formulated the following Human Factors study objective: “To contribute to the improvement of aviation safety and, to this end, to broaden the awareness of States about the role of Human Factors in their awareness of the importance of taking it into account in civil aviation operations.

Particular attention should be paid to those aspects of Human Factors that can affect flight safety [1].

The expression “human factor” is most often used in aviation as an explanation of the causes of aviation accidents and accidents that resulted in losses or human casualties [2].

Limitations or mistakes are inherent in every person. The psychological and psychophysiological characteristics of a person do not always correspond to the level of complexity of the tasks or problems being solved. The characteristics arising from the interaction of a person and technical systems are often called the "human factor".

Errors, called the manifestation of the human factor, are usually unintentional: a person performs erroneous actions, regarding them as correct or most appropriate.

The reasons contributing to the erroneous actions of a person can be combined into several groups [3]:

- lack of information support in flight activities, lack of consideration of the human factor;
- errors of aviation personnel and, first of all, of flight personnel, caused by external factors;
- pilot errors caused by the physical and psychological state and properties of a person;
- limited resources to support and implement the decision.

The lack of complete confidence in the success of the forthcoming action, doubts about the possibility of achieving the goal of the activity give rise to emotional tension, which manifests itself as excessive excitement, intense experience by a person of the process of activity and expected results [4].

Emotional tension leads to a deterioration in the organization of activity, overexcitation or general inhibition and stiffness in behavior, an increase in the likelihood of erroneous actions. The degree of emotional tension depends on a person's assessment of his readiness to act in given circumstances and responsibility for their results.

The appearance of tension is facilitated by such individual characteristics of a person as excessive impressionability, excessive diligence, insufficient general endurance, impulsivity in behavior.

Decreased attention in a familiar and calm environment can be a source of error. In such a situation, a person relaxes and does not expect any complications to arise. During monotonous work, mistakes sometimes appear, which almost never occur in stressful situations [5].

Errors in performing certain actions may be associated with an unsatisfactory mental state of a person. At the same time, a person has a depressed mood, increased irritability, slow reactions, and sometimes, on the contrary, excessive excitement, fussiness, unnecessary talkativeness. A person's attention is scattered, errors occur when performing the necessary actions, especially in case of unexpected equipment failures or sudden changes in the situation.

The reasons contributing to the appearance of such a state may be the experience of some unpleasant event, fatigue, an onset of the disease, as well as lack of confidence in one's abilities or insufficient preparation for this complex or new type of activity.

The reason for the appearance of human errors may be the lack or insufficient information support (special handlers for such situations in the software, visual materials and instructions). This problem is especially pronounced in extreme flight situations and in conditions of lack of time for making decisions by the aircraft flight crew members.

The problem of safety and reliability remains one of the main issues in professional activity. This problem has both moral (life safety) and economic (preservation of material assets) aspects and is especially relevant for professions associated with increased risk and operation of complex equipment. Among others, such professions include the profession of a UAV operator.

Most specialists now understand that the issues of optimization, safety and reliability of the UAV crew are a separate aspect of professional training and should remain so in the future. UAV operator training is an ongoing process driven by objective data reflecting operational issues [2, 5, 6].

Professional safety consists of the following components:

– compliance with general organizational and methodological rules and principles of work, excluding violations in the organization of activities and personnel management;

– prevention of accidents, incidents, errors, identification and elimination of hazardous factors of professional activity;

– reliability of the "man-machine system": failure-free operation of equipment and its compliance with the ergonomic capabilities of a person (crew);

– reliability of management and support (including psychological support);

– professional training of a specialist ensuring reliability.

Each of the components has its own, very complex structure and is interconnected with others.

Thus, the reliability of a specialist's activity is a property of a person that characterizes his ability to perform professional activities with the required quality for a certain time not only under given conditions, but also when the situation becomes more complicated, in non-standard situations. For this, a specialist needs a high level of professionalism, timely professional development in connection with the improvement and updating of technical equipment, professional health, a stock of psychophysiological reserves, discipline in observing general organizational and methodological rules and principles of work.

The reliability of professional activity is also ensured by the structure of personnel management, in which, in turn, several components can be distinguished:

– choice of a goal and means of achieving it;

– selection and distribution of personnel;

– organization of the work of specialists;

– distribution of duties, powers and responsibilities;

– corporate training of personnel;

– psychological support of activities;

– psychological analysis of erroneous actions, etc.

Let us turn to the analysis of the causes of UAV operator errors. Each of his flights is the performance of many different operations, which are a chain of thought and motor processes. For any action, a person needs information. The slightest error in the operation of the analyzers through which the pilot receives signals, or dysfunction of any organ through which the pilot receives information, can lead to incorrect actions or even to a disaster. Thus, the threshold for normal visual acuity is equal to one arc minute. From the moment the oncoming object is detected until the beginning of the change in the UAV's flight trajectory, an average of 3-4 s will pass. The higher the aircraft approach speed, the less time the UAV operator has. A decrease in visual acuity, a violation of circumspection in flight leads to an increase in the likelihood of an accident.

A feature of the UAV operator's work is that the rate of signals arriving at him fluctuates within wide limits. But since the optimal speed of information processing is in a rather narrow range, the pilot often has to work in conditions of excess or lack of information. The more information comes in, the more likely the pilot will miss it [7].

Another feature of this profession is the need for constant attention, the inability to relax throughout the flight. Even when flying in automatic mode, the UAV operator must monitor the operation of the UAV.

Over the past 60 years, the relative share of accidents due to personal factors is up to 90%. Thus, in the “Analysis of the state of flight safety...” for 2010 it is said that “the main reasons for more than 90% of aviation accidents were violations by the crews of the established flight rules, incorrect decisions in flight and errors in piloting techniques. Particularly high is the proportion of accidents resulting from direct violations by flight crews of established flight rules (62%). Only one (!) Aviation accident resulting from direct violations by the flight crew of the established flight rules was caused by the refusal of aircraft in flight. The human factor is the cause of more than 80% of all aviation accidents” [7].

When analyzing the causes of accidents, one should strictly distinguish between the concepts of "personal factor" and "human factor". The "personal factor" is understood as those deviations in the pilot's neuropsychic sphere that may lead to an accident. The most complete definition of this concept was given by the domestic aviation psychologist S.G. Gellershtein: the personal factor is the totality of all congenital and acquired physical and mental properties of a person, which can be related to the causes, nature of the course and the outcome of an aviation accident. The personal factor encompasses flight abilities, physical and psychophysiological characteristics, emotional and volitional qualities, health status, physical endurance, psychological stability, and the level of professional training [1].

The reasons for erroneous actions caused by a personal factor may be insufficient social and moral qualities (low focus on flight work, indiscipline, low personal responsibility, etc.);

– lack of knowledge, experience;

– psychophysiological characteristics, health status (illness, fatigue and overwork, neuro-emotional tension, decreased sensitivity of analyzers, unfavorable personality traits, insufficient volume, stability and distribution of attention, memory, spatial representations, etc.).

Systematically, in aviation practice, mistakes are observed that, under certain conditions, are made by healthy, efficient, emotionally stable and experienced UAV operators. The conditions that provoke errors of a trained pilot include the receipt of undefined, false information; anthropometric inconsistency of the workplace with the size of the pilot's body; physiological and hygienic discomfort in flight conditions; lack of time for making a decision, etc. All of the above leads to deterministic errors caused by the discrepancy between processes and means of activity, psychophysiological capabilities of a person and the combined concept of “human factor”.

The distinction between personal and human factors in aviation is of great importance. In the first, as mentioned above, the leading place is occupied by the individual qualities of a particular person, which hinder successful flight work. The human factor includes the dependence of the performance on the characteristics of the aircraft equipment and working conditions:

– shortcomings of conditions and means of activity (shortcomings of means for displaying information, control bodies, layout, placement, lighting; inconsistency of physical, chemical, socio-psychological factors with the required conditions of activity);

– discrepancy between the content of flight work and the psychophysiological capabilities of a person (shortcomings in the distribution of functions between a person and an automaton; excessive information and physical load, pace of activity, etc.);

– shortcomings in the organization of flights and their support (violation in the organization of work, rest and nutrition, shortcomings in the management and control of flights, etc.).

Thus, the prevention of erroneous actions caused by the human factor is carried out primarily with the help of ergonomic refinement of technology to the level of compliance with the psychophysiological capabilities of a person, improvement of conditions, maintenance, organization and provision of flight activities, and errors associated with the human factor should be prevented by optimizing the system "Operator - UAV". However, this is not enough to improve human interaction with the cockpit equipment.

## List of references for chapter 4

1. Gellerstein SG Problems of psychology as applied to aviation // Aviation medicine in the Great Patriotic War. M.: Medgiz, 1947. Issue. 1. P. 15-16.
2. Zinkovskaya SM Modern types of training of civil aviation flight personnel in the field of the human factor // Education and Science. Izv. UB RAO. 2006. No. 6 (42). S. 71–83.
3. Leichenko S. D., Malishevsky A. V., Mikhailik N. F. Human factor in aviation: monograph: in 2 books. St. Petersburg: St. Petersburg. un-t citizen Aviation, 2005. Book. 1.473 p.
4. Human Factors Training Manual. (Doc. 9683 - AN / 950). Canada; Montreal: ICAO, 1998.333 p.
5. Helmreikh RL Professional training in the field of CRM is the main line of defense against threats to flight safety, including personnel errors // ICAO. No. 2. 1999. P. 29–35.
6. ICAO Circular (240 - A # / 144). Human factor: Sat. materials. № 7. Study of the role of the human factor in aviation accidents and incidents. 1993.
7. The human factor. Flight Crew Training: Cockpit Optimization (CRM) and Realistic Flight Training (LOFT): Sat. materials. No. 2. Circular 217 - AN / 132. Canada; Montreal: ICAO, 1989.73 p.

# CHAPTER 5
# APPLICATION OF UNMANNED AERIAL VEHICLES GROUP FLIGHT

In recent years, Unmanned Aerial Vehicles (UAVs) are very popular in all countries. Especially relevant now UAVs use to perform many tasks that were previously difficult to solve. The UAVs effectively both: in military and civil aviation (Kreps, Zenko, 2014; Ignatiev, 2010; Sładkowski, 2019). The UAVs particular in combating the effects of emergencies and natural disasters, and agriculture, aerial photography, communications retransmission (Austin, 2010; Gulevich, 2012; Ganin, Karpenko, 1999), etc [1].

When planning UAV flights, it is important to comply with regulatory air navigation requirements and effective methods for flight operations (ICAO, 2009; 2011; 2015). The documents of ICAO are including the requirements and UAV management rules such as UAV certification and operator certification; UAV registration; rules for UAV operations; communication with the UAV; training of personnel for the operation of the UAV; emergency situations with UAV and flight safety; legal issues to ensure the possibility of performing safe, coordinated and effectively integrated flights UAVs (ICAO, 2005; 2011; 2015; 2017) [2].

Unmanned Aerial Vehicles (UAV)'s have several advantages, namely low operating cost, simplicity, availability, UAVs may be used in cases where the usage of manned aircraft is impractical, expensive or dangerous (Bondarev, Jafarzadeh, Kozub, 2014). The main advantage of using UAVs is tasks that involve risk to humans and efficiency in solving economic problems. Nowadays using of UAVs is effective for decision lot problems such as in monitoring forest fires; search and rescue operations; for relay communications in those places - where the antenna coverage cannot be set because of difficult terrain; in logistic as the safest, cheap and fast method of movement of goods; for aerial photography; for controlling traffic; for first aid to people under various extreme conditions, etc. (Austin, 2010; Gulevich, 2012; Sładkowski, 2019). The main advantage of using UAVs is tasks that involve risk to humans and efficiency in solving economic problems [3].

Obviously, UAVs are effective in monitoring forest fires, search and rescue operations in the processing of agricultural crops, relay communications and the movement of goods. In this sense, the usage of UAVs is more appropriate. In addition, UAVs are widely used for military purposes since 1961 (Austin, 2010; Chekunov, 2010) [4].

The disadvantages of UAVs include the limited capacity due to the small size of UAV that can be satisfied by using group flights (ICAO, 2015). Many of these tasks decision for an urban locality and wherein effectively use single and group flight of UAVs (Kucherov, Kozub, 2015; 2016, 2017; Amelin, Antal,Vasiliev, 2013; Kharchenko, Shmelova, Bondarev, & Stratij, 2017; Shmelova & Bondarev, 2016). In this sense, the usage of group flights UAVs is more appropriate, for example, for photo/video monitoring; group survey of large areas and patrol areas; delivery of big number cargo and use of an unmanned taxi to move passengers, etc. Noted additional useful properties such as faster coverage of big area fragment of urban and minimal risk in the movement of UAVs in town as in “smart-city”. Therefore, the disadvantages of UAVs that include the limited capacity due to the small size of UAV can be satisfied with the group flight usage (Shmelova & Bondarev, 2015; 2016) [5].

Emergencies may occur when flying both in manual and in the automatic modes. For operations carried out "manually", the human factor plays an important role and a significant part of emergency arises due to wrong actions of the operator. Using a constant two-way radio leads to continuous Manual control of device parameters, which results in certain restrictions and inconveniences. The operator cannot be distracted from the controlling and takes full responsibility for the UAVs, for his safety and for the safety of the environment and people.

Additional useful properties of the group of UAVs comparing to one UAV are faster coverage of area fragment and consequently more efficient at photo/video monitoring, relay communications, agricultural operations (Austin, 2010; Gulevich, 2012; Sładkowski, 2019). But despite a number of advantages, there are some drawbacks, namely the main problem associated with the use of airspace allocation of the frequency range for UAVs management and transmission of information from the board to the ground; lack of recommendation action algorithm of UAV operator in case of emergency situations (Kharchenko, Shmelova, Bondarev & Stratij, 2017; Shmelova & Bondarev, 2015; 2016). In (Kharchenko, Shmelova, Sikirda, 2012; 2016) researched an emergency engine stop, electrical problems, excess of the maximum and minimum the display height. In these situations, the parachute releases automatically, with transferring the coordinates of the forced landing site to the operator's monitor. The use of a parachute landing system will not only provide reliable survival craft in an emergency but also simplify its operation. When a loss of communication with the UAV occurs, it reports to the ATM unit immediately. The report states the time and place of loss of communication, the height of the UAV flight, the estimated remaining time of flight and the course of landing area (falling) UAV to follow (Kharchenko, Shmelova, Bondarev & Stratij, 2017; Shmelova & Stratij, 2015).

An American expert, John Warden, predicts that by the year 2025 about 90% of the planes will be unmanned, and only 10% will be piloted, and pilots will be a "golden reserve" for the most important and difficult tasks (Ganin, 1999; Amelin, 2013 Chekunov, 2010; Ignatiev, 2010). A similar situation is observed in connection with the development of UAV for civilian use. This is due to a number of important benefits. First of all, the absence of a crew on board an aircraft (aircraft), and thus eliminating the risk of death. The ability to perform maneuvers with large overloads exceeds the physical capabilities of the pilot, a large length and range in the absence of a crew tiredness factor. And, finally, the relatively small cost of UAVs, which may have small size and low cost of operation (Kreps, Zenko, 2014). Most of the works, which study the group's actions of the UAV, are guided by the main monograph (Fradkov, 2013), which uses the approaches of the classical theory of management to consider the management of a group, organized in the form of "order", which involves a separate representation of the movement of a particular object of the group mathematical model for lateral and longitudinal movement of the center of mass. In this case, there is the task of developing some "optimal" route for the UAV group. A number of research papers are devoted to the decision of the task of planning a route as one UAV, and the entire group of UAVs (Kucherov, Kozub, 2015; 2016, 2017; Marsh, 2005). The additional useful properties of the UAV group as compared to the use of one UAV are noted.

In work (Montgomery, 1998), an inhomogeneous group consisting of UAV helicopter and aircraft types is studied, which has a complex nature of information exchange through the use of flight control channels, operator channel, and the interaction of autonomous elements of the system with each other. At the same time, the complexity of tasks in the case of the management of a UAV group is noted, which consists in the inappropriateness of the application of the classical theory of control (Marsh, Calbert, Gossink, Kwok, 2005) [7].

### *5.1 Group flights of UAVs. Topology of an aircraft group*

To effectively solve these problems the Decision Support System (DSS) operators of unmanned aircraft have been developed. For the control of the UAVs, a system uses next schemes (Figure 5.1):

– Operator - single UAV;

– Group of operators – group of UAVs;
– Operator – CDR – group of UAVs.

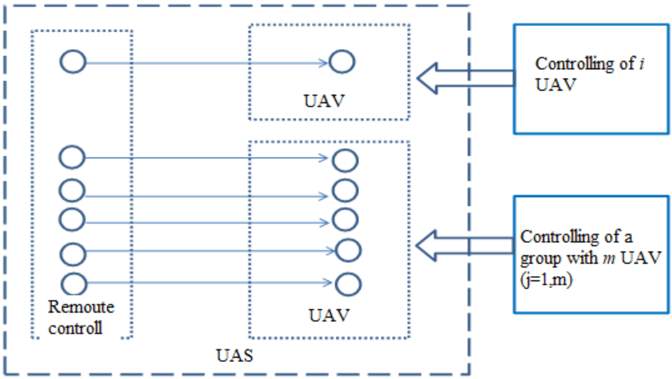



Figure 5.1 – Control system by one or a group of the UAV

Using graph theory, the effectiveness of different structures (topologies) in UAVs group formation. To control a group of drones from RPAS suggested choosing and using a Central Drone Repeater (CDR) to connect to the operator on the ground and control the other of the UAVs presented (Figure 5.2) using the method of server selection in local computer networks (Olifer, 2006; Kuzin, 2011; Shmelova & Bondarev, 2015; 2016; Kucherov, Kozub, 2015; 2016, 2017).

For planning and flight control UAV developed a Distributed Decision Support System (DDSS), which represents a complex system with complex interactions geographically distributed local Remote piloted aircraft (RPA). During the flight, UAVs may be controlled by remote piloting station (RPS). At any given time $t_i$ *k*-UAV must piloted by only one *j*-th RPS, if necessary, at time $t_i$+1 to be transmitted to the control $(j + 1)$-th RPS. This transfer flight control of the *j*-th RPS to $(j + 1)$-th RPS to be safe and effective, which is provided through the local operators UAV. To coordinate interaction and exchange of information between remoted pilots developed a database of local RPS NoSQL (Tarasov & Gerasimov, 2007; Shmelova & Stratij, 2015).

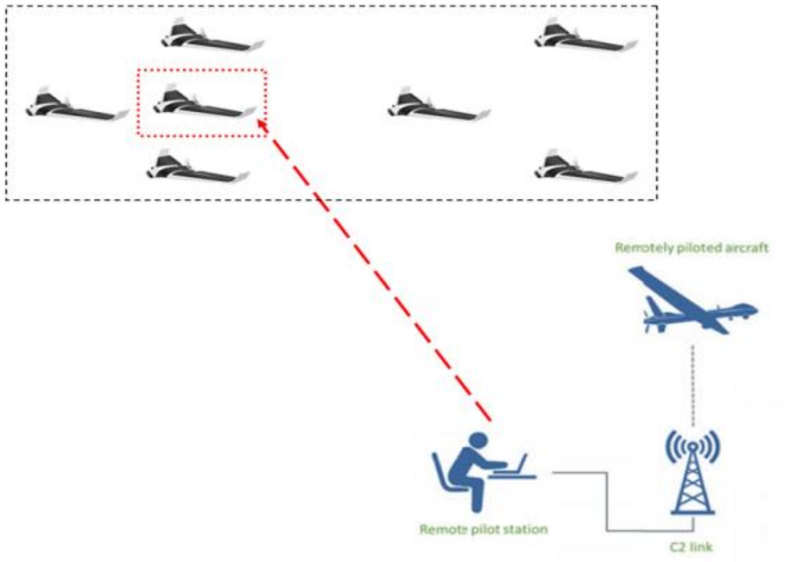



Figure 5.2 – Control system of UAVs group from RPAS using CDR-drone

The authors offer to use the opportunity to control a group of UAVs from a central UAV, which is a repeater of communication from an unmanned station. The central retransmission drone is determined using the method of organizing control in Local Computer Networks (Olefir, 2007). We are planning consider new methods of the performance of aviation chemical works by group of manned and unmanned aircrafts, such as airplanes, helicopters, UAV too (Figure 5.3).

Figure 5.3 – Performance of aviation chemical works by group of manned and unmanned aircrafts

Remotely piloted aircraft systems (RPAS) are a new component of the aviation system, one which International Civil Aviation Organization (ICAO), states and the aerospace industry are working to understand, define and ultimately integrate. These systems are based on cutting-edge developments in aerospace technologies, offering advancements which may open new and improved civil/commercial applications as well as improvements to the safety and efficiency of all civil aviation. It is obvious that the effectiveness of UAV group flights in many tasks such as monitoring forest fires, search and rescue operations, agriculture in the processing of crops, retransmission of communications and movement of goods is much higher than with single UAV flights.

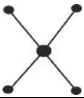
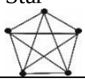
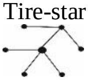
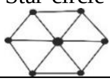
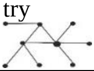
Emergency situations may occur when flying both in manual, and in the autonomous management. For operations carried out "manually", plays an important role the human factor and a significant part of emergency arises due to wrong actions of the operator. Using a constant two-way radio comes to continuous Manual control device parameters, which leads to certain restrictions and inconveniences - the operator can’t be distracted from the management and takes full responsibility for the state-controlled UAVs, for his safety and for the safety of the environment and people.

Let we have some UAV that performed different tasks purposes. Air traffic controller using technological procedures “ASSIST” (Acknowledge, Separate, Silence, Inform, Support, Time) decides in emergency situations of flight. At a certain stage of flight is probable extraordinary or emergency situations (for example: loss of control, engine failure, etc.), where it is some risk to lost UAVs. Taking into account the high cost of UAVs it is proposed to build an algorithm of UAV’s operator actions using module «ASSSIST» (Acknowledge, Separate, Synergetic ((Coordinated, Cooperation, Consolidation)) Silence, Inform, Support, Time) for each type of UAV. Module «ASSSIST» includes in Distributed Decision support system (DDSS) and has models of the Decision Making (DM) by H-O under Certainty, Risk and Uncertainty [3].

For a UAV’s group flight advisable to apply graph theory. The group structure may have a different configuration, location and connections between network nodes, the most common of which are: fully connected, a star, ring, tree, with a common tire, mixed, cellular. From UAV’s topology, which is performed by the flight of an aircraft group depends on the effectiveness of the task purpose. For the management of the UAV, a system for managing one or a group of the UAV’s is proposed, depending on the purpose of the UAV.

Taking into account the limited and dependence of the use of the UAV group on its intended purpose, it is tasked to analyze the network topology indicators for the implementation of the group flight. The analysis of existing topologies of information networks and their capabilities in accordance with table 1 shows the benefits of hybrid over classical variants such as "tire", "circle" and "star" (Kuzin, 2011; Olefir, 2006).

Table 5.1 – Analysis of network topologies

| Network | Deployment | Reliability | Delivery of packages | Access scheme |
|---|---|---|---|---|
| Tire  | Simple deployment, (up to 10 nodes) | Low reliability | Simultaneous delivery | Competitive access |
| Circle  | Simple deployment | Low reliability | Simultaneous delivery | Mark up access |
| Star  | The need for a hub when deployed | Critical element, Hub | Delivery delayed | Address Access |
| Star  | Need for additional equipment | High reliability | Address delivery | Address Access |
| Tire-star  | Need for additional equipment | High reliability | Need to distribute traffic | Tire Competitiveness,<br>Star Targeting |
| Star-circle  | Need for additional equipment | Dependence on the hub | Need to distribute traffic | Equal access at the expense of markers |
| Hybrid-pantry  | Need for additional equipment | Below just a pantry | Need to distribute traffic | Address Access |

For example, star-circle topology of group of the UAVs show on figure 5.4. The UAV flights use the above criteria. In addition, when performing group flights of the UAV it is expedient to apply specific criteria for the reliability of the group structure: connectivity, structural redundancy, uneven distribution of connections, structural compactness, degree of centralization in the system, survivability.

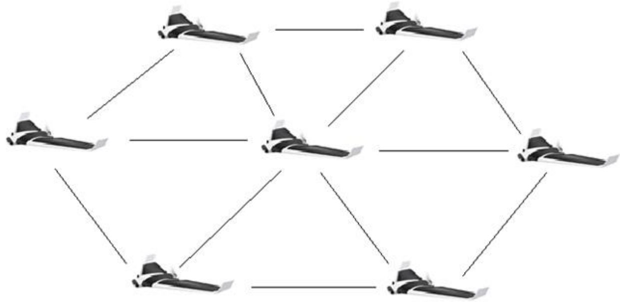


Figure 5.4 – Star-circle topology of group of the UAVs

The algorithm of finding central drone in group of the UAVs in flight for relaying control signals from other UAVs was obtained.

*Algorithm of finding Central Drone Repeater (CDR) in group of the UAVs in flight*

1. To build graph *G (n; m)* for UAVs group
2. To build adjacency matrix $A = \|a_{ii}\|$ of graph *G (n; m) of* UAVs group: $a_{ij} = \begin{cases} 1, i \leftrightarrow i \\ 0, i \not\subset i \end{cases}$ (Table 5.2)

Table 5.2 – The adjacency matrix for UAVs group

| Tops of graph $i = \overline{1, n}$ | Tops of graph *G (n; m)*, | | | | | |
|---|---|---|---|---|---|---|
| *G (n; m)*, | $U_1$ | $U_2$ | $U_i$ | …. | $U_n$ | $\sum_i U_i$ |
| $U_1$ | 1 (0) | 1 (0) | 1 (0) | 1 (0) | 1 (0) | |
| $U_2$ | 1 (0) | 1 (0) | 1 (0) | 1 (0) | 1 (0) | |
| $U_i$ | 1 (0) | 1 (0) | 1 (0) | 1 (0) | 1 (0) | |
| … | 1 (0) | 1 (0) | 1 (0) | 1 (0) | 1 (0) | |
| $U_n$ | 1 (0) | 1 (0) | 1 (0) | 1 (0) | 1 (0) | |
| $\sum_i \sum_l a_{ij}$ | | | | | | |

*3.* To build matrix of introspection $\rho = \left\| \rho_{ij} \right\|$ of UAVs group graph *G (n; m):* $a_{ij} = \begin{cases} 1, i \leftrightarrow j \\ 0, i \not\subset j \end{cases}$ (Table 5.3*)*

Table 5.3 – The matrix of introspection of graph G (n; m) for UAVs group

| Tops $i = \overline{1, n}$ | Ribs of the graph *G(n; m)*, $j = \overline{1, m}$ | | | | | | $\sum \rho_{ij}$ | $\sum \rho^2$ |
|---|---|---|---|---|---|---|---|---|
| $U_i$ | 1 | 2 | … | *j* | … | *m* | | |
| $U_1$ | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | | |
| $U_2$ | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | | |
| … | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | | |
| $U_i$ | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | | |
| … | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | | |
| $U_n$ | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | 1(0) | | |
| $\sum$ | | | | | | | | |

4. To build distance matrix $D = \left\| d_{ij} \right\|$ of UAVs group graph *G (n; m)* as the minimum distance $d_{ij}$ between the nodes *i* and *j* (Table 4)

Table 5.4 – The matrix of distance matrix $D = \left\| d_{ij} \right\|$ of graph G (n; m) for UAVs group

| | | Tops of graph *G(n; m)*, $i = \overline{1, n}$ | | | | | | $\sum d_{ij}$ |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | … | *i* | … | *n* | |
| Tops of graph *G(n; m)*, $i = \overline{1, n}$ | 1 | 1 | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | |
| | 2 | $d_{ij}$ | 1 | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | |
| | … | $d_{ij}$ | $d_{ij}$ | 1 | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | |
| | *i* | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | 1 | $d_{ij}$ | $d_{ij}$ | |
| | … | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | 1 | $d_{ij}$ | |
| | *n* | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | $d_{ij}$ | 1 | |
| $\sum \sum d_{ij}$ | | | | | | | | |

5. Determine the connectivity of UAVs group graph *G (n; m)*

$$L = \frac{1}{2}\sum\sum a_{ij} \geq n-1, \; i \neq j$$

$$L_{\min} = n-1$$

6. Determine the structural redundancy of R of UAVs group graph *G (n; m)*

$$R = \frac{1}{2}\left[\sum\sum a_{ij}\right]\frac{1}{n-1} - 1$$

7. Uneven distribution of relationships of UAVs group graph *G (n; m)*

$$\varepsilon^2 = \sum_{i=1}^{n}\left(\rho_i - \bar{\rho}\right)^2 = \sum \rho_i^{\,2} - 4\frac{m^2}{n},$$

where $\rho_i = \sum_{i=1}^{n} \rho_{ij}$

8. Structural compactness *D* of UAVs group graph *G (n; m)* shows the proximity of the parameters ($D_i$) to each other through the minimum chain length $d_{ij}$ - the smallest distance between *i* and *j*. The common proximity of the elements in the network. Structural compactness is characterized by the indicator - the diameter of the structure: $d = max\ d_{ij}$. The values of $D_{rel}$ and *D* integrally characterize the inertia of the processes in the system, with equal values of *R* and $\varepsilon^2$ their increase reflects the growth of the number of bonds that disconnect. This situation helps to reduce the reliability of the system as a whole.

$$D = \sum_i \sum_j d_{ij}$$

The relative distance:

$$D_{\text{rel}} = \frac{D}{D_{\min}} - 1;$$

where $D_{min} = n(n-1)$.

9. Degree of centralization in the system $\delta$ is determined using the centrality index:

$$\delta = (n-1)(2Z_{\max} - n)\frac{1}{Z_{\max}(n-2)},$$

where $Z_{max}$ maximum value of the indicator *Z*:

$$Z_i = \frac{D}{2}\left(\sum d_{ij}\right)^{-1}, \; i = 1, n, \; i \neq j$$

10. Determine the centrality of the nodes $C_i$ of the graph *G (n; m)*. The CDR in group of the UAVs in flight has $C_i = C_{max}$:

$$C_i = \frac{\sum\sum d_{ij}}{\sum d_{ij}}$$

Relative periphery of the node

11. Determine the periphery $P_i$ of the graph *G (n; m)*. The CDR in group of the UAVs in flight has Pi = 0. Relative periphery of the node

$P_i = C_{max} - C_i$

12. Determine the survivability of the network S, CRD in group of the UAVs in flight has S > 0:

$$S = \frac{\sum a_i - 2(n-1)}{2(n-1)}$$

13. Determine the moment of the network, *M* - characterizes the controllability of the CRD:

$$M = \frac{\sum_{i=1}^{n} a_i}{a_l^2} \sum_{i=1}^{n} (a_l - a_i)$$

14. Data table of parameters CRD in group of UAVs.

In order to quantify the reliability of the UAV group flight performance, it is necessary to submit a group flight in the form of a graph for the above-mentioned criteria. Let's consider the flight of a group of five UAVs that perform aerial search of the fragment of the terrain (Figure 5.5). Let's represent the group flight of the UAV in the form of a non-oriented graph *G (n; m)*, which has *n* nodes (UAVs) and *m* arcs (connection). Full-fledged topology will characterize the effectiveness of the group's task of the UAV.

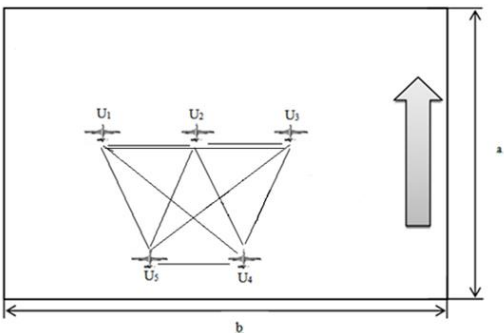



Figure 5.5 – Presentation a group the UAV's in a fully connected network proceeding aerial photography, n=5; m=10

For example: for making aerial photography of a fragment area with the help of 5 UAV's let us imagine group flight scheme as an undirected graph *G (n; m)*, which has *n* nodes (UAV's) and *m* arcs (connections), that is shown in Figure 6. So, fully connected topology will analyze the effectiveness of the task group UAV (Shmelova, Bondarev, Kucherov, 2015; Bondarev, Jafarzadeh, Kozub, 2014).

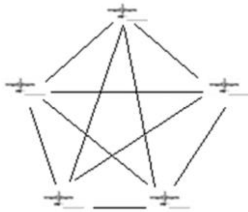


Figure 5.6 – Representation of a UAVs group in flight for aerial photography, n=5; m=10

It corresponds fully connected topology network, where each node is directly connected to all other nodes. For UAV's group's flight applicable criteria of reliability, represented as a structure using graph theory, connectivity, structural redundancy, uneven distribution relationships, structural compactness, degree of centralization in the system survivability.

Undirected graph *G (n; m)* is considered to be connected, if from any node (UAV's) there is the way to another nodes (the path may consist of any number of ribs). In our case the graph is connected, because all UAV's are connected between each other.

Applications of Algorithm of finding Central Drone Repeater in group of the UAVs in flight for determining the central drone and optimal topology of configuration in group of the UAVs in flight in examples are obtained [4]. For example, to select optimal structure for goal task - UAVs group in flight for aerial photography. We are building graph G (n; m) (Figures 8) for UAVs group according UAVs group in flight.

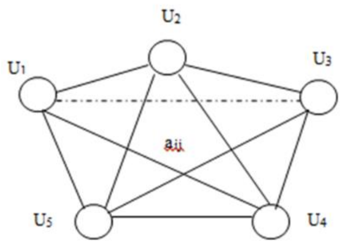



Figure 5.7 – Representation of a UAV group in the form of a non-oriented graph G (5; 10) of five elements of a full-fledged network.

In case of a UAVs group in flight for aerial photography we have high effectivity for star topology. With the help of graph theory, we can determine the effectiveness of different types of configuration of the group structures of UAV (full connecting, star-shaped, ring, tree, general tire, mixed, cell, etc.) and to select optimal structure for goal task. The type of lining (the structure of the UAV group), on which the flight of the group of aircraft depends on the effectiveness of the task.

The quantitative values of the effectiveness of group flights for different types of connections in the UAV group were calculated (Table 5.5, Figure 5.8).

Table 5.5 – Performance criteria of group flights for different topologies of UAVs groups

| Scheme | Connectivity | Marks | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Types: | (connective or not) | R | $\varepsilon^2$ | D | D*rel* | d | $\delta$ | П | К |
| Fully con-nected | + | 1,5 | 0 | 30 | 0,5 | 2 | 0 | 0 | 2,125 |
| Cellu-lar | + | 0,4 | 47,3 | 68 | 1,26 | 3 | 0,23 | 4,63 | 0,4 |
| Ring | + | 2,5 | 105 | 50 | 1,5 | 4 | 0 | 0 | 1,5 |
| Star | - | 0 | 13,3 | 50 | 0,6 | 2 | 1 | 22,5 | 0 |
| Tree | - | 0 | 5,42 | 96 | 1,28 | 4 | 0,0325 | 4,38 | 0 |
| Com-mon tire | + | 2,5 | -23,8 | 80 | 3 | 6 | 0,33 | 3,3 | 1,5 |
| Mixed | + | 1,26 | -9,14 | 755 | 3,14 | 9 | 0,67 | 101,98 | 0,26 |

The geometric modeling method is based on the interpretation of the relative position of the UAV on the terrain, taking into account forbidden zones and other limiting factors, such as a Discrete Network Model (DNM) of a connected surface built on a given contour, the topological, positional and metric properties of which are determined by the conditions of the problem and limiting factors. The DNM construction algorithm should satisfy requirements [10; 11]:

– compliance with the topological, positional and metric characteristics of the simulated object (formation of a group flight configuration in accordance with the target and estimated characteristics of the terrain);

– calculation of the minimum and maximum number of UAVs to perform the target task;

– software communication with the database.

– The DNM construction algorithm includes:

– building an accurate or approximate scan of a connected surface (allows you to reduce a three-dimensional problem to a two-dimensional one);

– selection of fragments that allow the construction of regular grids;

– automated breakdown of the contours of the connected parts of the surface;

– calculation of grid nodes coordinates using finite-difference patterns and the Gauss-Seidel method [9; 10] (UAV locations are interpreted as grid nodes);

– inverse transform scan to the original surface.

The process produced the optimal configuration of the UAVs group (Fig. 5.9), with set of restricted, dangerous areas and tracks of flight.

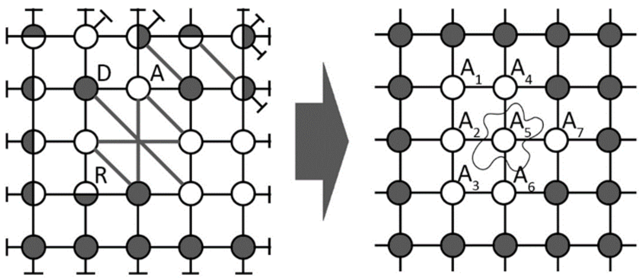



Figure 5.8 – Obtaining the optimal network configuration of UAV's group by geometric modeling using DNM

The coordinates of the nodes of discrete networks are determined based on the data of the structure of elementary sub-fragments. For a particular node, one can apply the following [9]:

$$\alpha_1(f^i_{j,k})+\alpha_2(f^i_{j-1,k}+f^i_{j,k-1}+f^i_{j+1,k}+f^i_{j,k+1})$$
$$+\alpha_3(f^i_{j+1,k}+f^i_{j-1,k-1}+f^i_{j+1,k}+f^i_{j-1,k+1}+f^i_{j+1,k+1})$$
$$+\alpha_4(f^i_{j-2,k}+f^i_{j+2,k}+f^i_{j,k-2}+f^i_{j,k-2}+f^i_{j,k+2})=0$$

Where: α - weight coefficients, the values of which are determined using the flight risk of UAVs (tension in network), f - coordinates of network nodes (UAVs) for calculation.

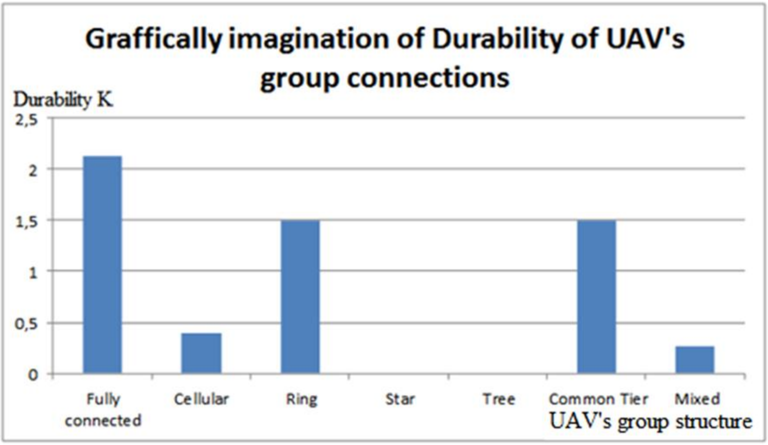



Figure 5.9 – Graphically representation of group durability

Table 5.6 shows the designation of reliability parameters of the group structure for the UAV flights. The reliability of the group flight of the UAV is determined using the criteria of the theory of graphs. In order to quantify the reliability of the UAV group flight performance, for the above criteria, it is necessary to submit a group flight in the form of a graph. Let's consider the flight of a group of five UAVs that perform aerial search of the fragment of the terrain. So, group use of UAVs is widely used in the world for the solution of national economic and military tasks. Among these tasks is the control of the state of large forestry for the purpose of preventing fires and floods in order to take appropriate measures for the timely fire suppression and rescue of the victims, monitoring of road safety, aircrafts, search and rescue operations, aerial surveying, and others.

The application of group action of remotely-manned devices allows timely DM and shortening the time to perform a task or executing it with higher quality. In the course of the application of aircraft, there are the following types of group construction: "wedge", "bearing", "ring" and mixed structure. These structures are characterized by certain geometric parameters of distance, intervals and excesses that are supported by the installed equipment for the purpose of ensuring flight safety. The option of building a group flight UAV is determined by the specific task assigned to the group [1-7].

An important component of UAV group flight operations is the availability of integrated and computing equipment, which suggests that the UAV group is part of an informational network whose elements exchange information with each other. To control a group of UAV flight computer program “Aggregation of heterogeneous information flows”developed (Shmelova, Stratij, 2015). To coordinate interaction and exchange of information between remoted pilots developed database of local RPS NoSQL. During developing a database of local RPS, UAV users, it was made UAS components analysis, UAV, RPS, C2, and so on. Taking into account the UAVs operating procedure that includes the purpose of the flight, flight rules, flight areas, functional level C2 lines and other standards (Figure 5.10).

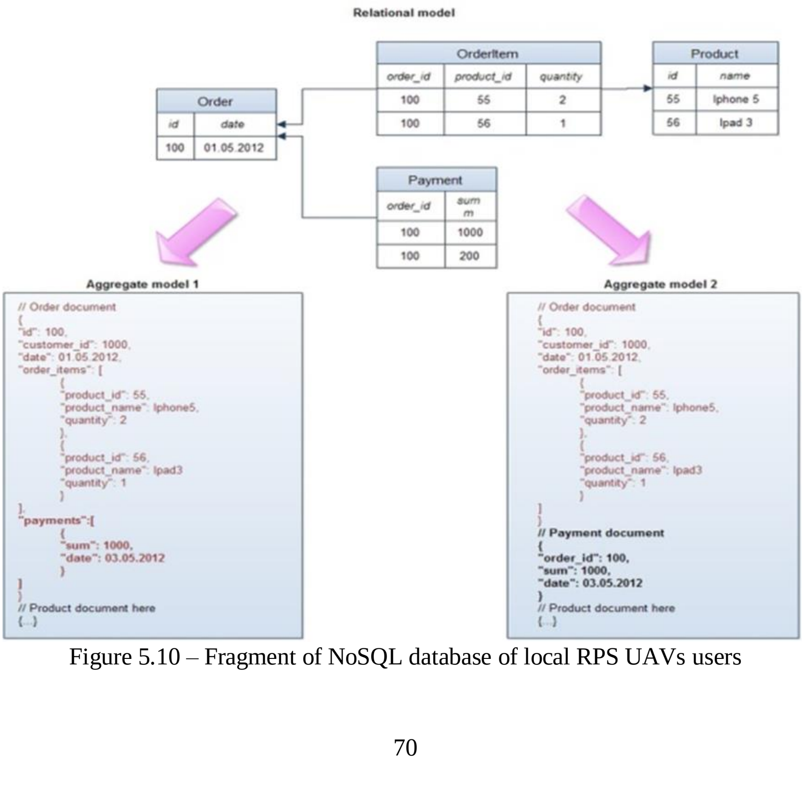


Figure 5.10 – Fragment of NoSQL database of local RPS UAVs users

To coordinate interaction and exchange of information between remoted pilots developed database of local RPS NoSQL. During developing a database of local RPS, UAV users, it was made UAS components analysis, UAV, RPS, C2, and so on (Shmelova, Stratij, 2015). For optimization the solution of problems are developed models of determination the optimal landing site in case of an extraordinary situation, search for optimal flight routes UAS with the module «ASSSIST». The investigation into the processes of modelling the DM by UAV's operator in the normal and unusual situations enabled to build the following models: DM under Certainty, DM under Risk and DM under Uncertainty.

During the flight UAVs may be controlled by RPS. At any given time $t_i$ *k*-UAV must piloted by only one *j*-th RPS, if necessary, at time $t_i$+1 to be transmitted to the control *(j + 1)* th RPS (Figure 5.10). This transfer flight control of the *j*-th RPS to (*j* + 1) - th RPS to be safe and effective, which is provided through the local DSS operators UAV [5-11].

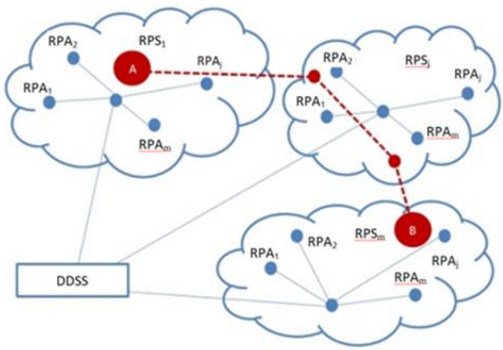



Figure 5.11 – The structure of distributed RPS Mission Control UAVs

The structure of the information system is determined by its topology. The most well-known topologies are full-fledged, star, ring, tree, common tire, cell, mixed. An analysis of these topologies in terms of reliability and efficiency can be found in the literature on computer topics. It should be noted that the analysis of topology traditionally takes into account the static nature of the structure, which is not always justified in terms of moving media and performance of individual elements of the group. The work of the wireless network is accompanied by malfunctions, failures of nodes. Therefore, the actual task is to optimize the structure according to certain criteria (Figure 5.12). Using graph theory we can determine the effectiveness of group structures in different types of UAV's formation. The type of formation (structure of UAV's group), which performed the flight of an aircraft's group depends on the effectiveness of their task purpose. It is intended flight group performance criteria for all types of connections. So, UAVs have a number of advantages, namely: low cost of operation, low radar and optical visibility, stability and flexibility, and simple and accessible technology for their creation.

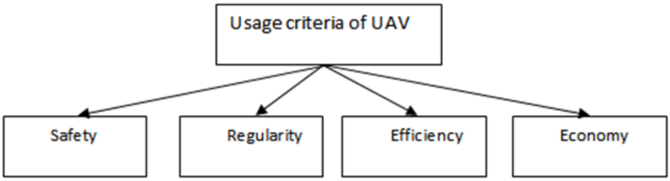



Figure 5.12 – Basic criteria for the flight of aircraft

Unmanned media can even be used in cases where the use of manned aircraft is impractical, expensive or risky. By 2008, 91% of all UAVs were built in the US, currently almost 40% is produced in other countries, including Ukraine. Initially UAVs were used mainly for military purposes: military intelligence, surveillance, detection, recognition and support of objects (purposes); provision of two-way and radio relay communication; radio and radio engineering and radio-electronic intelligence, electronic warfare; detection of the use of chemical, biological and nuclear weapons; delivery of goods; participation in information operations; solving search and rescue tasks; direct aviation support; participation in an airstrike operation; monitoring the state of the environment. Among all multipurpose UAVs of military purpose: reconnaissance - 100%, shock (for the fire by land and air targets) - 39% (Ignatiev, 2010) [10-15].

To evaluation, the safety of UAVs flights in town, need to obtain quantitative values of risks of flights in different segments of the territory of the town. Methods for evaluating "Risk" are the EJM and Fuzzy logic.

The air navigation rules for classification obstructions in town such as "Restricted" and "Dangerous" areas, but they have nothing in common with ICAO's official definitions, this is an estimation of risks movement ways of UAVs in smart-city. The "Restricted areas" in our case are such areas, where the risk of harming people is high, the "Dangerous areas" - the risk of harming people is very high.

*Initial data* for estimation risk:

*a). Buildings:* these are objects where people live and work (offices, factories, markets) and public places. Potential risk after these area penetrations:

– for UAVs → very high;

– for people → moderate to high.

*b). Columns and wired communication*: these objects are columns with its wires, masts, pipes antennas, which may endanger life and health of people nearby in case of breakdown. Potential risk after area penetration:

– for UAVs → moderate;

– for people → low to moderate.

*c). Trees and natural obstructions:* These objects are trees, hills, mountains etc. Potential risk after area penetration:

– for UAVs → high to very high;

– for people → very low.

*d). "Dangerous areas"* are classified on the basis of an application to the object of "Restricted area". "Dangerous areas" themselves are not hazardous, but permanent residence increases the risk directly proportional to the residence time. Potential risk at the moment of penetration:

– for UAVs → very low;

– for people → very low.

The potential risk when UAVs is staying in any period of time is a very complex task and depends on many factors, such as time, enclosing object, the previous trajectory of flight, maneuverability of UAVs, aerodynamic aspects, environmental conditions, etc.

*f). Track area:* it is a part of the planned flight path after UAV flight in which 99.99% UAV is or will be located according to "Flight plan" data:

– for UAVs → high to very high;

– for people → high to very high.

*e). Track conflict area:* It is unplanned part of space around "Track area":

– for UAVs → high to very high;

– for people → high to very high.

To evaluation, the safety of UAVs flights in town may use the EJM for building Expert System as AI. Nowadays in documents of International Civil Aviation Organization (ICAO) defined new added approaches for achieving the main goal of ICAO enhancing the effectiveness of global aviation security, and improving the practical and sustainable implementation of preventive aviation security measure. The Global Aviation Security Plan

(GASP) identifies five key outcomes for improving effectiveness, such as (ICAO, 2017):

– enhancing awareness and response of risk;
– development of security culture and human capability;
– improving technological resources and foster innovation;
– improving oversight and quality assurance;
– increasing cooperation and support between states.

So, the quality of decisions dependences from the development and using of innovative technology in aviation nowadays such as AI (ICAO, 2018). Developing of AI in Air Navigation System (ANS) such as Expert Systems (ES), DSSs are considering new concepts in aviation need with using modern information technologies and modern courses: Data Science, Big Data, Data Mining, Multi-Criteria Decision Analysis, CDM, Blockchain, (Shmelova, 2015; 2016; 2017) etc.

### *5.2 UAVs for Smart Cities: estimations of urban locality*

In recent years, the idea of smart-city became very popular in all countries. It is an urban area, which uses many electronic sensors to collect data and use it to manage assets and resources efficiently. The concept of “Smart City” is characterized by using the new achievements such as using Artificial Intelligence (AI) and Internet of Things (IoT) in order to monitor the state of urban infrastructure facilities and control them, based on the data obtained as a result of monitoring, optimal allocation of resources and ensuring the safety of citizens (González, 2016; GSMA, 2016; Vyrelkin & Kucheryavy, 2014; Kirichek & Makolkina, 2016; Montgomery, Bekey, 1998). Nowadays, the using of drones may help to perform many tasks that were previously difficult to solve.

The effectiveness of presenting using UAVs for a modern town as a “smart city” has some problems: the presence of buildings, roads, construction, recreation areas, and natural areas, etc.; availability of specific flight orders - target use of drones (Sładkowski, 2019); air navigation requirements (ICAO, 2011, 2015) for flight operations of the manned and unmanned aircraft, etc. The “smart city” is an aggregate of several information and communication technologies, mathematical methods and AI (ICAO, 2017). The usage of UAVs in the smart city concept will help solve such tasks: traffic jams monitoring; search and rescue tasks; photo/video monitoring; the mobile point of Wi-Fi retranslating; the movement of goods; taxing operations; ambulance operations, etc.

These applications of increasing variety and complexity demand collaborative and autonomous operation of groups or teams of UAV performing complex and versatile tasks and missions with minimal human control, due to limitations of management volume and human ability, while ensuring utmost safety, economic efficiency, precision and quality, minimal environmental impact and complying with other essential requirements and parameters [1]. Meeting these expectations and requirements would be possible with the introduction of operation management and control systems capable of supporting versatile and autonomous teams of UAV performing a wide range of complex tasks and activities with separation of roles in the team and with minimal human control while supporting highest standards of safety [2; 3].

However, nowadays systems suffer from the following performance weaknesses and limitations:

– Need for better autonomy: systems require significant control by a human operator in both time and cost;

– Hardwired to task: management system is designed for a specific task and doesn’t allow easy retargeting to a different mission;

– Limited role support: doesn’t allow significant variation of roles in a team collaboratively working on a complex task or activity;

– The predominance of proprietary management interfaces limiting the flexibility of management systems;

– Limited autonomous intelligence.

Types of UAV flights and UAV control and degrees of autonomy and control of UAV flight:

– under remote control by a H-O

– autonomously by onboard computers

– piloted by an autonomous robot

The mathematical methods such as Dynamic Programming (DP), Expert Judgment method (EJM), and fuzzy logic can be used for estimation of risks and minimal cost of a trajectory [9; 12].

The air navigation rules are using for classification obstructions in town such as “Restricted” and “Dangerous” areas, but they have nothing in common with ICAO’s official definitions [2], this is an estimation of risks of UAV trajectories in smart-city. In this way, ”Restricted area" designation is reserved for the areas where the risk of harming people is high, while “Dangerous area” indicates a very high risk of harm to people or property. Table I presents the results of identification and evaluation of risks of UAV trajectories. Fuzzy logic methods have been applied to assess risk levels [12].

Table 5.6 – Estimation of an areas in fragment of the territory

| **Name of obstruction** | **Parameter of obstruction** | **Identification** | **Results of estimation** |
|---|---|---|---|
| ***Restricted areas*** | | | |
| Building | Restricted area | B-RA (Building-Restricted Area) | 10 |
| Columns and wired communication | Restricted area | C-RA (Columns-Restricted Area) | 9 |
| Trees and natural obstructions | Restricted area | N-RA (Natural-Restricted Area) | 8 |
| ***Dangerous areas*** | | | |
| Vertical buffering area | Dangerous area | VBA (Vertical Buffering Area) | 5 |
| Horizontal buffering area | Dangerous area | HBA (Horizontal Buffering Area) | 7 |
| ***Tracks*** | | | |
| Track area | Track | TA (Track Area) | 50 |
| Track Conflict area | Track | TCA (Track Conflict Area) | 25 |
| Flight area | Track | FA (Flight Area) | 1 |

The algorithm of determining the optimal configuration of the group is as follows:

Grid-analysis: a grid is superimposed on a fragment of terrain (Fig. 5.13);

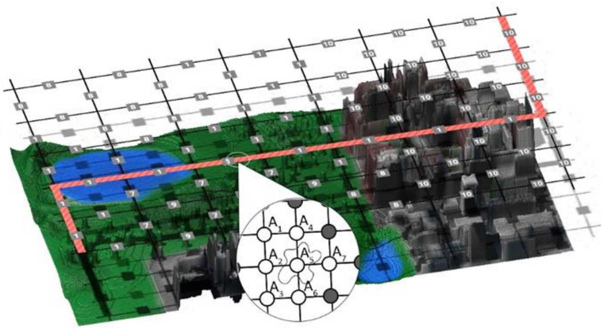


Figure 5.13 – Fragment of the territory with coverage of UAVs team

Risk assessment of Grid cells depending on the type of area (“Restricted”; “Dangerous” or “Tracks”;

Finding the minimum cost path $W_1$ for a $UAV_1$ (UAVs group) using the DP method for planning a flight in a level L1:

$$W_i(y_i) = y_{i-1}(RA;\ BA;\ TA;\ TCA;\ FA) +$$
$$+\min\left(y_i(RA;\ BA;\ TA;\ TCA;\ FA)\right)$$

Assessing the path $W_1$ (UAVs group) of the $UAV_1$ as “Dangerous”;

Finding the minimum cost path $W_2$ for a $UAV_2$ (UAVs group) using the DP method for planning a flight in a level L1, if necessary, the transition to the level L2, etc.

Building Discrete Network Model for “cover” (optimal configuration of UAVs group) and finding corridor for of UAVs group flight.

The optimal network configuration of UAV’s group obtained using DNM by geometric modeling method. For example, estimation and finding the minimum cost path $W_1$ for a $UAV_1$ or UAVs group, $W_1$=39 for fragment of the territory.

Fuzzy logic methods have been applied to assess risk levels and is based on the logical rules "IF (condition) - TO (conclusion)" [13-26]. In this case, the corresponding probabilities of events and the size of possible outcomes are considered as Fuzzy sets $P_j$ and $L_{ij}$, membership functions $\mu(P_j), \mu(L_{ij})$. Risk $R$ is determined as:

$$R = \mu(P_j) \times \mu(L_{ij})$$

The qualitative risk level indicator includes next characteristics of risk, namelyv [27]:

1. “Very low risk” corresponds to the flight of UAV.
2. “Low risk” corresponds to restricted areas such as columns and wired communication;
3. “Average risk” corresponds to restricted areas such as a building;
4. “High risk” corresponds to dangerous areas;
5. “Very high risk” corresponds to the tracks area by busy of UAV.

The degree of belonging of a certain value determined as the ratio of the number of responses in which the value of the linguistic variable occurs in a certain interval, to the maximum value of this number in all intervals [28].

Experts were interviewed by the Delphi method in two rounds. There are 35 experts attend the survey. The results of the survey are listed in Table 5.7. Units of intervals – 1 for 0 - 0,1; 2 for 0,1- 0,2, 3 for 0,2- 0,3, etc.

Table 5.7 – The results of the survey are listed

| | **Interval, units** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Value | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | 18 | 16 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 8 | 20 | 11 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 7 | 17 | 12 | 4 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 23 | 15 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 9 | 24 |
| kj | 18 | 24 | 25 | 19 | 18 | 12 | 6 | 30 | 24 | 24 |

To process the data, using a matrix of prompts, which is a string with the elements defined by the formula:

$$k_j = \sum_{i=1}^{5} b_{ij}, \quad j = \overline{1,10}.$$

The matrix of prompts in our case has the form:

$$M = \begin{Vmatrix} 18 & 24 & 25 & 19 & 18 & 12 & 6 & 30 & 24 & 24 \end{Vmatrix}$$

Choose from the matrix of prompts the maximum element and convert the elements of table 2 according to the formula:

$$k_{\max} = \max_j k_j = \max\{18;24;25;19;18;12;6;30;24;24\} = 30$$

$$c_{ij} = \frac{b_{ij} k_{\max}}{k_j},$$

The results of calculations are included in the Table 5.8, based on which the functions of membership will be built [29].

Table 5.8 – The results of calculations based on which the functions of membership will be built

| | **Interval, units** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Value | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 30,0 | 20,0 | 6,0 | 1,6 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| 2 | 0,0 | 10,0 | 24,0 | 17,4 | 1,7 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| 3 | 0,0 | 0,0 | 0,0 | 11,1 | 28,3 | 30,0 | 20,0 | 0,0 | 0,0 | 0,0 |
| 4 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 10,0 | 23,0 | 18,8 | 0,0 |
| 5 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 7,0 | 11,3 | 30,0 |

The maximum elements in each line are finding as:

$$c_{i\,max} = \max_j c_{ij}, \; i = 1,2,...,m, \; j = 1,2,...,n$$

$c_{1max} = 25,0$, $c_{2max} = 21,0$; $c_{3max} = 25,0$; $c_{4max} = 21,4$; $c_{5max} = 25,0$.

The value of the membership function is determined by the formula:

$$\mu = \frac{\acute{n}_{ij}}{c_{i\,max}}$$

The results of calculations are shown in the Table 5.9.

Table 5.9 – The results of experts' opinion

| | **Interval, units** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Value | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| FA | 1,00 | 0,67 | 0,20 | 0,05 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| TCA | 0,00 | 0,42 | 1,00 | 0,72 | 0,07 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| TA | 0,00 | 0,00 | 0,00 | 0,37 | 0,94 | 1,00 | 0,67 | 0,00 | 0,00 | 0,00 |
| RA | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,43 | 1,00 | 0,82 | 0,00 |
| Dan-gerous area | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,23 | 0,38 | 1,00 |

The membership functions for estimation of risk were obtained based on experimental data. Assume that the minimum risk level is zero units and the maximum is 100 units respectively. The fuzzy-logic functions of estimation in risk moving UAVs in flight, track conflict area, track area, restricted area, and dangerous area in Fig.3 (after the first round of the poll) [34].

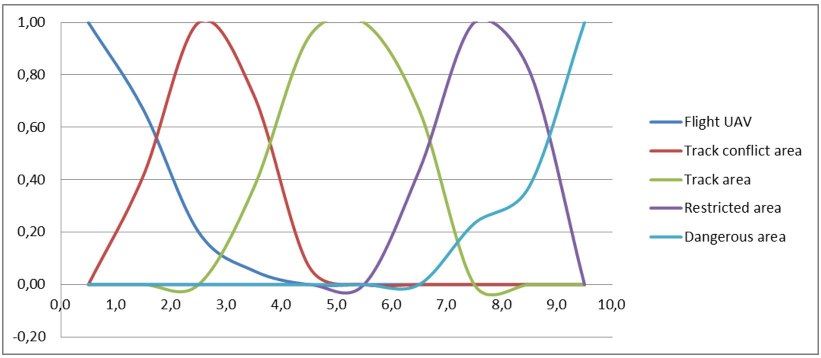



Figure 5.14 – Fuzzy-logic function of estimation risk

From the resulting diagrams, determined the quantitative indicators that correspond to the values of the linguistic variable "risk level"(after the second round of the poll) [31]:

– "Very low risk" corresponds to the quantitative significance of the level of risk in 10.

– "Low risk" corresponds to the quantitative significance of the level of risk in 35;

– "Average risk" corresponds to the quantitative significance of the level of risk in 60;

– "High risk" corresponds to the quantitative significance of the level of risk in 80;

– "Very high risk" corresponds to the quantitative significance of the level of risk in 100.

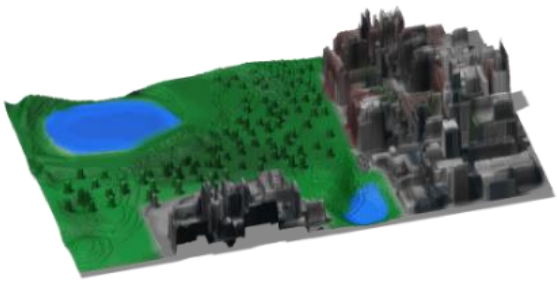
The mathematical methods such as the Dynamic Programming (DP), EJM, and fuzzy logic for estimation risks and minimal cost of ways of moving. For a definition, minimal cost and safety of UAVs movement ways in smart-city of town may use mathematical methods and modern air navigation rules. Estimation of an area in a fragment of the territory in fig.4a. Algorithm of definition minimal cost and safety of UAVs movement ways in town next:

Grid-analysis - cells are superimposing on a fragment of terrain (Fig.4b).

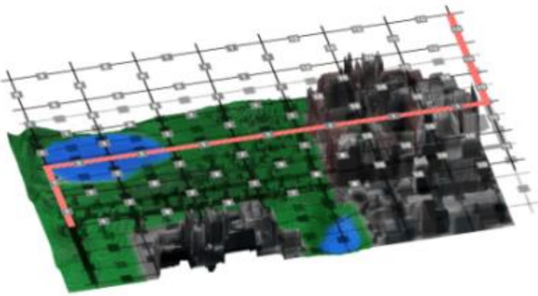
Risk assessment of Grid cells depending on the type of area ("Restricted" or "Dangerous").

Finding the minimum cost path $W_1$ for a $UAV_1$ using the DP method for planning a flight in a level *L1*:

$$W_i(y_i) = y_{i-1}(RA;\ BA;\ TA;\ TCA;\ FA) + \min\left(y_i(RA;\ BA;\ TA;\ TCA;\ FA)\right)$$



a



b

Figure 5.15 – Fragment of the territory for estimation minimal cost and safety of UAVs movement

Assessing the path $W_1$ (level *L1*) of the $UAV_1$ as “Dangerous”;

Finding the minimum cost path $W_2$ for a $UAV_2$ using the DP method for planning a flight in a level *L1*, if necessary, the transition to the level *L2*, etc.

For example, estimation and finding the minimum cost path $W_1$ for a $UAV_1$ on Fig.5.16, and the minimum cost path W*1* for a UAV1 on Fig.6 ($W_1$=39).

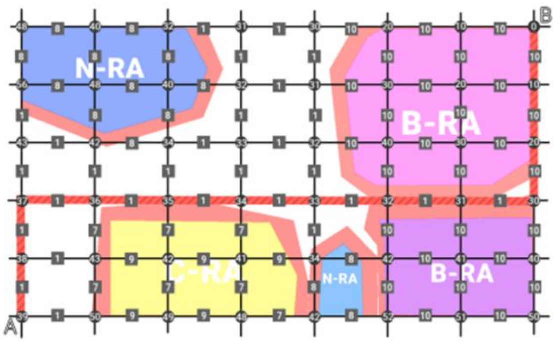



Figure 5.16 – Risk assessment of Grid cells

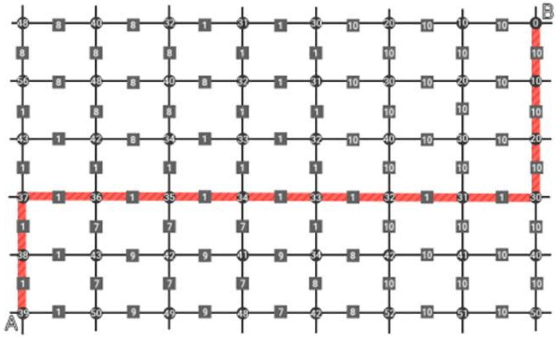



Figure 5.17 – The minimum cost path $W_1$ for a $UAV_1$.

The transfer of a UAV flight from level L1 to level L2 is shown in Figure 5.17 when loading the first level.

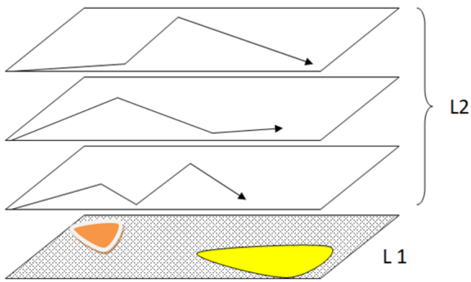



Figure 5.18 – Creating of root with flight levels

Flow optimization and flexible redistribution of autonomous UAV routes in multi-level airspace is performed in accordance with air navigation rules. The documents of ICAO include main recommendations for using UAVs, i.e. the operation of the UAV should minimize the threat of harm to life or health of people, damage of property, danger to other aircraft [20-30].

### *5.3 Expert system of operator of UAV*

Further research should be directed to the solution of practical problems of actions UAV's operator in case of emergencies, software creation. The organization of CDM by all aviation operators using collaborative DM models (CDMM) based on general information on the flight process and ground handling of the UAVs. Models of flight emergencies (FE) development and of DM in Risk and uncertainty by UAV's in FE will allow predicting the operator's actions with the aid of the Informational-analytic and Diagnostics complex for research UAV operator's behavior in extreme situation.

For example, the synthesis of models for DM in an emergency if is solving logistic problem UAV flight in bad weather condition (emergency - "loss connection"). (in Figure 5.19). In the process of analysis and synthesis of DM models of AI in emergency tend to simplify models (stochastic, the neural network, fuzzy, the Markov network, GERT-models, reflexion models to deterministic models).

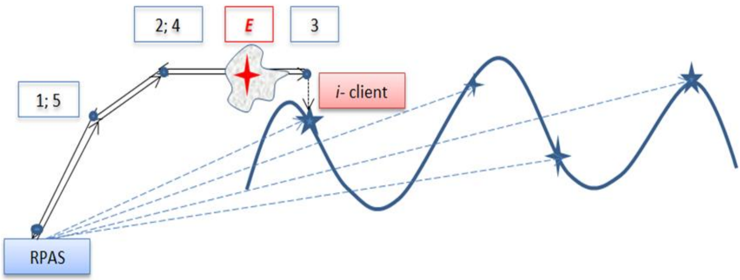



Figure 5.19 – Solving Logistic task using UAVs flights (1 - takeoff and climb, 2 - echelon, 3 - cargo discharge, 4 - echelon reverse, 5 - descent and landing)

In order to simulate DM under conditions of an emergency, next steps: an analysis of an emergency; intelligent data processing; analysis and identification of the situation using stochastic models; decomposition of the situation as a complex situation into subclasses and the formation of adapted deterministic models of AI actions are made.

In cases of big and difficult data methods can be integrated into traditional and next-generation hybrid DM systems by processing unsupervised situation data in the deep landscape models, potentially at high data rates and in near real time, producing a structured representation of input data with clusters that correspond to common situation types [30-41]. Deterministic action model targeted to specific situation type. Another benefit of these models is a potential ability of such systems to learn to identify relationships between different types of situations.

## List of references for chapter 5

1. Shmelyova T.F. Multicriteria evaluation of the efficiency of aviation chemical works by aircraft / T.F. Shmelyova, D.I. Bondarev, V.V. Korobko // Proceedings of the V International scientific-practical conference "Problems of air transportation and the use of aviation in the economy" November 24, 2017 year, Kyiv. NAU Austin, R. 2010.
2. Unmanned Aircraft Systems: UAVs Design, Development and Deployment. UK: John Wiley & Sons Ltd.
3. Amelin K. S. Antal E., Vasiliev V. Adaptive management of an autonomous group of Unmanned Aerial Vehicles. St. Petersburg State University 2013, 10 p.
4. Bondarev D., Jafarzadeh R., Kozub A. Effectiveness of Group Flight of Unmanned Aerial Vehicles" scientific article. Systems of information processing - Scientific periodicals, issue 6, Kharkov,2014, 9-15
5. Bondarev D., Shmelova T., Kucherov D. Models of group flights of Unmanned Aerial Vehicles using Science and technology of the Air Forces of the Armed Forces of Ukraine - Scientific periodicals, issue 3, Kharkov, 2015, 68-75.
6. Chekunov E. Application of the UAV of US Armed Forces in Military Conflicts. Foreign Military Review No. 7 Moscow, 2010, 41-50.
7. Ganin S., Karpenko A. Unmanned Aerial Vehicles. St. Petersburg Guinness World Record, 2017. http://www.guinnessworldrecords.com/news -411677
8. GSMA Smart Cities Guide: Traffic Management, GSM Association, 2016. Available https://www.gsma.com/iot/gsma-smart-cities-guide-traffic-management/
9. Drone life. Urban Air Mobility, 2018. https://dronelife.com/2018/11/28/urban-air-mobility-the-first-uic2-forum-at-amsterdam-drone-week-shows-europes-commitment-to-smart-cities/
10. Gulevich S.P. Veselov Y.G., Pryadkin S.P, & Tirnov S.D. Analisis of factors affecting the safety of the flight of Unmanned Aerial Vehicles. Ru. Causes of accidents drones and methods of preventing them «Science and education», 2012, № 12
11. Fradkov A., Grigoriev G. Decentral adaptive control of synchronization of networks of dynamical systems of dynamic systems with limited perturbations. Automation and telemechanics. 2013, No. 5
12. Ignatiev O. UAV: The state and prospects of their use in the interests of NATO. Foreign Military Review. 2010 №12. 45-52.

13. International Civil Aviation Organization. Global Air Traffic Management Operational Concept. Doc. ICAO Doc 9854-AN/458. Canada, Montreal: 2005, Author.
14. International Civil Aviation Organization. Manual on Global Performance of the Air Navigation System. Doc. ICAO 9883. Canada, Montreal: 2009, Author.
15. International Civil Aviation Organization. Manual of Remoted Piloted Aircraft Systems (RPAS). Doc. ICAO 10019/AN 507. Canada, Montreal: 2015, Author.
16. International Civil Aviation Organization. Unmanned Aircraft Systems (UAS), Circ. 328-AN/190, Canada, Montreal: 2011, Author.
17. International Civil Aviation Organ Global. Aviation Security Plan (GASP). International Civil Aviation Organization, Canada, Montreal. 2017.
18. International Civil Aviation Organization. Potential of Artificial Intelligence (AI) in Air Traffic Management (ATM). In: Thirteenth Air Navigation Conference ICAO, Montréal, Canada, 9-19 October 2018
19. Kirichek R., Makolkina M., Sene J., and Takhtuev V. Estimation quality parameters of transferring image and voice data over zigbee in transparent mode // Communications in computer and information science. 2016. pp. 260–267. (references)
20. Kharchenko V., Shmelova, T., & Sikirda, Y. Decision-Making in Socio-Technical Systems: monograph. Kyiv: NAU. 2016.
21. Kharchenko V., Shmelova T., & Sikirda Y. Decision-Making of Operator in Air Navigation System: monograph. Kirovograd: KFA of NAU. 2012.
22. Kharchenko V., Shmelova T., Bondarev D., & Stratiy A. (2017). Modelling of Decision Making of Unmanned Aerial Vehicle's Operator in Emergency Situations. Proceedings of the National Aviation University, 1, 20-28.
23. Kucherov D.P., Kozub A.N. Control System Objects with Multiple Stream of Information. Proceedings IEEE 3rd International Conference "Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD)", Kyiv, Ukraine, 2015, pp.290-293.
24. Kucherov D.P., Kozub A.N. Group Behavior of UAVs in obstacle presence. Proceeding IEEE 4th International Conference "Methods and Systems of Navigation and Motion Control (MSNMC)", Kyiv, Ukraine, 2016. Pp.51-54.
25. Kucherov D.P., Kozub A.N., Kostyna A.N. Group of UAVs Moving on Smooth Control Law with Fixed Obstacles. Advances in Science,

Technology and Engineering Systems Journal Vol. 2, No. 3, 2017. Pp.1034-1041

26. Kuzin A.V. Computer networks / A.B. Cousin. Moscow: FORUM: INFRA-M, 2011. P.192.
27. Nikiforov A., Munimaev V. Analysis of foreign Unmanned Aerial Vehicles. St. Petersburg Forestry Academy. 2010.
28. Olifer V.G., Olifer N.A. Computer networks: principles, technologies, protocols St. Petersburg. 2006. Pp.958.
29. Shmelova T., Stratij A. Computer Program“Aggregation of heterogeneous information flows”: certificate of registration of copyright in the product № 59466. 2015.
30. Shmelova T., Bondarev D., & Znakovska Y. Modeling of the Decision Making by UAVs Operator in Emergency Situations. In 4th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC-2016). Kyiv: NAU. 2016.
31. Shmelova T., & Bondarev D. Graph Theory Applying for Quantitative Estimation of UAVs Group Flight into Aerial Photography. Electronics and Control Systems, 4(46), 2016. Pp.128-133.
32. Shmelova T.F. Graph theory applaying for quantitative estimtion of UAV’s group flight into aerial photography/ T.F. Shmelova, D.I. Bondarev // Electronics and Control Systems 2016. N 4(46): P. 128-133.
33. Kharchenko V. Modelling of decision making of Unmanned Aerial Vehicle's operator in emergency situations // Kharchenko V, Shmelova T., Bondarev D., Stratiy A. // Proceedings of the National Aviation University. 2017. №1, P.20-28
34. Tarasov V., & Gerasimov B. Intelligent Decision Support Systems: Theory, Synthesis, Efficiency: monograph. Kyiv: International Academy of Computer Science and Systems. 2007.
35. Sara Kreps, Micah Zenko. The Next Drone Wars. Foreign Affairs, 2014: http://bmpd.livejournal.com/861105.html
36. Sładkowski A., Wojciech K. Cases on Modern Computer Systems in Aviation. Chapter 3 Using Unmanned Aerial Vehicles to Solve Some Civil Problems. International Publisher of Progressive Information Science and Technology Research, 2019. pp.52-127, USA, Pennsylvania.
37. Vyrelkin A., Kucheryavy A. The usage of unmannedaircraftto solve the tasks of "a smart city" SPbGUT, St. Petersburg, Russian Federation. 2014.
38. Ben-David A. Monotonicity maintenance in information-theoretic machine learning algorithms. *Machine Learning*, *19*, 1995. Pp. 29-43.

39. Montgomery J.F., Bekey G.A. Learning helicopter control through "teaching by showing". IEEE Conference on decision and Control. 1998.
40. Marsh L., Calbert G., J. Gossink Tu, D., Kwok H. Multi-Agent UAV Path Planning. Defence Science and Technology Organization, Australia, 2005, Pp. 2188 – 2194.
41. Sizova O.A. The application of graph theory in various types of scientific activity. Scientific article Baku 2012.

# 6 CHAPTER
# EXPERT SYSTEM FOR EVALUATING THE EFFECTIVENESS

## *6.1 Expert system for evaluating the effectiveness of aircraft for customer service in hard to reach areas*

The integrated dynamic system of situational collective control of manned and Unmanned Aerial Vehicles in a single airspace is designed for efficient use in the national economy, such as performing aerochemical work in agriculture, customer service in hard to reach areas. In order to achieve maximum efficiency of airspace, an expert system of methodological and methodological principles of building an integrated dynamic system of collective management of manned and Unmanned Aerial Vehicles in a single airspace is presented [1].

Recently, Unmanned Aerial Vehicles have been developing rapidly. The use of Unmanned Aerial Vehicles (UAV) is effective in both military and civilian tasks, for example, in dealing with the consequences of emergencies, natural disasters, for reconnaissance, aerial photography, agricultural work and more. The priority area of tank development is multitasking (multi-purpose use), corporate integration into the existing airspace of Ukraine, collective management in conditions of risk, uncertainty depending on the situation. Joint planning and organization of airspace involves the cooperative definition of the structure of airspace with the participation of all users so that it provides optimal trajectories for all users (piloted (aircraft, helicopters, ultralight aircraft (UACs), Unmanned Aerial Vehicles), using the benefits that provided with the possibility of la (helicopters, Unmanned Aerial Vehicles) to serve customers in hard to reach areas [2].

***Requirements for the use of aircraft in hard-to-reach areas***

Unmanned aircraft - an Unmanned Aerial Vehicle (UAV) - an aircraft whose flight control and control is carried out remotely by means of a PDP located outside the aircraft, or an aircraft flying autonomously according to the relevant program. Unmanned Aerial Vehicle equipment (Unmanned Aerial Vehicle system) - Unmanned Aerial Vehicle (aircraft), associated PDP, necessary control and monitoring lines. Bpak may include several Unmanned Aerial Vehicles that can operate regular base-client flights.

Unmanned Aerial Vehicles are becoming increasingly popular in our country, as it has a lot of undeniable advantages. Light, controlled, has the ability to fly on the weaving machine, where it is directed. Unmanned

Aerial Vehicles differ from manned aircraft in the ability to do without the runway, quietness, the ability to move at the lowest altitude and hang in the air. In addition, Unmanned Aerial Vehicles are much cheaper and do not require a lot of fuel (kerosene). It is enough to charge the batteries regularly and on time. With the help of remotely controlled Unmanned Aerial Vehicles make aerial photography of events (anniversaries, weddings, etc.), volcanic eruptions, nuclear power plant accidents, military theaters, shoot TV reports and video clips, recital equipment real estate and houses, mo power lines for possible repairs, guard and patrol closed and secret industrial facilities, observe archaeological excavations and conduct chemical treatment and inventory of agricultural land. That is, Unmanned Aerial Vehicles are used wherever you need to see and evaluate from above everything that can not be seen from the ground [1].

Recently, Unmanned Aerial Vehicles have been used for express delivery of goods in hard-to-reach areas, such as aircraft, in the mountains, where it is irrational to spend on a truck, car and even a bicycle, and pay the courier if radio-controlled Unmanned Aerial Vehicles do well. urgent delivery of goods?

Unmanned Aerial Vehicles as an express courier is able to carry objects weighing from 1 to 8 kilograms, is able to overcome quite large distances (up to five kilometers) in a relatively short time (speed can reach 16 meters per second). It is clear that he is not afraid of any off-road, where one hundred percent of any land transport will slip. The altitude of a quadcopter is up to one hundred (and sometimes up to two hundred) meters. It has its own navigation system, which does not allow to deviate from the course. It is enough to program the device for delivery of cargo to the necessary address of the client - and it will reach the most hard-to-reach point in an offline mode. In the process of overcoming the route, the on-board computer will understand to check the map of the area, will fly lower in the area of low-rise buildings and rise higher among the skyscrapers. The main thing - do not forget to charge the battery, which is enough for twenty minutes [5].

If the distance is too large for Unmanned Aerial Vehicles - "lone", the sending company uses the so-called swarm of quadcopters, ie a whole "team" of express couriers. Every five kilometers, they pass a load to each other on a special relay at special stations for recharging and "transplantation" (Fig. 6.1) [4].

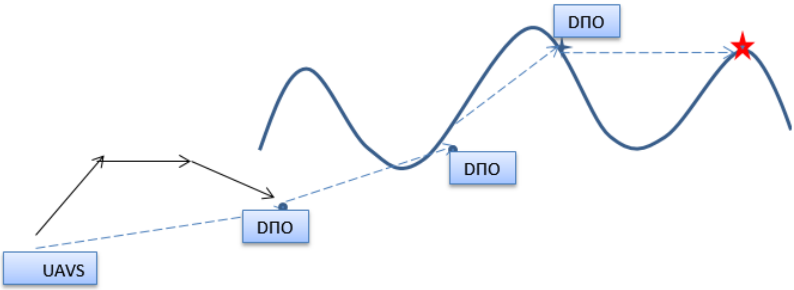



Figure 6.1 – Solving Logistic task using UAVs flights

Helicopters, as an aircraft, which can take off from the site and do not require a runway, can also be used for urgent cargo delivery. The disadvantage is the significant cost of delivery [2].

Method of expert assessments for quantitative assessment of the complexity of the stages of the flight unmanned aircraft when delivering cargo on the route base UAVS A - the *i-th* client

The initial information for processing is numerical data expressing the preferences of experts and a substantiated justification of these benefits. The purpose of processing is to obtain generalized data and new information contained in a latent form in expert assessments. Based on the results of processing, a solution to the problem is formed. The presence of both numerical data and meaningful statements of experts leads to the need to use qualitative and quantitative methods of processing the results of group expert evaluation. The proportion of these methods significantly depends on the cellular apparatus and the problems solved by expert evaluation.

Depending on the purposes of expert evaluation and the chosen method of measurement when processing the survey results, the following main tasks arise:

1) construction of the generalized estimation of objects on the basis of individual estimations of experts;
2) construction of a generalized assessment based on a pairwise comparison of objects by each expert;
3) determining the relative importance of objects;
4) determining the consistency of experts' opinions;
5) determining the relationships between rankings;
6) assessment of the reliability of processing results.

Rational use of information received from experts is possible provided that it is converted into a form suitable for further analysis aimed at preparing PR. The form of presentation of expert data depends on the accepted criterion, the choice of which in turn is significantly influenced by the specifics of the problem. So, the most important thing for us is to formalize this information so as to help choose from a set of actions one (or more) that is most acceptable in relation to some criterion.

If the expert is able to compare and evaluate the possible options for action, assigning each of them a certain number, we will assume that he has a certain system of advantages [4].

Depending on the scale on which these benefits can be set, expert assessments contain more or less information and have different abilities for mathematical formalization.

In cases where the studied objects can be arranged as a result of comparison in a certain sequence, taking into account any significant factor (factors), ordinal scales are used to establish equivalence or dominance. The use of ordinal scales allows to distinguish objects even in cases when the factor (criterion) is not specified explicitly, ie when we do not know the signs of comparison, but can partially or completely organize objects based on the system of preferences that the expert (experts) has.

When solving many practical problems, it often turns out that the factors that determine the final results are not directly measurable. The arrangement of these factors in ascending (or decreasing) significance is called ranking. Ranking allows you to choose from the studied set of factors the most significant. In this case, get a ranking scale - scalatal apparatus, which contains elements arranged in order of importance [11].

When ranking, the expert must arrange the objects (parameters) in the order that seems to him the most rational, and assign to each of them numerical devices of the natural series - ranks. In this case, rank 1 receives the most acceptable alternative, and rank $N$ - the least preferred. Therefore, the ordinal scaling apparatus obtained as a result of ranking must satisfy the condition of equality of numerical apparatus of ranks $N$ to the number of objects $n$ ranked.

It happens that the expert is unable to specify the order of observance for two or more objects or he has different devices of the same rank, and as a result the number of ranks $N$ is not equal to the number of ranked objects n. In such cases, the objects are assigned so-called standardized ranks. For this purpose, the total number of standardized ranks is considered equal to $n$, and objects with the same ranks, approaching apparatus standardized rank, the value of which represents the average sum of places divided between objects with the same ranks.

When evaluating the objects of research, experts often disagree on the problem to be solved. In this regard, there is a need to quantify the degree of agreement of experts - the consistency of expert opinion. Obtaining a quantitative measure of consistency allows a more reasonable interpretation of the reasons for differences of opinion. Using pairwise comparison methods, a rank correlation can be found between the scores of each pair of experts. With a large number of experts, the calculations become extremely time-consuming, so the consistency of experts' opinions is assessed using the concordance coefficient W, ie the total rank correlation coefficient for the group of scleral apparatus with *m* experts [5].

***Principles of construction of generalized criteria (reduction of a multicriteria task to a single-criteria one) [5]***

The general formulation of the problem of decision-making in the presence of many alternatives and a large number of criteria (not always consistent with each other and sometimes contradictory), is as follows [1]:

- there are some set of alternatives *A*, and each alternative a is characterized by a certain set of properties $a_1, a_2, ., a_n$;
- there is a set of criteria $q = (q_1, q_2, ..., q_i, ..., q_n)$, that reflect the quantitative set of properties of the system, ie each alternative is characterized by a vector $q(a) = [q_1(a), q_2(a), ..., q_i(a), ..., q_n(a)]$;
- it is necessary to decide on the choice of one of the strategies, and the decision is called simple if the choice is made on one criterion, and complex if the chosen alternative is not the best on any one criterion, but may be the most acceptable for all of them;
- the task of deciding on the choice of alternatives on many criteria is formally reduced to finding a mapping $\varphi$, that matches each vector with a real number $F = \varphi(q) = \varphi(q_1, q_2, ..., q_n)$, that determines the degree of advantage of this solution.

The operator $\varphi$ is called an integral (generalized) criterion. The integral criterion of the approach apparatus gives each decision to choose an alternative the appropriate value of efficiency F. This allows you to organize many solutions as you prefer. There are many methods of forming generalized criteria, but most of them are built on the basis of formal rules and do not take into account the value, usefulness of individual criteria $\varphi$, used in solving the problem of choosing an alternative. When constructing a generalized efficiency indicator in accordance with the theory of utility, the combination of criteria is most often done on the basis of additive transformation

$$F = \varphi(q_1, q_2, ..., q_n) = \sum_{i=1}^{n} w_i q_i .$$

The additive form of the criterion function, which represents the sum of quality indicators reduced to a single scale, is the most convenient and simple form of evaluation [1].

One of the possible ways to solve the problem is as follows. Each j-th expert first determines a set of numbers Cij, which reflects his opinion on the relative value of the i-th criterion, and the numbers are written on an arbitrary scale. Then they scale, resulting in a result

$$w_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}}; \quad \sum_{i=1}^{n} w_{ij} = 1.$$

The final values of the coefficients are calculated as a result of averaging the values $w_{ij}$, obtained from all experts. If the competence of the experts in the group is considered to be the same, then

$$w_i = \frac{1}{m} \sum_{i=1}^{m} w_{ij}.$$

If the competence of the ***j-th*** expert is evaluated by a number $g_j$, $\sum_{j=1}^{m} g_j = 1$, then

$$w_i = \sum_{j=1}^{m} g_j w_{ij}$$
.

One of the methods of forming the coefficients **Cij**, which reflect the opinion of the ***j-th*** expert on the value of the i-th criterion, is that first each expert ranks all the criteria, ie organizes them according to relative value so that in the first place is the most important criterion. The transition from ranks to coefficients **Cij** is made on the basis of the hypothesis of a linear relationship between rank and the relative value of the criterion. The lower the rank, the more important the relevant criterion. Determination of the coefficients **Cij** for an arbitrary rij is done according to the following formula [2]:

$$C_{ij} = 1 - \frac{r_{ij} - 1}{n}.$$

Consider the algorithms for applying the method of expert estimates and determination of weights [3].

**Algorithm №1**

*application of the method of expert assessments*

0. Development of a questionnaire for an expert survey (examples in Annex A) and conducting an expert survey
1. The structure of the matrix of individual preferences $A_{nxn}=(a_{ii})$ $(i=1,n)$
2. Defining the system of individual preferences of the j-th expert:

$$R_j = R_1 \succ R_2 \succ_3 \succ ...,\ j=1,n$$

3. The structure of the matrix of group preferences:

$$A_{nxm}=(a_{ii})\ (i=1,n,\ j=1,n)$$

4. Determining the system of group preferences $R_{gr} = R_1 \succ R_2 \succ_3 \succ R_4 \succ R_5 \succ ...$ by the average value of the ranks of group parameters:

$$R_{grj} = \frac{\sum_{i=1}^{m} R_i}{m}$$

5. Determining the degree of coherence of the group of experts

5.1 Dispersion:

$$Dj = \frac{\sum_{i=1}^{m} \left(R_{grj} - R_i\right)^2}{m-1}$$

5.2 The standard deviation:

$$\sigma_j = \sqrt{D_j}$$

5.3 Coefficient of variation:

$$\nu_j = \frac{\sigma_j}{R_{grj}} \bullet 100\%$$

If ν < 33 % - experts' opinions are consistent, if ν > 33 % - experts' opinions are inconsistent, it is necessary to repeat the expert survey or use the concordance coefficient [4].

$$W = \frac{12S}{m^2(n^3-n) - m\sum_{j=1}^{m} T_j}$$

where $t_j$ - the number of identical ranks in the j-th line, set by the j-th expert:

$$T_j = \sum (t_i^{\,3} - t_i)$$
,

variance (total):

$$S = \sum (\sum_{i=1}^{m} R_{ij} - \overline{R})^2$$

the average sum of ranks for each parameter:

$$\overline{R} = \frac{1}{n} \sum_{i=1}^{m} R_{ij}$$

If W = 0,6..0,7 - consistency of experts' opinions - high, if W <0,6 - it is necessary to repeat the expert survey.

5. Determining the statistical significance of the concordance coefficient *W* by the criterion $\chi^2$

$$\chi^2 = \frac{S}{\frac{1}{2} m(n+1) - \frac{1}{12(n-1)} \sum_{j=1}^{m} R} > \chi_t^2$$

6. Finding Spearman's rank correlation coefficient to determine the consistency of the j-th expert and the group of experts:

$$r_{s_I} = 1 - \frac{6 \sum_{I=1}^{n} (x_I - y_I)^2}{n(n^2 - 1)}$$

Table 6.1 – Parameters being evaluated

| Ranks | | The parameters being evaluated | | | |
|---|---|---|---|---|---|
| | | $r_1$ | $r_2$ | $r_3$ | $r_4$ |
| Rgr- Group rankings | xi | | | | |
| Ri– ranks of the i-th expert | yi | | | | |

7. Statistical significance of Spearman's rank correlation coefficient according to Student's criterion

$$t_{\phi} = r_s \sqrt{\frac{n-2}{1-r_s^2}} > t_{st}$$

8. Obtaining a model of the significance of the studied parameters according to an agreed system of group preferences of experts:

$$R_{gr} = R_1 \succ R_2 \succ_3 \succ R_4 \succ R_5 \succ \ldots$$

9. The end of the problem

*Algorithm №2*
*determination of weights*

1. Determining the system of group preferences of experts according to the algorithm №1
2. Determination of weights:

$$\omega_i = \frac{C_i}{\sum_{i=1}^{n} C_j},$$

where, $C_i = 1 - \frac{R_{ij} - 1}{n}$ - estimate obtained under the assumption of the hypothesis of a linear relationship between rank and the relative value of the parameter;

$R_{ij}$ - rank of the i-th parameter of the j-th expert ($R_{i\ gr}$ – ranks of the group of experts).

$$\sum_{i=1}^{m} w_i = 1,$$

3. Graphic interpretation of weights

The end of the problem

*Example 1.* The problem of determining the scleral apparatus of the stages of flight Unmanned Aerial Vehicles in the delivery of cargo from base A to the i-th client.

Decision:

1). Each expert fills in a matrix of individual preferences and by means of methods of pair comparisons and rankings determines ranks of scleral apparatus of stages:

R1-2 - takeoff / climb;
R3 - echelon;
R4 - dumping of cargo;
R5 - return / echelon;
R6-7 - return / decrease / landing

Table 6.3 – Experts

| | takeoff and climb | echelon | cargo dis-charge | eche-lon re-verse | descent and landing | |
|---|---|---|---|---|---|---|
| **Expert** | **1-2** | **3** | **4** | **5** | **6-7** | Rs |
| 1 | 1,5 | 4,5 | 3 | 4,5 | 1,5 | 0,98 |
| 2 | 2,5 | 4,5 | 1 | 4,5 | 2,5 | 0,78 |
| 3 | 1,5 | 3,5 | 5 | 3,5 | 1,5 | 0,68 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | 3 | 5 | 2 | 4 | 1 | 0,88 |
| 5 | 1,5 | 4,5 | 3 | 4,5 | 1,5 | 0,98 |
| R grs | 2 | 4,4 | 2,8 | 4,2 | 1,6 | |
| Di | 0,4 | 0,24 | 1,76 | 0,16 | 0,24 | |
| σi | 0,7071 | 0,5477 | 1,4832 | 0,4472 | 0,5477 | |
| υi, % | 35% | 12% | 53% | 11% | 34% | |

Determine the opinion of a group of experts (average):

$$R_{gr} = \frac{\sum_{I=1}^{m} R_I}{m};$$

For each procedure we determine the value of Rgr.

In the cellular apparatus, when dialing:

Rsr1/5=1,8

We determine the consistency of the opinion of a group of experts. To do this, we determine the variance Di, the standard deviation σi, and the coefficient of variation υi. If υ≤ 33%, the opinion of experts is agreed [5].

Dispersion for each procedure:

$$D_I = \frac{\sum_{I=1}^{m} (R_{gr} - R_I)^2}{m-1}$$

Dispersion for the set: D2/4=0,325

Determine the standard deviation:

$$\sigma_I = \sqrt{D_I}$$

For recruitment:

$$\sigma_2 = \sqrt{0,325} = 0,57$$

Determined coefficient of variation for each procedure:

$$v_I = \frac{\sigma_I}{R_{гpI}} \bullet 100\%$$

$$v_2 = \frac{0,57}{1,8} \bullet 100\% = 31,67\% < 33\%$$

Coefficient of variation (<33%, which means that the opinions of experts on assessing the complexity of the set procedure coincide. For the procedure of "reduction" the opinion of experts does not match. Since for 3 procedures the coefficient of variation (<33%)) for the importance of procedures agreed and distributed according to the normal law.To assess the consistency of all procedures it is necessary to use the concordance coefficient Kendallitali apparatus or repeat the survey of experts [6].

The system of advantages of a group of experts:

$$R_1 = R_3 \succ R_2 \succ R_4 \succ R_1$$

6. Determine the consistency of expert opinions using the concordance coefficient ***W***.

The concordance coefficient is most often calculated by the formula proposed by Kendall [7]:

$$W = \frac{12S}{m^2(n^3 - n)} = 0{,}756$$

$S = \sum_{i=1}^{n} \left\{ \sum_{j=1}^{m} x_{ij} - a_{ij} \right\}^2$ - sum of squares of differences (deviations)

$a_{ij} = \frac{1}{2} m(n+1)$ - the average value for the total ranks of the series.

In our case **m=5**, **n=4**.

$$a_{ij} = \frac{1}{2} 5(4+1) = 12,5,$$

$$S = (20 - 12{,}5)^2 + (9 - 12{,}5)^2 + (7{,}5 - 12{,}5)^2 + (13{,}5 - 12{,}5)^2 = 94{,}5$$

In cases where an expert cannot establish a rank difference between several related factors and assigns them the same ranks (which we observe in our case), the calculation of the concordance coefficient is done according to the formula

$$W = \frac{S}{\frac{1}{12} m^2(n^3 - n) - m \sum_{j=1}^{m} T_j},$$

$$T_j = \frac{1}{12} \sum_{T_j} (t_j^3 - t_j),$$

where is the number of identical ranks in the j-th series.

2). Compare the opinion of the group and the expert №1 using the rank correlation coefficient Rs.

Let's compare the opinions of a group of experts and expert 1 using Spearman's rank correlation:

$$r_{s_1} = 1 - \frac{6 \sum_{I=1}^{n} (x_I - y_I)^2}{n(n^2 - 1)}$$

Table 6.4 – Expert 1

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Group | X | 2 | 4,4 | 2,8 | 4,2 | 1,6 | | | |
| Expert 1 | У | 2,5 | 4,5 | 1 | 4,5 | 2,5 | | Rs= | 0,78 |
| | (X-У) | -0,5 | -0,1 | 1,8 | -0,3 | -0,9 | | | |
| | (x-У)^2 | 0,25 | 0,01 | 3,24 | 0,09 | 0,81 | 4,4 | | |

$$r_{s_1} = 1 - \frac{6[(4-4)^2 + (2-1{,}5)^2 + (1-1{,}5)^2 + (3-3)^2]}{4(4^2-1)} = 0{,}991 \quad -1 \le r_s \le 1$$

Since rs = 0.991, the consistency of opinion of the group and the expert №1 is high.

3) Determination of coefficients of complexity of flight stages Unmanned Aerial Vehicles. We pass from the ranks Ri to the weights using the method of rankings. The method is based on the assumption of a linear relationship between rank and the relative value of the performance indicator. Weights are determined by formulas:

$$\omega_1 = \frac{C_1}{\sum_{1=1}^{n} C_j},$$

Rij - rank of the i-th procedure for the j-th expert (Ri gr - group ranks).

C1=1 -/4=0,25

ω1 =0,25/2,5=0,1

Table 6.5 – Results

| | 1-2 | 3 | 4 | 5 | 6-7 | |
|---|---|---|---|---|---|---|
| | takeoff and climb | echelon | cargo discharge | echelon reverse | descent and landing | |
| Rgr | 2 | 4,4 | 2,8 | 4,2 | 1,6 | |
| C | 0,75 | 0,15 | 0,55 | 0,2 | 0,85 | 2,5 |
| wi | 0,3 | 0,06 | 0,22 | 0,08 | 0,34 | 1 |

The initial information for processing is numerical data expressing the preferences of experts and a substantial justification for these benefits. Based on the results of processing, a solution to the problem is formed. The presence of both numerical data and meaningful statements of experts leads to the need to use qualitative and quantitative methods of processing the results of expert evaluation. The share of these methods significantly depends on the class of problems solved by expert evaluation [7].

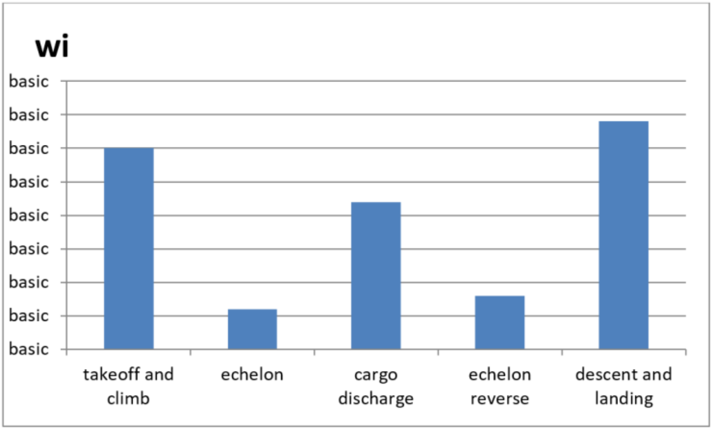



Figure 6.2 – Expert evaluations

### *6.2 Expert system for evaluating the effectiveness of aircraft for aerochemical work in collective airspace*

The integrated dynamic system of situational collective management of manned and Unmanned Aerial Vehicles in a single airspace is designed for efficient use in the national economy, for example for performing aerochemical work in agriculture. In order to achieve maximum efficiency of airspace, an expert system of methodological and methodological principles of building an integrated dynamic system of collective management of manned and Unmanned Aerial Vehicles in a single airspace is presented [8].

Recently, Unmanned Aerial Vehicles have been developing rapidly. The use of Unmanned Aerial Vehicles (tank) is effective in both military and civilian tasks, for example, in dealing with the consequences of emergencies, natural disasters, for reconnaissance, aerial photography, agricultural work and more. The priority area of tank development is multitasking (multi-purpose use), corporate integration into the existing airspace of Ukraine, collective management in conditions of risk, uncertainty depending on the situational state of the DPO. Joint planning and organization of airspace involves the cooperative definition of the structure of airspace with the participation of all users so that it provides optimal trajectories for all users (piloted (aircraft, helicopters, ultralight aircraft (UAVs), Unmanned Aerial Vehicles), using the benefits that provided with the capabilities of the aircraft to perform aerochemical work (Fig. 6.3) [9].

Figure 6.3 – Execution of aerochemical works

Today, farmers and farmers are increasingly using the aviation method of treating fields with plant protection products. Aircraft (aircraft, helicopters, ultralight aircraft) registered in the State Register of Civil Aviation of Ukraine and certified for the right to perform relevant works may be used to perform aviation work on the use of pesticides in agrochemical measures for agricultural and forestry crops.

Unmanned Aerial Vehicles have recently been successfully used for aerochemical work as a reliable, safe, efficient type of air transport. Permanent or temporary aerodromes, heliports, remote pilot stations (ground control stations) (GCS) with a sanitary passport or a permit for the right to operate must be used for the performance of working flights in the aviation application of pesticides in agriculture. The calculation of the efficiency of the use of manned aircraft and drones (Fig. 6.4) [10].


Figure 6.4 – The use of manned and Unmanned Aerial Vehicles
for aerochemical work

Unmanned Aerial Vehicle - an Unmanned Aerial Vehicle (Unmanned Aerial Vehicles) - an aircraft whose flight control and control is carried out remotely by means of a PDP located outside the aircraft, or an aircraft flying autonomously according to the relevant program. Unmanned

Aerial Vehicle equipment (Unmanned Aerial Vehicle system) (UAV) - Unmanned Aerial Vehicle (aircraft), associated PDP, necessary control and monitoring lines. The UAV may include several Unmanned Aerial Vehicles.

Requirements for aerochemical works.

Agricultural lands, which are designated for aerochemical treatments, must be plotted on land use maps agreed with the State Food and Consumer Service and the Ministry of Ecology and Natural Resources. When using pesticides by aircraft, it is necessary to strictly maintain the size of sanitary protection zones to other facilities (settlements, livestock and poultry farms, water supply sources, etc.). Application of pesticides by aviation method in agriculture should be carried out at a height of up to 3 m above the object of treatment, in the morning and evening hours of the day, at an air speed not exceeding - 3 m / s (fine drip spraying) and 4 m / s (coarse drip spraying) and air temperature not exceeding +22 C. The customer of aero-chemical works, three days before the start of aviation treatments, must take the following precautions [11]:

a) to inform the population of the area through the media (radio, press, television) about the place, timing, date of treatment with pesticides and agrochemicals; about the prohibition to carry out agricultural and other works, to graze animals closer than 1 km from the place of processing; on the need to take the apiaries to another place of medical collection at a distance of more than 5 km from the places of aviation treatments of crops with pesticides for a period of up to 5 days;

b) install special safety warning signs indicating the deadline for waiting at a distance of 300 m from the treated areas, as well as on the roads passing through these areas and on the roads leading to the aerodrome.

It is prohibited to carry out aviation pesticide treatments of all toxicity groups in order to control pests and diseases of crops, forests and other lands located closer to [12]:

a) 5 km from the places of permanent residence of honey apiaries;

b) 2 km from fishery reservoirs, open sources of water supply, places for grazing domestic animals, objects of nature reserve fund (reserves, national parks, botanical and zoological reserves, etc.);

c) 1 km from settlements, livestock and poultry farms, crops used for food without heat treatment (onions, celery, dill, cucumbers, tomatoes, strawberries, raspberries, etc.), as well as orchards and vineyards and places of agricultural work.

Aviation use of arboricides in the treatment of forests and forest protection strips, as well as routes of high-voltage power lines located closer to:

a) 3.6 km from places of rest for children and adults;

b) 2 km from settlements, forest nurseries, forest crops.

Aviation application of mineral fertilizers and biological products should be carried out in compliance with the sanitary protection zone from the treatment areas to the settlement, livestock and poultry farms, water supply sources - not less than 500 m at wind speeds up to 8 m / s [12].

The use of pesticides by aviation in agriculture should be carried out in the morning and evening, at a permitted air velocity and a temperature not exceeding 22 degrees. Preference should be given to such forms of drugs and methods of treatment that minimize environmental pollution (granules, heavy aerosols, edge treatment, diagonal treatment, etc.), as well as the use of combined drugs that increase the effectiveness of treatments while reducing pesticide consumption rates.

Thus, the following aircraft are used for aerochemical works [13]:

• aircraft,
• helicopters,
• ultralight aircraft,
• Unmanned Aerial Vehicles.

The initial information for processing is numerical data expressing the preferences of experts and a substantiated justification of these benefits. The purpose of processing is to obtain generalized data and new information contained in a latent form in expert assessments. Based on the results of processing, a solution to the problem is formed. The presence of both numerical data and meaningful statements of experts leads to the need to use qualitative and quantitative methods of processing the results of group expert evaluation. The share of these methods significantly depends on the class of problems solved by expert evaluation [14].

Depending on the purposes of expert evaluation and the chosen method of measurement when processing the survey results, the following main tasks arise:

1) construction of the generalized estimation of objects on the basis of individual estimations of experts;
2) construction of a generalized assessment based on a pairwise comparison of objects by each expert;
3) determining the relative importance of objects;
4) determining the consistency of experts' opinions;
5) determining the relationships between rankings;
6) assessment of the reliability of processing results.

Rational use of information received from experts is possible provided that it is converted into a form suitable for further analysis aimed at preparation. The form of presentation of expert data depends on the accepted criterion, the choice of which in turn is significantly influenced by the specifics of the problem. So, the most important thing for us is to formalize this information so as to help choose one (or more) from the set of actions that is most acceptable in relation to some criterion [15].

If the expert is able to compare and evaluate the possible options for action, assigning each of them a certain number, we will assume that he has a certain system of advantages.

Depending on the scale on which these benefits can be set, expert assessments contain more or less information and have different abilities for mathematical formalization.

In cases where the studied objects can be arranged as a result of comparison in a certain sequence, taking into account any significant factor (factors), ordinal scales are used to establish equivalence or dominance. The use of ordinal scales allows to distinguish objects even in cases when the factor (criterion) is not specified explicitly, ie when we do not know the signs of comparison, but can partially or completely organize objects based on the system of preferences that the expert (experts) has [16].

When solving many practical problems, it often turns out that the factors that determine the final results are not directly measurable. The arrangement of these factors in ascending (or decreasing) significance is called ranking. Ranking allows you to choose from the studied set of factors the most significant. In this case, get a ranking scale - a scale that contains elements arranged in order of importance.

When ranking, the expert must arrange the objects (parameters) in the order that seems to him the most rational, and assign to each of them numerical devices of the natural series - ranks. In this case, rank 1 receives the most acceptable alternative, and rank N - the least preferred. Therefore, the ordinal scale obtained as a result of ranking must satisfy the condition of equality of numerical devices of ranks N to the number of objects n that are ranked [17].

It happens that the expert is unable to specify the order of observance for two or more objects or he assigns the same rank to different objects, and as a result the number of ranks N is not equal to the number of objects n that are ranked. In such cases, the objects are assigned so-called standardized ranks. For this purpose, the total number of standardized ranks is considered equal to n, and objects with the same ranks are assigned a standardized rank, the value of which represents the average of the sum of places divided between objects with the same ranks.

When evaluating the objects of research, experts often disagree on the problem to be solved. In this regard, there is a need to quantify the degree of agreement of experts - the consistency of expert opinion. Obtaining a quantitative measure of consistency allows a more reasonable interpretation of the reasons for differences of opinion. Using pairwise comparison methods, a rank correlation can be found between the scores of each pair of experts. With a large number of experts, the calculations become extremely time-consuming, so the consistency of experts' opinions is assessed using the concordance coefficient W, ie the overall rank correlation coefficient for a group consisting of m experts [18].

Principles of construction of generalized criteria (reduction of a multicriteria task to a single-criteria one) [19]

The general formulation of the task of PR in the presence of many alternatives and a large number of criteria (not always consistent with each other and sometimes contradictory), is as follows [20]:

- there are some set of alternatives A, and each alternative a is characterized by a certain set of properties $a_1, a_2,., a_n$;

- is a set of criteria $q = (q_1, q_2, ..., q_i, ..., q_n)$, that reflect the quantitative set of properties of the system, ie each alternative is characterized by a vector $q(a) = [q_1(a), q_2(a), ..., q_i(a), ..., q_n(a)]$;

- it is necessary to decide on the choice of one of the strategies, and the decision is called simple if the choice is made on one criterion, and complex if the chosen alternative is not the best on any one criterion, but may be the most acceptable for all of them;

- the task of choosing an alternative to many criteria is formally reduced to finding a mapping $\varphi$, that matches each vector with a real number $F = \varphi(q) = \varphi(q_1, q_2, ..., q_n)$, that determines the degree of advantage of this solution.

The operator $\varphi$ is called an integral (generalized) criterion. The integral criterion assigns to each decision on a choice of an alternative the corresponding value of efficiency ***F***. It allows to organize a set of decisions in order of preference. There are many methods of forming generalized criteria $\varphi$, but most of them are built on the basis of formal rules and do not take into account the value, usefulness of individual criteria $\varphi$ used in solving the problem of choosing an alternative. When constructing a generalized efficiency indicator in accordance with the theory of utility, the combination of criteria is most often done on the basis of additive transformation [21]

$$F = \varphi(q_1, q_2, ..., q_n) = \sum_{i=1}^{n} w_i q_i.$$

The additive form of the criterion function, which represents the sum of quality indicators reduced to a single scale, is the most convenient and simple form of evaluation [22].

One of the possible ways to solve the problem is as follows. Each j-th expert first determines a set of numbers Cij, reflecting his opinion on the relative value of the i-th criterion, and the numbers are written on an arbitrary scale. Then they scale, resulting in a result

$$w_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}}; \quad \sum_{i=1}^{n} w_{ij} = 1.$$

The final values of the coefficients are calculated as a result of averaging the values obtained from all experts. If the competence of the experts in the group is considered to be the same, then

$$w_i = \frac{1}{m} \sum_{i=1}^{m} w_{ij}.$$

If the competence of the j-th expert is evaluated by a number $g_j$, $\sum_{j=1}^{m} g_j = 1$, then

$$w_i = \sum_{j=1}^{m} g_j w_{ij}.$$

One of the methods of forming the coefficients ***Cij***, which reflect the opinion of the *j-th* expert on the value of the *i-th* criterion, is that first each expert ranks all the criteria, ie organizes them according to relative value so that in the first place is the most important criterion. The transition from ranks to coefficients ***Cij*** is made on the basis of the hypothesis of a linear relationship between rank and the relative value of the criterion. The lower the rank, the more important the relevant criterion. The determination of the coefficients ***Cij*** for an arbitrary rij is done according to the following formula [23]:

$$C_{ij} = 1 - \frac{r_{ij} - 1}{n}.$$

Consider the algorithms for applying the method of expert estimates and determination of weights [24].

*Algorithm №1*
*application of the method of expert assessments*

1. Development of a questionnaire for an expert survey (examples in Annex A) and conducting an expert survey
2. The structure of the matrix of individual preferences *Anxn = (aii) (i = 1, n)*
3. Defining the system of individual preferences of the j-th expert:

$$R_j = R_1 \succ R_2 \succ_3 \succ ...$$, j=1,n

4. The structure of the matrix of group preferences:

*$A_{nxm}$=($a_{ii}$) (i=1,n, j=1,n)*

5. Determining the system of group preferences $R_{gr} = R_1 \succ R_2 \succ_3 \succ R_4 \succ R_5 \succ ...$ by the average value of the ranks of group parameters:

$$R_{grj} = \frac{\sum_{i=1}^{m} R_i}{m}$$

6. Determining the degree of coherence of the group of experts

6.1 Dispersion:

$$Dj = \frac{\sum_{i=1}^{m} \left(R_{grj} - R_i\right)^2}{m-1}$$

6.2 The standard deviation:

$$\sigma_j = \sqrt{D_j}$$

6.3 Coefficient of variation:

$$\nu_j = \frac{\sigma_j}{R_{grj}} \bullet 100\%$$

If ν < 33 % - experts' opinions are consistent, if ν > 33 % - experts' opinions are inconsistent, it is necessary to repeat the expert survey or use the concordance coefficient.

$$W = \frac{12S}{m^2(n^3 - n) - m\sum_{j=1}^{m} T_j}$$

where $t_j$ - the number of identical ranks in the j-th line, set by the j-th expert:

$$T_j = \sum (t_i^{\,3} - t_i)$$
,

dispersion (total):

$$S = \sum (\sum_{i=1}^{m} R_{ij} - \overline{R})^2$$

the average sum of ranks for each parameter:

$$\overline{R} = \frac{1}{n}\sum_{i=1}^{m} R_{ij}$$

If W = 0,6..0,7 - agreement of opinions of experts - high, if W <0,6 - it is necessary to repeat expert interrogation.

Determining the statistical significance of the concordance coefficient ***W*** by the criterion $\chi^2$

$$\chi^2 = \frac{S}{\frac{1}{2}m(n+1) - \frac{1}{12(n-1)}\sum_{j=1}^{m} R} > \chi_t^2$$

Finding Spearman's rank correlation coefficient to determine the consistency of the j-th expert and the group of experts:

$$r_{s_1} = 1 - \frac{6\sum_{1=1}^{n}(x_1 - y_1)^2}{n(n^2-1)}$$

Table 6.6 – Evaluated parameters

| Ranks | | Evaluated parameters | | | |
|---|---|---|---|---|---|
| | | r1 | r2 | r3 | r4 |
| Rgr- group ranks | xi | | | | |
| Ri– ranks of the i-th expert | yi | | | | |

Statistical significance of Spearman's rank correlation coefficient according to Student's criterion

$$t_{\phi} = r_s\sqrt{\frac{n-2}{1-r_s^2}} > t_{st}$$

Obtaining a model of the significance of the studied parameters according to an agreed system of group preferences of experts [23]:

$$R_{gr} = R_1 \succ R_2 \succ_3 \succ R_4 \succ R_5 \succ \ldots$$

7. The end of the problem

*Algorithm №2*
*determination of weights*

1. Determining the system of group preferences of experts $R_{gr} = R_i \succ R_{i+j} \cdots$ according to the algorithm №1
2. Determination of weights:

$$\omega_i = \frac{C_i}{\sum_{i=1}^{n} C_j},$$

where, $C_i = 1 - \frac{R_{ij} - 1}{n}$ - estimate obtained under the assumption of the hypothesis of a linear relationship between rank and the relative value of the parameter;

$R_{ij}$ - rank of the i-th parameter of the j-th expert ($R_{i\ gr}$ – ranks of the group of experts).

$$\sum_{i=1}^{m} w_i = 1,$$

Graphic interpretation of weights

The end of the problem

*Example 1*. The task of determining the coefficients of importance of maintenance of aircraft such as airplanes, helicopters, ultralight aircraft, Unmanned Aerial Vehicles and determining the appropriate load of the agricultural area using the method of expert assessments on the criteria of economic efficiency and safety.

Criterion "security" [24].

Decision:

1). Each expert fills in a matrix of individual preferences and by means of methods of pair comparisons and rankings defines ranks of complexity of the executed procedures:

R1 - planes;

R2 - ultralight aircraft;

R3 - Unmanned Aerial Vehicles (UAV);

R4 - helicopters

Table 6.7 – Matrix of individual preferences

| | | planes | ultralight aircraft | UAV | helicopters | Σr | R | R |
|---|---|---|---|---|---|---|---|---|
| planes | R1 | | 0 | 0 | 0 | 0 | 4 | 4 |
| ultralight aircraft | R2 | 1 | | 0,5 | 1 | 2,5 | 1;2 | 1,5 |
| UAV | R3 | 1 | 0,5 | | 1 | 2,5 | 1;2 | 1,5 |
| helicopters | R4 | 1 | 0 | 0 | | 1 | 3 | 3 |

Expert preference system №1

$R_1 = R_2, R_3 \succ R_4 \succ R_5$

According to the priorities set by the expert №1, the significance of aircrafts is as follows [25]:

1st i 2nd places - ultralight aircraft, UAV, R2 = R3 = 1,5

3rd place- helicopters; R4 =3

4th place- planes, R1 = 4

2). We compile a matrix of group preferences for a group of experts and determine the opinion of the group. Ranks of expert №1 - author of control work; expert №2 - set according to the option; experts №3 - №5 - according to table.

Table 6.7 – Matrix 2Matrix of individual preferences

| Experts | Procedures | | | |
|---|---|---|---|---|
| | planes | ultralight aircraft | UAV | helicopters |
| | ω1 | ω2 | ω3 | ω4 |
| 1 | 4 | 1,5 | 1,5 | 3 |
| 2 | 4 | 1 | 2 | 3 |
| 3 | 4 | 2,5 | 1 | 2,5 |
| 4 | 4 | 2 | 1 | 3 |
| 5 | 4 | 2 | 2 | 2 |
| total | 20 | 9 | 7,5 | 13,5 |
| Rgr | 4 | 1,8 | 1,5 | 2,7 |
| R 'gr | 4 | 2 | 1 | 3 |
| Di | 0 | 0,325 | 0,25 | 0,2 |
| σi | 0 | 0,57009 | 0,5 | 0,44721 |
| υi, % | 0 | 31,6715 | 33,3333 | 16,5635 |

Determine the opinion of a group of experts (average):

$$R_{gr} = \frac{\sum_{I=1}^{m} R_I}{m};$$

For each procedure we determine the value of Rgr.

For example, when:

Rsr1/5=1,8

We determine the consistency of the opinion of a group of experts. To do this, we determine the variance Di, the standard deviation σi, and the coefficient of variation υi. If υ≤ 33%, the opinion of experts is agreed [26].

Dispersion for each procedure:

$$D_I = \frac{\sum_{I=1}^{m}(R_{gr} - R_I)^2}{m-1}$$

Dispersion: D2/4=0,325

Determine the standard deviation:

$$\sigma_I = \sqrt{D_I}$$

$$\sigma_2 = \sqrt{0{,}325} = 0{,}57$$

Determined coefficient of variation for each procedure:

$$\nu_I = \frac{\sigma_I}{R_{grI}} \bullet 100\%$$

$$\nu_2 = \frac{0{,}57}{1{,}8} \bullet 100\% = 31{,}67\% < 33\%$$

Coefficient of variation (<33%, which means that the opinions of experts on assessing the complexity of the set procedure coincide. For the procedure of "reduction" the opinion of experts does not match. Since for 3 procedures the coefficient of variation (<33%)) for the importance of procedures agreed and distributed according to the normal law.To assess the consistency of all procedures it is necessary to use the concordance coefficient Kendallitali apparatus or repeat the survey of experts [27].

The system of advantages of a group of experts:

$$R_1 = R_3 \succ R_2 \succ R_4 \succ R_1$$

6. Determine the consistency of expert opinions using the concordance coefficient W.

The concordance coefficient is most often calculated by the formula proposed by Kendall:

$$W = \frac{12S}{m^2(n^3 - n)} = 0{,}756$$

$$S = \sum_{i=1}^{n}\left\{\sum_{j=1}^{m} x_{ij} - a_{ij}\right\}^2$$ - sum of squares of differences (deviations)

$$a_{ij} = \frac{1}{2}m(n+1)$$ - the average value for the total ranks of the series.

In our case **m=5**, **n=4**.

$$a_{ij} = \frac{1}{2}5(4+1) = 12{,}5,$$

$S$ = (20 - 12,5) $^2$ + (9 - 12,5) $^2$ + (7,5 - 12,5) $^2$ +(13,5 - 12,5) $^2$ = 94,5

In cases where an expert cannot establish a rank difference between several related factors and assigns them the same ranks (which we observe in our case), the calculation of the concordance coefficient is done according to the formula

$$W = \frac{S}{\frac{1}{12}m^2(n^3-n) - m\sum_{j=1}^{m} T_j},$$

$$T_j = \frac{1}{12}\sum_{T_j}(t_j^3 - t_j),$$

2). Compare the opinion of the group and the expert №1 using the rank correlation coefficient Rs.

Let's compare the opinions of a group of experts and expert 1 using Spearman's rank correlation:

$$r_{s_1} = 1 - \frac{6\sum_{I=1}^{n}(x_I - y_I)^2}{n(n^2-1)}$$

Table 6.7 – Ranks Aircrafts

| Ranks | | Aircrafts | | | |
|---|---|---|---|---|---|
| | | planes | ultralight aircraft | UAV | helicopters |
| Rgr - group ranks | xi | 4 | 2 | 1 | 3 |
| R1- expert №1 ranks | yi | 4 | 1,5 | 1,5 | 3 |

$$r_{s_1} = 1 - \frac{6[(4-4)^2 + (2-1{,}5)^2 + (1-1{,}5)^2 + (3-3)^2]}{4(4^2-1)} = 0{,}991 \quad -1 \le r_s \le 1$$

Since rs = 0.991, the consistency of opinion of the group and the expert №1 is high.

3) Determination of coefficients of significance of aircraft in aerochemical works. We pass from the ranks Ri to the weights using the method of rankings. The method is based on the assumption of a linear relationship between rank and the relative value of the performance indicator. Weights are determined by formulas [26]:

$$\omega_I = \frac{C_I}{\sum_{I=1}^{n} C_j},$$

Rij - rank of the i-th procedure for the j-th expert (Ri гр - group ranks).

C1=1 -/4=0,25

ω1 =0,25/2,5=0,1

Table 6.8 – Aircrafts

| Aircrafts | Rank | Ci | ωi |
|---|---|---|---|
| planes | 4 | 0,25 | 0,1 |
| ultralight aircraft | 2 | 0,75 | 0,3 |
| UAV | 1 | 1 | 0,4 |
| helicopters | 3 | 0,5 | 0,2 |

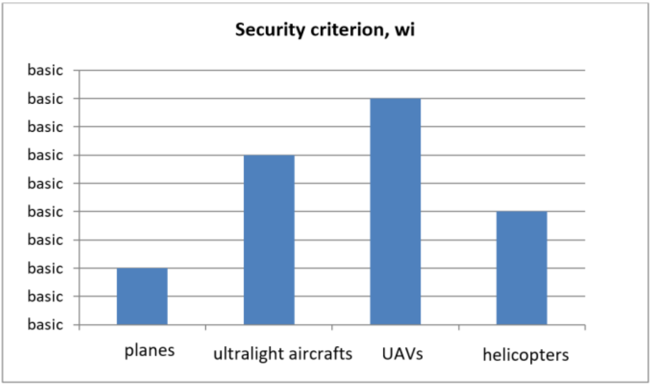



Figure 6.5 – Criterion "economic efficiency".

Decision:

1). Each expert fills in a matrix of individual preferences and by means of methods of pair comparisons and rankings determines ranks of scleral apparatus of the executed procedures [27]:

R1 - planes;

R2 - ultralight aircrafts;

R3 - Unmanned Aerial Vehicles;

R4 – helicopters

Table 6.9 – Matrix of individual preferences

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | planes | ultralight aircraft | UAV | helicopters | Σr | R |
| planes | R1 | | 0 | 0 | 1 | 1 | 3 |
| ultralight aircraft | R2 | 1 | | 0 | 1 | 2 | 2 |
| UAV | R3 | 1 | 1 | | 1 | 3 | 1 |
| helicopters | R4 | 0 | 0 | 0 | | 0 | 4 |

Expert preference system №1

$$R_1 = R_2, R_3 \succ R_4 \succ R_5$$

According to the priorities set by the expert №1, the significance of aircrafts is as follows [28]:

1st i 2nd places - ultralight aircraft, UAV, R2 = R3 = 1,5

3rd place- helicopters; R4 =3

4th place- planes, R1 = 4

2) We compile a matrix of group preferences for a group of experts and determine the opinion of the group. Ranks of expert №1 - author of control work; expert №2 - set according to the option; experts №3 - №5 - according to table.

Table 6.10 – Matrix of group preferences.

| Experts | Procedures | | | |
|---|---|---|---|---|
| | planes | ultralight aircraft | UAV | helicopters |
| | ω1 | ω2 | ω3 | ω4 |
| 1 | 3 | 2 | 1 | 4 |
| 2 | 4 | 1 | 2 | 3 |
| 3 | 4 | 2,5 | 1 | 2,5 |
| 4 | 4 | 2 | 1 | 3 |
| 5 | 4 | 2 | 2 | 2 |
| total | 20 | 9 | 7,5 | 13,5 |
| Rgr | 3,8 | 1,9 | 1,4 | 2,9 |
| R'rgr | 4 | 2 | 1 | 3 |
| Di | 0,2 | 0,3 | 0,3 | 0,55 |
| σi | 0,4472136 | 0,54772256 | 0,547722558 | 0,74161985 |
| υi, % | 11,7687788 | 28,827503 | 39,12303982 | 25,5730982 |
| C | 0,3 | 0,775 | 0,9 | 0,525 |
| w | 0,12 | 0,31 | 0,36 | 0,21 |

Determine the opinion of a group of experts (average):

$$R_{gr} = \frac{\sum_{I=1}^{m} R_I}{m};$$

For each procedure we determine the value of Rgr.

For example, when climbing:

Rsr1/5=1,8

We determine the consistency of the opinion of a group of experts. To do this, we determine the variance Di, the standard deviation σi, and the coefficient of variation υi. If υ≤ 33%, the opinion of experts is agreed.

Dispersion for each procedure:

$$D_{\mathrm{I}} = \frac{\sum_{\mathrm{I}=1}^{m}(R_{gr} - R_{\mathrm{I}})^2}{m-1}$$

Dispersion for climb: D2/4=0,325

Determine the standard deviation:

$$\sigma_{\mathrm{I}} = \sqrt{D_{\mathrm{I}}}$$

For climb:

$$\sigma_2 = \sqrt{0{,}325} = 0{,}57$$

Determined coefficient of variation for each procedure:

$$\nu_{\mathrm{I}} = \frac{\sigma_{\mathrm{I}}}{R_{gr\mathrm{I}}} \bullet 100\%$$

$$\nu_2 = \frac{0{,}57}{1{,}8} \bullet 100\% = 31{,}67\% < 33\%$$

Coefficient of variation (<33%, which means that the opinions of experts on assessing the complexity of the set procedure coincide. For the procedure of "reduction" the opinion of experts does not match. Since for 3 procedures the coefficient of variation (<33%)) for the importance of procedures agreed and distributed according to the normal law.To assess the consistency of all procedures it is necessary to use the concordance coefficient Kendallitali apparatus or repeat the survey of experts [29].

The system of advantages of a group of experts:

$$R_1 = R_3 \succ R_2 \succ R_4 \succ R_1$$

6. Determine the consistency of expert opinions using the concordance coefficient W.

The concordance coefficient is most often calculated by the formula proposed by Kendall [30]:

$$W = \frac{12S}{m^2(n^3 - n)} = 0{,}756$$

$$S = \sum_{i=1}^{n}\left\{\sum_{j=1}^{m} x_{ij} - a_{ij}\right\}^2$$ - sum of squares of differences (deviations)

$$a_{ij} = \frac{1}{2}m(n+1)$$ - the average value for the total ranks of the series.

In our case **m=5**, **n=4**.

$$a_{ij} = \frac{1}{2}5(4+1) = 12,5,$$

$S$ = (20 - 12,5) $^2$ + (9 - 12,5) $^2$ + (7,5 - 12,5) $^2$ +(13,5 - 12,5) $^2$ = 94,5

In cases where an expert cannot establish a rank difference between several related factors and assigns them the same ranks (which we observe in our case), the calculation of the concordance coefficient is done according to the formula

$$W = \frac{S}{\frac{1}{12}m^2(n^3 - n) - m\sum_{j=1}^{m} T_j},$$

$$T_j = \frac{1}{12}\sum_{T_j}(t_j^3 - t_j),$$

2) Compare the opinion of the group and the expert №1 using the rank correlation coefficient Rs.

Let's compare the opinions of a group of experts and expert 1 using Spearman's rank correlation:

$$r_{s_1} = 1 - \frac{6\sum_{I=1}^{n}(x_I - y_I)^2}{n(n^2 - 1)}$$

Table 6.11 – Aircrafts

| Ranks | | Aircrafts | | | |
|---|---|---|---|---|---|
| | | planes | ultralight aircraft | UAV | helicopters |
| Rgr - group ranks | xi | 4 | 2 | 1 | 3 |
| R1- expert №1 ranks | yi | 4 | 1,5 | 1,5 | 3 |

$$r_{s_1} = 1 - \frac{6[(4-4)^2 + (2-1,5)^2 + (1-1,5)^2 + (3-3)^2]}{4(4^2 - 1)} = 0,991 \qquad -1 \le r_s \le 1$$

Since rs = 0.991, the consistency of opinion of the group and the expert №1 is high.

3) Determination of coefficients of significance AIRCRAFT in aircraft chemistry. We pass from the ranks Ri to the weights using the method of rankings. The method is based on the assumption of a linear relationship between rank and the relative value of the performance indicator. Weights are determined by formulas:

$$\omega_I = \frac{C_I}{\sum_{I=1}^{n} C_j},$$

Rij - rank of the i-th procedure for the j-th expert (Ri gr - group ranks).

C1=1 -/4=0,25

ω1 =0,25/2,5=0,1

Table 6.12 – Aircrafts

| Aircrafts | Ranks | Ci | ωi |
|---|---|---|---|
| planes | 4 | 0,25 | 0,1 |
| ultralight aircraft | 2 | 0,75 | 0,3 |
| UAV | 1 | 1 | 0,4 |
| helicopters | 3 | 0,5 | 0,2 |

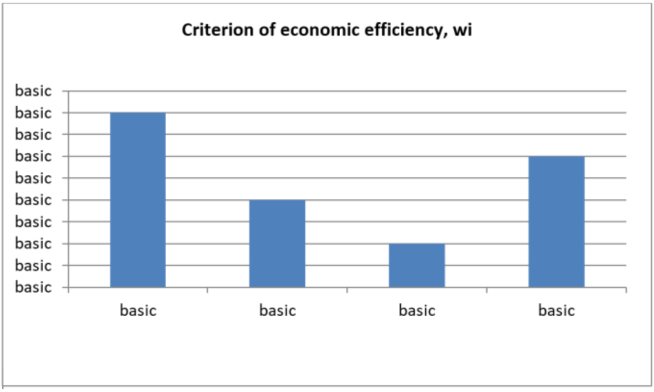



Figure 6.6 – Criterion of economic efficiency, wi

In the case of aircraft for aerochemical work, the efficiency (advantages) of different types of aircraft were determined: small aircraft, helicopters, helicopters, ultralight aircraft), Unmanned Aerial Vehicles using the method of expert evaluations on the criteria: economic efficiency (Ee), safety (S), efficiency (E), regularity (R) (fig.6.7). Let's define advantages of use of Unmanned Aerial Vehicles for aerochemical works in comparison with other types of aircrafts [31].

Table 6.13 – Weighting efficiency of aircraft in aerochemical robots

| Criteria | Weights of efficiency of aircraft | | | |
|---|---|---|---|---|
| | planes | ultralight aircraft | UAV | helicopters |
| security | 0,1 | 0,3 | 0,4 | 0,2 |
| economic efficiency | 0,12 | 0,31 | 0,36 | 0,21 |

| | | | | |
|---|---|---|---|---|
| efficiency | 0,12 | 0,33 | 0,35 | 0,2 |
| regularity | 0,37 | 0,17 | 0,13 | 0,33 |

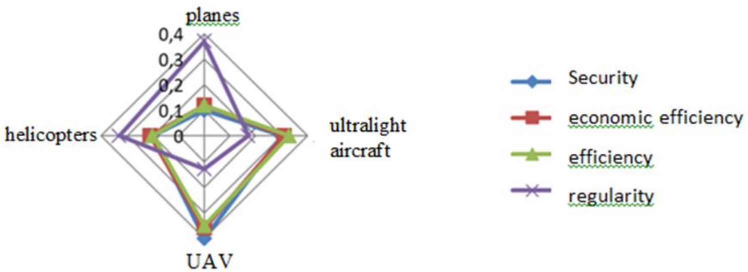



Figure 6.7 – Graphical representation of the efficiency of the use of aircraft in aerochemical robots

The risks of using aircraft, taking into account the above criteria, are determined using the criteria of decision-making in conditions of uncertainty: the criteria of Wald, Laplace, Savage. That is, according to Wald's criterion, we have the following solution that satisfies all the criteria [32]:

$$A^*=\max\min u_{ij}=\max(0{,}1;\ 0{,}1;\ 0{,}2;\ 0;15) = 0{,}2 = A_{UAV}$$

That is, the use of Unmanned Aerial Vehicles for aerochemicals is an appropriate solution due to safety, cost-effectiveness, despite some irregular flights due to meteorological phenomena.

Table 6.14 – Calculation of risks of efficiency of application of aircrafts in aerochemical works

| Aircrafts | B | EE | E | P | V | L | C |
|---|---|---|---|---|---|---|---|
| planes | 0,1 | 0,15 | 0,1 | 0,35 | 0,1 | 0,175 | 0,25 |
| ultralight aircraft | 0,3 | 0,3 | 0,3 | 0,1 | 0,1 | 0,25 | 0,15 |
| UAV | 0,4 | 0,4 | 0,4 | 0,2 | 0,2 | 0,35 | 0,15 |
| helicopters | 0,2 | 0,15 | 0,2 | 0,35 | 0,15 | 0,225 | 0,2 |

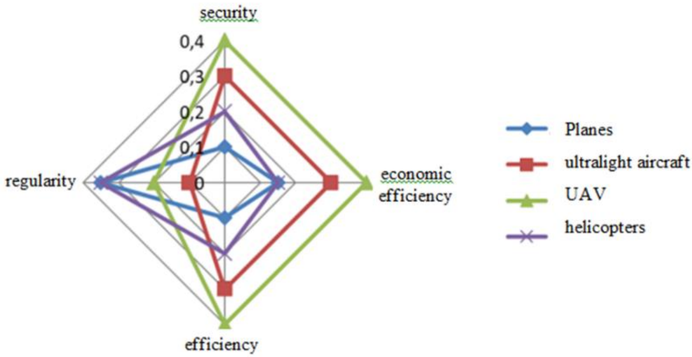



Figure 6.8 – The effectiveness of aircraft in aerochemical works in accordance with the criteria of security, efficiency, economic efficiency, regularity.

Data for calculating the economic efficiency of aircraft are given in Fig.6.8

Table 6.15 – Calculation of economic efficiency of aircrafts in aerochemical works

| | security | economic efficiency | efficiency | regularity | $ |
|---|---|---|---|---|---|
| planes | 100000 | 150000 | 100000 | 350000 | 175000 |
| ultralight aircraft | 300000 | 300000 | 300000 | 100000 | 250000 |
| UAV | 400000 | 400000 | 400000 | 200000 | 350000 |
| helicopters | 200000 | 150000 | 200000 | 350000 | 225000 |
| | 1000000 | 1000000 | 1000000 | 1000000 | 1000000 |

$$W = \sum_{j=1}^{n} \frac{\sum_{i=1}^{m} w_{ji} S_{ji}}{m}$$

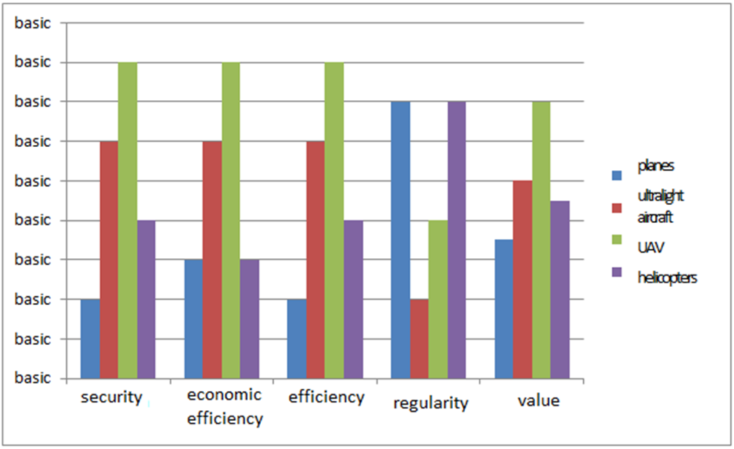



Figure 6.9 – Economic efficiency of aircraft in aerochemical works

The initial information for processing is numerical data expressing the preferences of experts and a substantial justification for these benefits. Based on the results of processing, a solution to the problem is formed. The presence of both numerical data and meaningful statements of experts leads to the need to use qualitative and quantitative methods of processing the results of expert evaluation. The share of these methods significantly depends on the class of problems solved by expert evaluation [33].

**List of references for chapter 6**

1. Methodology of situational collective control of manned and Unmanned Aerial Vehicles in a single airspace: scientific materials. In 3 volumes. Vol..A., Argunov G.F., Malyutenko T.L., Bondarev D.I., Petrushevsky A.O., Chinchenko O.G. / Ed. Kharchenko VP: K.: NAU, 2017. 120 p.
2. Methodology of situational collective control of manned and Unmanned Aerial Vehicles in a single airspace: scientific materials. In 3 volumes. Volume 2. Integrated corporate models for collective management of manned and DRIVED AIRCRAFT in a single airspace in conditions of risk and uncertainty / Kharchenko V.P., Shmelyova T.F., Znakovskaya E.A., Bugayko D.O., Lupovitryany prostiro OE, Aircraft V.A., Argunov G.F., Mukhina M.P., Malyutenko TL, Kuzmenko NS, Bondarev D.I., Petrushevsky A.O., Shostak O.V., Blitalni aparatigaya L.V. / Ed. Kharchenko VP: K.: NAU, 2017. 120 p.
3. Intelligent Expert Decision Support Systems: Methodologies, Applications and Challenges / Abdel-Badeeh M. Salem, Tetiana

Shmelova International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. 2018. P. P. 215-242

4. Stochastic Methods for Estimation and Problem-Solving in Engineering: Stochastic Methods of Decision Making in Aviation, / Tetiana Shmelova International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania.2018. P. 139-160
5. Advanced Macroergonomics and Sociotechnical Approaches for Optimal Organizational Performance Chapter 3. Socio-Technical Approaches for Optimal Organizational Performance: Air navigation systems as socio-technical systems / Tetiana Shmelova, Yuliya Sikirda. International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. November, 2018. P. 39-70
6. Cases on Modern Computer Systems in Aviation Chapter 3 Artificial Neural Network for Pre-Simulation Training of Air Traffic Controller / Tetiana Shmelova, Yuliya Sikirda, Togrul Rauf oglu Jafarzade. International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. 2019. P. 20-58
7. Automated Systems in the Aviation and Aerospace Industries Chapter 1 Machine Learning and Text Analysis in Artificial Intelligent System for Training of Air Traffic Controllers / Tetiana Shmelova, Yuliya Sikirda, Nina Rizun, Vitaliy Lazorenko, Volodymyr Kharchenko. International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. 2019. P. 1-50
8. Unmanned Aerial Vehicles in Civilian Logistics and Supply Chain Management. Chapter 5 Automated System of Controlling Unmanned Aerial Vehicles Group Flight /Tetiana Shmelova, Dmitriy Bondarev - International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. November, 2019. P. 167-204
9. Unmanned Aerial Vehicles: Breakthroughs in Research and Practice. Information Resources Management Association (USA)/ Chapter 8 Applications of Decision Support Systems in Socio-Technical Systems / Tetiana Shmelova, Yuliya Sikirda, International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. IRMA 2019. P.182-214
10. Handbook of Artificial Intelligence Applications in the Aviation and Aerospace Industries. Chapter 1 Artificial Intelligence in Aviation Industries: Methodologies, Education, Applications, and Opportunities / Tetiana Shmelova, Arnold Sterenharz, Serge Dolgikh. International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. 2019. P. 1 – 35

11. Bondarev DI Models of group flights of Unmanned Aerial Vehicles using graph theory / D.I. Bondarev, DP Kucherov, TF Shmelyova // Science and Technology of the Air Force of the Armed Forces of Ukraine. 2015. Vip. 3 (20). P. 68–75.
12. Shmelova T. Graph Theory Applying for Quantitative Estimation of UAV's Group Flight / T. Shmelova, D. Bondarev // Actual Problems of Unmanned Aerial Vehicles Developments (APPUAVD). 2015 **IEEE** 3d International Conference. Kyev, 13-15 October 2015.: Proceeding. P. 328-331
13. Chynchenko Y. Remotely piloted aircraft systems operations under uncertainty conditions / Y. Chynchenko, T. Shmelova, O. Chynchenko // Proceedings of the National Aviation University. 2016. №1. P. 18-22.
14. Shmelova T.F. Graph theory applaying for quantitative estimtion of UAV's group flight into aerial photography/ T.F. Shmelova, D.I. Bondarev // Electronics and Control Systems 2016. N 4(46): P.128-133.
15. Bondarev D.I. Optimization of group flight structure of Unmanned Aerial Vehicles / D.I. Bondarev, D.P. Kucherov, T.F. Shmelyova // Collection of scientific works of Kharkiv University of the Air Force. 2016. Vip. 3 (48). P. 61 - 66.
16. Shmelova T. Artificial neural network for air traffic controller's pre-simulator training / T. Shmelova, Y. Sikirda, A. Zemlyanskiy. V. Lazoprenko, O. Danilenko // Proceedings of the National Aviation University. 2016. №3, P.13-23
17. Shmelyova TF Distributed control system for remotely piloted aircraft / T.F. Shmelyova, GFAargunov, AV Stratiy, // Bulletin of the Engineering Academy of Ukraine. 2016. №3, C.57-62.
18. Shmelova T.F. Distributed control system for remotely piloted aircraft / T.F. Shmelova A.V.Stratiy// 7th World Congress „Aviation in the XXIst century. Safety in Aviation And Space Technologies" NAU, Sept.21, 2016 C.2.46-2.51
19. Shmelova T. Unmanned Aircraft Usage in the Municipal Air Transport of Ukraine. / T.F. Shmelova, D. Bondarev O. Alexeiev, A. Sedina// 7th World Congress „Aviation in the XXIst century. Safety in Aviation And Space Technologies" NAU, Sept.21, 2016 C. 2.43-2.46
20. Shmelova T. Modeling of the Decision Making by UAV's Operator in Emergency Situations / T. Shmelova, D. Bondarev. Y. Znakovska // 4th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC-2016). 2016 IEEE 4d International Conference. Kyev, 18-20 October 2016.: Proceeding. P. 31-34

21. Shmelova T. Models of personality and activities of Remotely Piloted Aircraft System's operator / T. Shmelova, Y. Kovaljov, V. Shostak // 4th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC-2016). 2016 IEEE 4d International Conference. Kyev, 18-20 October 2016.: Proceeding. P. 121-125
22. Bondarev D.I., Modeling of decision-making of the operator of a remotely piloted aircraft (AIR SPACE)./ Bondarev D.I., Petrushevsky A.O., Shmelyova T.F. // Abstracts of the All-Ukrainian scientific-practical conference of young scientists and students "Problems of development of the global system of communication, navigation, surveillance and organization of air traffic CNS / ATM" Kyiv, November 23-25, 2016 К.: NAU, 2016.
23. Shmelyova T.F. Methodology of collective control of unmanned and manned aircraft in a single airspace / T.F. Shmelyova, A.V. Stratiy // Proceedings of the IV International Scientific and Practical Conference "Problems of air transportation and the use of aviation in the economy" November 16, 2016, Kyiv. NAU.
24. Kharchenko V. Modelling of decision making of Unmanned Aerial Vehicle's operator in emergency situations // Kharchenko V., Shmelova T., Bondarev D., Stratiy A. // Proceedings of the National Aviation University. 2017. №1, P.20-28
25. Shmelyova T.F. Development of a database of a distributed control system for remotely piloted aircraft / T.F. Shmelyova, V.V. Stratiy // AVIA-2017: XIII International. scientific and technical Conf., Kyiv, April 19-21, 2017: abstracts. - Kyiv: National Aviation University, 2017. P. 13.10-13.15
26. Shmelyova T.F. Application of fuzzy set theory in the aeronautical system // Shmelyova T.F., Sikirda Y.V., Yakunina I.L. Proceedings of the Nineteenth International Scientific and Practical Seminar "Combinatorial Configurations and Their Applications" April 7-8, 2017 171 - 177
27. Shmelyova T.F. Determination of qualitative indicators of action by an aviation specialist using the methods of fuzzy logic Shmelyova T.F., Yakunina I.L. Proceedings of the Nineteenth International Scientific and Practical Seminar "Combinatorial Configurations and Their Applications" April 7-8, 2017. 177-183
28. Shmelova T. Decision Making by Remotely Piloted Aircraft System's Operator / T. Shmelova, Sikirda Yu., Kovaliov Yu. Actual Problems of Unmanned Aerial Vehicles Developments (APPUAVD). 2017 IEEE 4d International Conference. Kyev, 2017.: Proceeding. P. 92-99

29. Decision Support System of Unmanned Aerial Vehicle's Operator for Choosing of the Alternate Aerodrome/Place in the Case of Emergency Landing / Tetiana Shmelova, Yuliya Sikirda // 8th World Congress „Aviation in the XXIst century. Safety in Aviation And Space Technologies" NAU, October.10, 2018 P. 5.2.1-5.2.5
30. Shmelova T. Group flights of Unmanned Aviation Vehicles for Smart cities / T. Shmelova, V.Lazorenko, D.Bondarev, O.Burlaka // 2019 IEEE 9th International Conference on Advanced Computer Information Technologies (ACIT'2019), Ceske Budwjovice, Czech Republic, June 5-7, 2019. P. 230-233
31. Shmelova T. Optimization of flows and flexible redistribution of autonomous UAV routes in multilevel airspace / T. Shmelova, A. Sterenharz, O. Burlaka // 2019 IEEE Proceedings of the 15th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer; 5th International Workshop on Theory of Reliability and Markov Modelling for Information Technologies (TheRMIT 2019) Volume IV: Workshops, Kherson, Ukraine, June 12-15, 2019. P. 703-714
32. Shmelova T. Geometry-modeling based flight optimization for autonomous groups of UAVs / T. Shmelova, Kovalyov Yu., Dolgikh S., Burlaka O. Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD). 2019 IEEE 5d International Conference. Kyiv, 2019.: Proceeding. P. 79-82 ISBN: 978-1-7281-2591-6
33. Shmelova T., Burlaka O. Integration of Decision-Making Models for Decision Support System of UAVs operator in emergencies / Shmelova T., Burlaka O.// IX International Scientific and Practical Conference "Information Control Systems &Technologies (ICST-2020)" Proceedings of the International Workshop, Odessa

# 7 CHAPTER
# AVIATION OF THE MINISTRY OF INTERNAL AFFAIRS OF UKRAINE

In order to promptly and adequately respond to the challenges and threats facing Ukrainian society, the Ministry of Internal Affairs plans to create a single system of aviation security.

As part of the construction of the System, it is planned to use both existing and purchased aircraft, including UAVs.

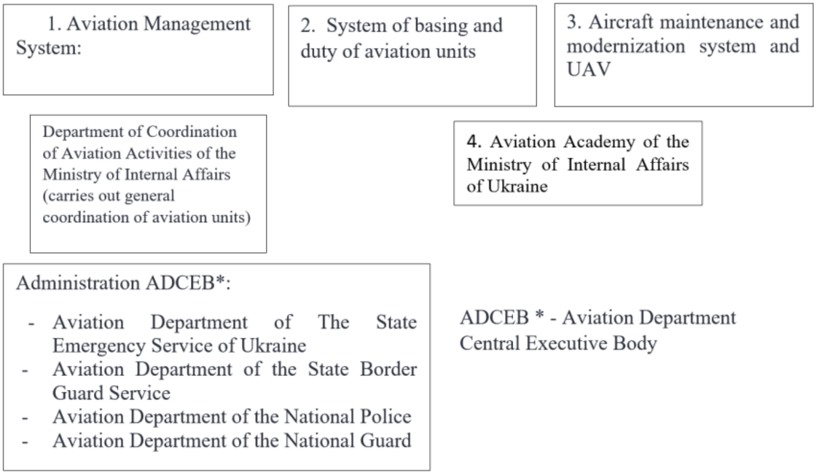
The aircraft and UAV are planned to be used in the aviation units of the following bodies: the State Emergency Service, the State Border Guard Service, the National Police and the National Guard [1].

Table 7.1 – The main tasks of Unmanned Aerial Vehicles of the Ministry of Internal Affairs of Ukraine:

| | Task | Brief description | Regulatory framework |
|---|---|---|---|
| 1 | Rescue operations | aviation search and rescue - a set of measures aimed at identifying aircraft that have suffered or are in distress, and providing timely assistance to victims of an aviation accident | Ministry of Internal Affairs, Order on approval of the Rules of aviation search and rescue in Ukraine dated March 16, 2015 № 279 |
| 2 | Maintaining public order | Maintaining public order, stopping manifestations of disrespect for citizens, as well as the protection of state premises, bodies and institutions, performing functions related to state security of citizens, etc. | Law of Ukraine "On the Judiciary and the Status of Judges"<br>Law of Ukraine "On the National Police" Law of Ukraine "On the National Guard of Ukraine" |
| 3 | Anti-terrorist and special operations | anti-terrorist operation - a set of coordinated special measures aimed at preventing, preventing and stopping terrorist activities, releasing hostages, ensuring public safety, neutralizing terrorists, minimizing the consequences of terrorist activities | Law of Ukraine "On Combating Terrorism"<br>Of the Law of Ukraine "On State Protection of Public Authorities of Ukraine and Officials"<br>Of the Law of Ukraine "On the Armed Forces of Ukraine"<br>Of the Law of Ukraine "On the State Border Guard Service of Ukraine" |

| | | | |
|---|---|---|---|
| | | | Of the Law of Ukraine "On the State Service for Special Communications and Information Protection of Ukraine" |
| 4 | Protection of the state border and maintenance of safety on roads | The protection of the state border of Ukraine on land, sea, rivers, lakes and other bodies of water is entrusted to the State Border Guard Service of Ukraine, and in the air and underwater space within the territorial sea - to the Armed Forces of Ukraine. | Law of Ukraine "On the State Border Guard Service of Ukraine", Law of Ukraine "On the State Border Guard Service of Ukraine", Law of Ukraine "On the State Border of Ukraine", Law of Ukraine "On Border Control", Resolution of the Cabinet of Ministers of Ukraine of July 27, 1998 № 1147 regime" |
| | | Road safety is a set of measures aimed at ensuring the safety of all road users. | Laws of Ukraine "On Road Traffic", "On Transport", "On Road Transport", "On Sources of Financing of the Road Economy of Ukraine", "On Local Self-Government in Ukraine", "On Concessions for Construction and Operation of Motor Roads", "On Motor Roads" » |

## The general structure of management of system of aviation of divisions of the Ministry of Internal Affairs of Ukraine




## Description of the management structure of the aviation system of the units of the Ministry of Internal Affairs of Ukraine [1]:

**Department of Aviation Coordination of the Ministry of Internal Affairs** is a structural subdivision of the Ministry of Internal Affairs which is tasked with general supervision and coordination of the activities of the Aviation Departments of the ADCEB, making proposals for the formation of state policy in the field of aviation safety.

**Aviation Management ADCEB -** ensure the functioning of aviation units, management of flight and technical staff, maintenance of airfields, bases and other flight infrastructure, ensuring the duty of aviation units and departures.

**The base and duty system of aviation units** consists of a network of own aerodromes (parking places) of the Ministry of Internal Affairs and (for example, an aerodrome in Nizhyn (The State Emergency Service of Ukraine), Oleksandriya (the National Guard), Kharkiv (the State Border Guard Service), a parking place in Kyiv airport (The State Emergency Service of Ukraine), the National Guard), etc.). In total, it is planned to place aircraft at 15 airfields to ensure maximum coverage of Ukraine. In addition, it is planned to form a register of possible points of temporary base of aircraft for the period of tasks outside the places of permanent deployment.

**System of maintenance and modernization of aircraft and UAVs** - provides scheduled maintenance of aircraft and UAVs, warranty and post-warranty repairs, including overhaul of major components and units, the formation of the base of major spare parts and components.

**System of training, retraining and advanced training of flight and flight-technical staff -** I provide high-quality training of personnel for the staffing of aviation units of the ADCEB. To ensure the most effective educational process, the educational institution for the training of flight and flight technical staff, UAV operators is planned to provide modern models of aircraft and UAVs. In addition, it is planned to involve experienced pilots and technicians from ADCEBs who have practical experience in both the use of aircraft and the implementation of particularly important and dangerous flights - firefighting, piloting in difficult weather conditions and more.

**Tasks facing the system.**

The Aviation Civil Protection Service is created in order to build an effective system of assistance to the population in the event of emergencies, prevent emergencies and eliminate their consequences.

**The main idea of this project.**

All aircraft that will operate within this system will operate in a single deployment, coordination and management system [1].

In the event of an emergency, the involvement of aircraft for its liquidation will be based on the functional readiness and its immediate territorial accessibility, and not on the basis of the affiliation of such equipment to a particular central executive body.

The planned work of the aviation units of the ADCEB will be carried out in accordance with their functional direction of work, at the same time, in the event of an emergency, all the necessary aircraft will be involved in its elimination.

The Aviation Civil Protection Service is created in order to build an effective system of assistance to the population in the event of emergencies, prevent emergencies and eliminate their consequences.

**Apparatus of the Ministry of Internal Affairs perform the following main functions** [2]**:**

The State Emergency Service of Ukraine

1. Execution of search and rescue operations within the framework of Ukraine’s international obligations
2. Execution of search and rescue operations on water, in mountainous areas and in hard-to-reach places.

The State Border Guard Service

1. Supervision of the state border;
2. Carrying out special operations.

The National Police

1. Patrolling the territory to detect illegal activities (illegal mining, deforestation, cultivation of drug-containing plants);
2. Monitoring of critical infrastructure facilities (railways, ports, oil and gas pipelines, etc.);
3. Search for missing persons and wanted criminals;

The National Guard

1. Participation in ensuring the safety of important government facilities and nuclear facilities.
2. Conducting special police operations.

**Tasks for training UAV operators**

The main task is professional training (retraining) and coordination of crews of Unmanned Aerial Vehicles (hereinafter - UAC) of all units of the Ministry of Internal Affairs of Ukraine, which are armed with UAC.

Task [3]:

- training of crew operators (individual training, Military accounting specialty training and advanced training of crews for a certain type of UAC);
- training of operators for manning part-time crew (individual training, training for Military accounting specialty and advanced training of crews for a certain type of UAC);
- introduction into training of operational experience in the use of UAC, acquired by units of the Ministry of Internal Affairs of Ukraine during the tasks of the Joint Forces (Anti-Terrorist Operation) and best practices of NATO partner countries using UAC using SPACROW, A1-SM Fury, Leleka-100, PD-1, SPECTATOR-M, RQ-11B Analog Raven, FLY EYE).

**Unmanned Aerial Vehicles used by Unmanned Aerial Vehicles of the Armed Forces of Ukraine**

"PD-1" tactical radius up to 120 km

“UA-BETA” tactical radius up to 25 km

ACS-3 tactical radius up to 120 km

Fury A1-C / A1-SM tactical radius up to 50 km

"LELEKA-100" tactical radius up to 50 km

"Sparrow" tactical radius up to 25 km

"Spectator-M" tactical radius up to 50 km
Figure 7.1 – UAC of the Ukrainian production

Fly Eye “WB Electronics” tactical radius up to 50 km

RQ-11B Raven “AeroVironment” tactical radius up to 10 km

Figure 7.2 – UAC of foreign production

**The main tasks of uAC for use during special operations within the units of the Ministry of Internal Affairs of Ukraine**

Conducting air reconnaissance [3]:
– radio and radio engineering;
– optoelectronic;
– radar;
– radiation, chemical and biological;
– engineering;
– meteorological.

Providing communication retransmission in combat control systems

Determination of coordinates, sizes and other characteristics of objects of defeat (purposes)

Radio electronic suppression of control systems (means)

Strikes on land and sea targets (objects), including for the breakthrough of the enemy's air defense system

Creating false air targets to mislead the enemy's air defense system

Execution of search activities in the search and rescue system

**Features of training pilots to perform combat missions**

The training of pilots for specific combat missions may be conducted in the form of aviation competitions using airspace near the state border for the purpose of conducting demonstration operations [4].

The initial stages of the competition can be held covertly at the level of parts and (connections).

The peculiarity of the competition is to identify the best crews of aircraft and helicopters to participate in the final stage of the competition.

The purpose of the event: to determine the best crews of aviation, to disseminate their experience and to develop areas for further development and improvement of the combat training system of the Air Force.

Determining and increasing the level of tactical training and readiness for combat use of flight crews of various types of aviation.

At the final stage, in order to work out the coordination of parts, the competition involves all types of aviation (from 4 to 20 aircraft from each type of aviation):

Modern anti-aircraft missile systems are used to simulate conventional air defense means.

Stages of the event [4]:

– testing and evaluation of physical, theoretical training of aircraft crews, exercises of visual reconnaissance of ground targets and piloting techniques.

– active phase of exercises (combat exercises to overcome air defense means. air combat (group, single), rocket-bomb attack, firing of air guns, landing of cargoes.

– summing up.

Tasks that can be completed during the active phase of the competition [5]:

– performing navigation exercises;

– technique of piloting in a group and alone at medium and low altitudes;

– practice of anti-missile maneuver.

– combat use in pairs of aircraft and helicopters:

– overcoming enemy air defenses;

– exit to the target groups of aircraft and helicopters at a given time;

– performing a group strike from the first event or from the second event; execution of group militants firing at ground targets with unguided rockets and bombing; conducting group maneuver battles.

For effective control of the flight crew's performance, UAVs could be involved, which transmitted data on combat use in real time [6].

2. Knowledge and skills of operators are determined by the following BCR:

1) BKR I - performing operations according to the Visual Flight Rules (hereinafter - VFR) in the airspace according to ICAO classification E, F and G, as well as in the reserved airspace up to an altitude of 900 m (3000 feet) AGL (above ground level - above land). Knowledge and skills of UAV class I operators (micro and mini-UAVs) must comply with BKR I;

2) BKR II - performance of PVP operations in airspace according to ICAO classification D, E, F and G, as well as in reserved airspace up to an altitude of 1500 m (5000 ft) AGL. Knowledge and skills of UAV class I operators (small UAVs) must comply with BKR II;

3) BKR III - performance of VFR operations in the entire airspace according to the ICAO classification, excluding class A, up to an altitude of 5500 m (18000 feet) AGL or FL180. Knowledge and skills of UAV class II operators (tactical (operational-tactical) UAVs) must comply with BKR III;

4) BKR IV - performance of operations on PVP and Instrument Fight Rules (further - IFR) in all airspace. Knowledge and skills of UAV class III operators (operational, strategic) must comply with BKR IV.

BKR is cumulative, ie in order to obtain a qualification for BKR IV, it is necessary to first obtain BKR I - III.

Operators of UAVs that operate UAVs outside the line of sight of BLOS, regardless of the UAV class, must have BKR IV.

**List of references for chapter 7**

1. Methodology of situational collective control of manned and Unmanned Aerial Vehicles in a single airspace: scientific materials. In 3 volumes. Vol..A., Argunov G.F., Malyutenko T.L., Bondarev D.I., Petrushevsky A.O., Chinchenko O.G. / Ed. Kharchenko V.P.: K.: NAU, 2017. 120 p.
2. Intelligent Expert Decision Support Systems: Methodologies, Applications and Challenges / Abdel-Badeeh M. Salem, Tetiana Shmelova - International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania.2018. P.215-242.
3. Stochastic Methods for Estimation and Problem-Solving in Engineering: Stochastic Methods of Decision Making in Aviation, / Tetiana Shmelova

International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania.2018. P.139-160.

4. Cases on Modern Computer Systems in Aviation Chapter 3 Artificial Neural Network for Pre-Simulation Training of Air Traffic Controller / Tetiana Shmelova, Yuliya Sikirda, Togrul Rauf oglu Jafarzade. International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. 2019. P. 20-58.
5. Unmanned Aerial Vehicles in Civilian Logistics and Supply Chain Management. Chapter 5 Automated System of Controlling Unmanned Aerial Vehicles Group Flight /Tetiana Shmelova, Dmitriy Bondarev International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. November, 2019. P. 167-204.
6. Unmanned Aerial Vehicles: Breakthroughs in Research and Practice. Information Resources Management Association (USA)/ Chapter 8 Applications of Decision Support Systems in Socio-Technical Systems / Tetiana Shmelova, Yuliya Sikirda, International Publisher of Progressive Information Science and Technology Research, USA, Pennsylvania. IRMA 2019. P.182-214.

## CONCLUSION

Ukraine has a full cycle of aircraft development and occupies a significant place in the global aviation market in the sector of transport and regional passenger aviation, which allows to develop and manufacture aircraft in such areas as aircraft construction, on-board electronic equipment focused on satellite communications, navigation and surveillance, ultralight and light aircraft, helicopter construction, Unmanned Aerial Vehicles. Unmanned Aerial Vehicles (UAVs) are no exception. Today, this technology is used in many areas of activity and has extremely great prospects for other areas. Currently, Unmanned Aerial Vehicles (UAVs) are used to solve a wide range of tasks, such as border patrols, reconnaissance, transportation and armed attacks. This diversity is due to the fact that UAVs are very technological, which explains their widespread use. Modern technologies for power supply of UAVs have not yet reached the appropriate level, due to the dynamic development of this technology.

Further research should be directed to the solution of problem in control systems of drones for different goal tasks. To develop uniform standards for the management of various types of Unmanned Aerial Vehicles that perform single and group flights. Develop systems for the use of drones in various areas of industry, education, social spheres, etc. The control systems of drones must use various new modern information technologies to increase the efficiency of the system operation, such as Data Analysis and DM, Big Data, Data Mining, Machine Learning, Intelligent Data Analysis, Artificial Intelligence System, Knowledge Discovery, etc. It is necessary to study behaviour of operators in RPAS in extreme situations, prerequisites of emergency situations and preventing catastrophic situations too. It is necessary to develop modern DSSs of H-O of ANS (pilots, ATCs, UAV operators) in flight emergencies and in other situations too. On next steps we are planning consider Multi-criteria decision analysis (MCDA) multicriteria assessment of the performance of aviation chemical works by group of manned and unmanned aircrafts, such as airplanes, helicopters, UAV too. Multi-criteria decision analysis is a discipline aimed at supporting decision makers who are faced with making numerous and conflicting evaluations (ICAO, 2009). MCDA aims at highlighting these conflicts and deriving how to arrive at a compromise in a transparent process. We are planning to create Intelligence Further research should be directed to the solution of practical problems of actions UAV's operator in case of emergencies, software creation. Models of FE development and of DM by UAV's in FE will allow to predict the H-O's actions with the aid of the informational-analytic and diagnostics complex for research H-O behavior in extreme situation. It is necessary to analyze the all factors influencing on the operators in these systems in order to predict the development of the catastrophe and prevent it with using Intelligent DSSs.

The problems of using drones for different purposes in civil aviation are considered, and the analysis of the advantages of groups flights of UAVs are presented. To control a group of drones, the authors suggest choosing and using a Drone - Repeater to connection to the operator on the ground and to control of the drones in group flight. To select the effective Drone – Repeater and optimal configuration network of UAV’s group, authors used the method of server selection in computer networks. In chapter criteria of efficiency for the performance of tasks of UAVs group flight was analyzed. It was used graph theory for quantity estimation of effectiveness of UAVs group flight. Also it was intended flight group performance criteria for all types of UAVs connections (fully connected, a star, ring, tree, with a common tire, mixed, cellular). The algorithm of finding central drone in group of the UAVs in flight for relaying control signals from other UAVs was obtained. Thus, the creation of topology groups UAV advisable to focus on fully connected topology, as the most effective. Further research should be directed to the solution of practical problems of implementation of group management in driving the UAV, which leads to more efficient use of UAVs, namely the possibility of an adjustment plan and optimize the flight route, based on data already obtained from other UAVs. The possibility of setting different tasks for members of multi-UAV considering efficiency topology groups.

At the same time, UAC operators must undergo a full comprehensive program of practical flight and technical training, which consists of flight training in the UAC, UAC maintenance, and theoretical training in the basics of UAC operation at the UAC training and model complex. Flight training enables UAC operators to demonstrate skills and abilities in controlling the UAC (UAV, RCP) in the entire range of its altitudes and speeds at any stage of flight.

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