

THE REPUBLIC OF AZERBAIJAN

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ABSTRACT

of the Dissertation submitted to receive the scientific degree of
Doctor of Sciences

CREATION OF A CONVERTOPLAN-TYPE UNMANNED FLIGHT VEHICLE AND OPTIMIZATION OF ITS MAIN PARAMETERS IN THE CONTEXT OF OBSERVATION OF STRATEGIC OBJECTS

Speciality: 3324.04 – Operation of surface complexes, output equipments, flying machines and their systems

Field of science: Technical sciences

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GENERAL CHARACTERISTIC OF THE DISSERTATION

Relevance of the topic and the degree of development. In modern times, unmanned aerial vehicles (UAVs) have entered all spheres of our lives. The creation, improvement, and further simplification of operational characteristics of this type of aircraft are important issues. UAVs play an indispensable role in observing and monitoring areas that are dangerous for people, solving military problems, and ensuring the security of states¹.

The experience of the April 2016 battles, the second Karabakh war, the conducted anti-terrorist operations, as well as other wars and a number of local armed conflicts showed that in cases where the use of piloted aviation is not possible or advisable when solving tasks of various nature, it is possible to achieve a high level of solving the tasks set by effectively using reconnaissance or armed unmanned aerial vehicles to achieve accurate and higher results. The effectiveness of the application of payloads and weapons systems installed on modern UAV complexes, the flight of which is based on artificial intelligence, has significantly increased. Thus, the methods of applying the weapons systems installed on them have changed in accordance with the technical characteristics of UAVs when solving civil and military tasks.

Recently, the design and development of UAVs has been developing dynamically. Due to the simplicity of their operational characteristics and the wide range of application areas, the interest and demand for small-sized UAVs based on multirotation and glider is increasing among UAV operators. The comprehensive development of a hybrid-based universal VTOL (Vertical takeoff and landing) type UAV, designed in a multirotation and fixed-wing (glider) flight configuration and providing vertical takeoff and landing and horizontal flight in aircraft modes, remains an urgent task for aviation specialists.

¹Набиев, Р.Н., Абдуллаев, А. А. Малоразмерные беспилотные летательные аппараты и средства борьбы с ними // – Баку: Вестник Азербайджанской Инженерной Академии, – 2017, №2, том 9. – с. 15-20.

Important steps have been taken in our republic towards the development of UAV infrastructure, regulation of the increasing UAV load in civil, commercial and state aviation, and improvement of legislation ². The main direction and goal in the development of this type of UAVs is to increase the autonomy of flight, reduce the likelihood of detection during observations. The mentioned technical and software capabilities increase the reliability of the device, ensure ease of use, significantly reduce the requirement for the operator to be a highly qualified specialist, and significantly reduce the costs of completing the task.

Due to the extremely urgent nature of the tasks set in the dissertation topic, in order to solve the above-mentioned issues, an analysis of the scientific and technical literature was carried out, the main priority aspects of the research direction were determined, functional, conceptual and structural schemes of the VTOL-type UAV were developed, an element base that meets modern requirements was selected, and finally a VTOL-type UAV that meets the technical requirements was created ³.

Computer models of the remotely controlled VTOL-type UAV were developed on the basis of various software and simulation was carried out to study the technical and aerodynamic characteristics of the model. The purpose of the payload was selected and its effect on the structural parameters of the VTOL-type UAV was determined. Its functional capabilities were experimentally studied and the results obtained were tested theoretically and experimentally in laboratory and then experimentally - in stages in aviation and flight safety conditions with test flights ⁴.

²Набиев, Р.Н., Абдуллаев, А.А. Беспилотные летательные аппараты конвертопланового типа: Текущее состояние и перспективы // Естественные и технические науки. – Москва: – 2021, №3 (154), – с. 146-162.

³Набиев Р.Н. Разработка концептуальной функциональной схемы беспилотного конвертоплана с гибридным источником энергии / Р.Н.Набиев, А.А.Абдуллаев, Г.И.Гараев // Авиакосмическое приборостроение, - Москва: - 2021, №5, - с. 03-18.

⁴Набиев, Р.Н. Конструктивное оформление беспилотного летательного аппарата конвертопланового типа / Р.Н.Набиев, А.А.Абдуллаев, Г.И. Гараев // Авиакосмическое приборостроение, – Москва: – 2022, №6. – с. 03-13.

In order to ensure long-term flight of a VTOL-type UAV, the required research work was carried out to select the elements that will form a hybrid-based energy source and power system, as well as to calculate the aerodynamic characteristics of the UAV.

A methodology has been developed for determining the centers of gravity (CG) for nano, micro, mini and small-sized UAVs, as well as for the process of centering the element base of the UAV in the fuselage based on the calculated values of the CG during the design and manufacture of the UAVs⁵.

Despite the creation of a flight data recorder for medium and large-sized UAVs, the lack of a device that records this type of universal parameters for nano, micro, mini-sized UAVs remains an urgent issue for drone and UAV operators. For this purpose, an on-board control measurement system (OBCMS) has been developed to simultaneously record technical and navigation data of the power systems of VTOL-type micro UAVs before flight, in “online” mode during flight, and after flight. After flight, the data recorded on the memory card using the OBCMS is used for comprehensive diagnostics of the power units of the flight apparatus⁶.

Equipped with lithium-polymer accumulator batteries (LPAB) with very low surface reflectance (SRC) and acoustic noise effect, very easy to replace and fast charging characteristics, and created from a hybrid unity of “flying wing” glider-shaped and multirotation-based structures that do not require runways, the VTOL-type UAV will be useful in conducting aerial reconnaissance and in successfully completing tasks and activities in this direction. Also, in the context of observing strategic objects, methods of conducting aerial reconnaissance have been analyzed, generalized, and priority directions have been determined.

⁵Набиев, Р.Н. Определение центра тяжести беспилотного летательного аппарата конвертопланового типа / Р.Н.Набиев, А.А.Абдуллаев, Г.И.Гараев [и др.] // Известия ЮФУ. Технические науки, – Таганрог: – 2022, № 5, – с. 258-268.

⁶Nabiyev R.N. On-board control-measurement system for micro convertiplane-type unmanned aerial vehicles / R.N.Nabiyev, A.A.Abdullayev, Q.I.Qarayev // Eurasian Physical Technical Journal, - Karaganda: - 2024, № 2(48), Vol 21, - p. 61-69.

Evaluation of observation with UAVs and optimization of its application have been shown on practical examples. The present dissertation work is devoted to solving the issues discussed above.

The object and subject of the research.

The object of the study is VTOL micro UAVs.

The subject of the study is the creation of a VTOL micro UAV and its optimization in the context of surveillance of strategic objects by studying its aerodynamic characteristics.

Purpose and tasks of the research.

The purpose of the research is to develop a multirotation and fixed-wing glider-based VTOL type UAV and create a flight device with a hybrid power source, a propulsion system, aerodynamic characteristics that meet the requirements, and optimized support in the context of observing strategic objects in order to ensure its long-term flight.

To achieve the goal, the following issues were raised and resolved in the dissertation:

1. Selection of hybrid-based power sources and propulsion systems for a VTOL-type UAV with multirotation and glider construction;
2. Development of a conceptual functional scheme for a VTOL-type UAV with a hybrid power source;
3. Study of the main aerodynamic parameters of the glider of a VTOL-type UAV based on the “SolidWorks”, “ANSYS”, “Profili” and “Xflir5” application programs;
4. Structural design of a VTOL-type UAV, selection of supporting elements and substantiation of its effect on the aerodynamic characteristics of the UAV with theoretical and practical knowledge;
5. Determination of the center of gravity of a VTOL-type unmanned aerial vehicle;
6. Development of an on-board control and measurement system to record the technical parameters of the engines of a VTOL-type unmanned micro-aircraft vehicle and data determining the position of the glider in space in flight.
7. Construction of time schedules and flight studies based on technical parameters recorded by the on-board control and measurement system in various flight modes (stationary, VTOL and VTOL-aircraft) of the UAV.

8. Study of observation methods carried out by UAV, evaluation and optimization of observation.

Research methods. In the process of carrying out the dissertation work, the issues set for the purpose of research were solved theoretically and experimentally - by using the onboard control measurement system developed for the purpose of monitoring and applying the power circuit of a VTOL micro UAV, practical engine operations of the UAV in various flight conditions and data obtained from flights, as well as the application of the "scale-mass" method applied to determine the center of gravity, and by using a computer model and simulation of the aerodynamic characteristics of the glider using standard laboratory equipment and special software.

The research work was carried out both in laboratory conditions with devices and equipment equipped with modern control and measurement systems, and in real flights, and the scientific results obtained were evaluated using mathematical-statistical and graphical-analytical interpretation of research data. A methodology for performing a test flight to diagnostically check and assess the condition of the aircraft engines is given.

The issues raised in the dissertation were solved theoretically and experimentally using the methods of measure and similarity theory, and the results obtained in the laboratory and in real flights were processed with a mathematical model based on the use of computer technology.

The main provisions for defence:

1. In order to ensure the long-term operation of UAVs and portable electronic devices, a comprehensive comparative analysis of the operational characteristics and technical characteristics (energy capacities per specific weight and volume) of accumulator batteries (AB) and fuel cells and the selection of energy sources that ensure the long-term operation of such devices; the characteristics of the use of LIAB and LPAB as energy sources in UAVs and devices requiring high current and power, as well as the reasons for the low use of fuel cells and hydrogen-powered internal combustion engines (ICEs) as the main energy source in UAVs;

2. Research of VTOL-type UAV as a UAV incorporating

hybrid energy sources and hybrid propulsion systems, use of an electric generator in combination with AB, fuel cell (FC), as well as internal combustion engines as an energy source in a VTOL-type UAV with a brushless electric motor, features of developing hybrid energy sources and hybrid propulsion systems based on them;

3. Development of a conceptual scheme of a VTOL-type micro UAV based on the elements and calculated parameters that make up a hybrid aircraft prepared based on various schemes;

4. Selection of an aerodynamic profile that provides vertical and horizontal flight, combining the flight-technical characteristics of an airplane and a helicopter, determination of the optimized aerodynamic characteristics of the aircraft by computer modeling of a VTOL type UAV with a fixed "flying wing" glider structure based on the "SolidWorks", "ANSYS", "Profili" and "Xflir5" application programs and design of the aircraft based on these results;

5. Structural design of a VTOL type UAV, selection of its components with their designation, determination of their locations, justification of the effect of the selected elements on the aerodynamic characteristics of the UAV with theoretical and experimental knowledge and development of a functional block diagram of the electrical circuit;

6. Development of a method and measurement methodology for determining the center of gravity of the aircraft with higher accuracy, presentation of a model for constructing the proposed system. Conducting theoretical and experimental studies performed to determine the weight and center of gravity of the UAV and analyzing their results;

7. Development of a device that automatically determines the poles during battery charging;

8. Creation of an on-board control measurement system for recording the technical parameters of each engine of a VTOL-type UAV, the power circuit of which consists of four lifting and one traction collectorless electric motor, during flight, flight evaluation and comprehensive diagnostics of aviation equipment after the flight, and a comprehensive approach to preventing the recurrence of the emergency situation in subsequent flights. Conducting experimental

studies in stationary (laboratory) and real flight in various flight modes using the created system;

9. The main points that must be taken into account during the constructive placement of elements in a VTOL-type UAV:

- In the VTOL hybrid UAV, the equilibrium conditions were met during the constructive placement of the elements, the aerodynamic and electromagnetic compatibility requirements were met. The static and dynamic equilibrium conditions were met by evenly distributing the mass and forces relative to the center of gravity of the glider;

- in order to meet the aerodynamic requirements, the protrusions on the surface of the glider that create counter-aerodynamic forces were reduced as much as possible, radio-electronic devices with sharply different operating frequencies were used to protect against the noise effects of electromagnetic waves, and sensitive and power devices were placed at a certain distance and position. The insulation layer was made of electrical wires that are resistant to both high temperatures and mechanical effects;

- The coordinates of the location of the control and navigation devices relative to the center of gravity of the aircraft were taken into account in the program written to the control unit. The orientation diagrams of the antennas of the radio-electronic devices were directed as much as possible in the direction of the communication channel. The manufacture of the RC receiver from a radio-transparent composite material allowed it to be placed inside the fuselage;

- To ensure the correct positioning and stable flight of the VTOL type UAV in the air, the flight controller (accelerometer, gyroscope) is placed at the center of gravity of the aircraft;

- In order to prevent the observation camera installed on the UAV from blocking the viewing sector and the blades from being close to the ground surface, 4 brushless electric motors providing vertical flight are placed at the ends of the tube structurally attached to the upper part of the wings of the VTOL type UAV;

- The power unit included in the power supply of the “Pixhawk” flight controller microprocessor kit only provides the flight

controllers with the required voltage and current. The issue of providing the required power to other devices connected to the flight controller (servo mechanisms, stabilizer of the observation camera, etc.) was solved by placing 2 additional 24V DC - 5V DC voltage inverters in the aircraft;

- in order to prevent the aircraft from adversely affecting its aerodynamic properties during flight (reverse drag force), the global positioning system (GPS) antenna is placed on the surface of the UAV structure;

- the manufacture of the glider from composite material leads to the placement of the radio receiving and transmitting antenna inside the fuselage of the UAV and the low surface reflectivity, as well as its weight. This greatly reduces the probability of detection of the aircraft by radar systems (ARS);

- the use of electric motors as lifting and traction motors in the aircraft reduces the probability of detection of the UAV by acoustic detection and ARS means;

- the manufacture in white color reduces the probability of detection of the aircraft by visual detection means;

- when placing the accumulator battery in the fuselage of the aircraft, the condition of weight distribution around the center of gravity was met;

- in order to meet the requirements of the system's strength and stability, the arms connecting the lifting motors in the UAV design were placed close to the fuselage of the glider.

The scientific novelty of the research consists of the following:

1. An on-board control and measurement system has been created to monitor the technical parameters of the micro UAV engines and telemetric indicators of the aircraft's flight, as well as to comprehensively collect information about these parameters ^{6,7};

⁷Pashayev A.M. Research of a vertical takeoff and landing micro UAV in the plane mode with the onboard control - measurement system / A.M.Pashayev, R.N.Nabiyev, A.A.Abdullayev [et. al] // Tuijin Jishu/Journal of Propulsion Technology. - 2025, ISSN 1001-4055, Vol. 46(1), -p. 870-878.

2. By means of the created onboard control and measurement system, the technical parameters of the aircraft before, during and after the flight are recorded in a comprehensive manner (İ1...İ5 - current consumed by the engines, T1...T5 - engine temperatures, RPM1...RPM5 - number of revolutions per minute, A1...A3 - accelerometer readings, G1...G3 - gyroscope readings) and online control, as well as diagnostics of the aircraft's power systems ⁸.

3. A device that automatically determines the polarity during battery charging for safe charging of UAVs and other electronic devices has been developed ⁹;

4. The mass-energy dependence parameters of the power source have been determined and at the same time the parameters serving to increase the flight duration have been optimized ¹⁰;

5. The conceptual scheme of a VTOL type UAV with a hybrid power source based on the “flying wing” profile has been developed, its design and main technical and aerodynamic parameters have been studied ¹¹;

6. A hybrid power source (HPS) has been developed to ensure long-term flight of a VTOL type UAV ¹².

7. A methodology for classifying and evaluating observation methods with UAVs has been developed, as well as its optimization has been carried out ^{13, 14};

8. A methodology for determining the center of gravity of a VTOL type micro UAV using the “balance-mass” method has been developed ¹⁵.

Theoretical and practical significance of the research:

1. The developed VTOL micro UAV is suitable for civil (scientific research, conducting aerial electron-optical (EO) surveillance of the territory, monitoring the situation during emergencies, monitoring the safety of oil and gas pipelines,

⁸Nəbiyev, R.N. Kiçik ölçülü konvertoplan tipli pilotsuz uçuş aparatları üçün bort nəzarət-ölçü sistemi / R.N.Nəbiyev, A.A. Abdullayev, Q.İ.Qarayev [və b.] // Milli Aviasiya Akademiyasının Elmi Məcmuələri, - Bakı: - 2023, №4, cild 25, - s. 1-12.

⁹Paşayev, A.M. Akkumulyatorun doldurulması zamanı qütbləri özü təyin edən qurğu, Patent (İxtira) İ 2022 0034, Azərbaycan Respublikası / Nəbiyev R.N., Qarayev Q.İ., Abdullayev A.A.

identifying oil leaks at sea and on land, in the film and TV advertising shooting industry, in agriculture, monitoring the condition of crop and livestock farms, cargo delivery, in the geology and archaeology industry) and military purposes (conducting reconnaissance with day-night and thermal EO cameras from the air, dropping "conditional loads", directing guided (laser and GPS-guided) rocket-bombs to the target, etc.);

2. On-board control and measurement system created for micro UAVs. Through the system, it is possible to record the main technical parameters of the engines of the unmanned micro UAV in various flight modes (the number of revolutions of each engine, current consumption and temperature) and data determining the position of the glider in space (the angular change and acceleration of the glider along the three coordinate axes). Based on the recorded parameters, it is possible to conduct a diagnostic check of the aircraft and assess its technical condition, as well as study the takeoff, hover, flight and landing modes.

3. The on-board control and measurement system created for micro UAVs allows for full online control of technical parameters, which allows for operational decision-making by recording changes in the situation on board during the flight. Also, a methodology has been developed for diagnosing the engine operation of micro UAVs before and during the flight.

4. A methodology has been developed for determining the center of gravity of a VTOL micro UAV using the "scale-mass" method. It was noted that if additional engineering or design work is carried out on an aircraft with a determined CG, it is advisable to re-measure the distance between the supports and the weights falling on the supports, recalculate and refine the coordinates of the CG.

5. In order to increase the reliability of safe charging of UAV batteries, a device has been developed that automatically determines the polarity during battery charging.

6. Small-sized (mini, micro, nano) UAVs, means of combating them and their detection characteristics have been extensively studied. It has been shown that the low surface reflectance and noise of small-sized UAVs equipped with brushless electric motors and

made of composite materials, their small overall dimensions, and their white or light blue color lead to their low detection by radar systems, visual and acoustic detection means.

7. Evaluation and optimization when observing with UAVs;

8. The dissertation is a scientific work with sufficient scientific capacity and technological information in the direction of UAVs, their development trends, classification, constructive design, design, power sources, and application areas. The dissertation work can be useful for students and teachers studying at bachelor's, master's and doctoral levels of higher education institutions, as well as specialists working in the relevant areas.

Personal participation of the author. The results obtained in the dissertation were confirmed by the research conducted by the author. The formulation of the issues, conducting experiments, and systematization were carried out.

Approbation and application of the research. The scientific results obtained in the dissertation were reported and discussed at the following international, republican, and intra-university conferences:

1) “Azerbaijan in the International Transport System: Goals and Perspectives”. International Scientific-Practical Conference, Baku Engineering University, Baku, Azerbaijan, 02-05 October 2018;

2) “Measurement and Quality: Problems, Prospects” International Scientific and Technical Conference, Azerbaijan Technical University, Baku, Azerbaijan, 21-23 November 2018;

3) “Transport of Azerbaijan: Achievements, Problems and Prospects” Republican Scientific Conference. Azerbaijan Technical University, Baku, Azerbaijan 16-17 April 2019;

¹⁰ Nəbiyev, R.N. Litium əsaslı akkumulyator batareyalarının inkişaf mərhələləri / R.N.Nəbiyev, A.A.Abdullayev, Q.İ.Qarayev // Azərbaycan Mühəndislik Akademiyasının Xəbərləri, - Bakı:- 2019, cild 11, №4, -s. 70-81.

¹¹ Абдуллаев, А.А. Тəбиқи proqramlar əsasında konvertoplan tipli pilotsuz uçan aparatın planerinin kompüter modelləşdirilməsi // Azərbaycan Mühəndislik Akademiyasının Xəbərləri, – Bakı: – 2022, cild 14, №2, – s. 95-106.

¹² Abdullayev, A.A. Konvertoplan tipli hibrid pilotsuz uçuş aparat üçün hibrid əsaslı enerji mənbələrinin və hərəkətverici sistemlərin seçilməsi // Azərbaycan Milli Aerokosmik Agentliyin xəbərlər jurnalı, – Bakı: – 2022, cild 25, №1, – s. 47-55.

4) 1st International Conference: Modern Information, Measurement and Control Systems: Problems and Perspectives (MIMCS'2019), Azerbaijan State Oil and Industry University, Baku, Azerbaijan, 01-02 July 2019;

5) Tokyo summit 4th International Conference on Innovative Studies of Contemporary Sciences. Tokyo, Japan, July 29-31.2021;

6) 4th International New York conference on evolving trends in interdisciplinary research & practices. Manhattan, New York City, May 2-4, 2021;

7) II International Baku scientific research conference. Odlar Yurdu University, Baku, Azerbaijan, 28-30 april 2021;

8) Proceedings of the 2nd International Scientific and Practical Conference. Concepts for the development of society's scientific potential., Prague, Czech Republic, Scientific Collection "Inter-Conf+", 19-20.05.2022;

9) Proceedings of the 6th International Scientific and Practical Conference «Current issues and prospects for the Development of Scientific Research». Orleans, France, Scientific Collection «Inter-Conf+». № 26(129), 19-20.10. 2022;

10) National Defense University of the Ministry of Defense of the Republic of Azerbaijan. "Actual Problems of Military Art". International Scientific and Practical Conference dedicated to the 100th anniversary of the birth of the national leader Heydar Aliyev, Baku, Azerbaijan, May 3-4, 2023;

11) "February Reports 2021: Creative Potential of Youth in Solving Aerospace Issues" IX International Scientific and Practical Youth Conference. Baku, National Aviation Academy, February Reports, February 8-10, 2024;

¹³ Nəbiyev, R.N., Abdullayev, A.A. Pilotsuz uçuş aparatlar ilə elektron-optik müşahidənin aparılması və tətbiq imkanlarının optimallaşdırılması // Milli Aviasiya Akademiyasının Elmi Məcmuələri, – Bakı: – 2025, №1, cild 27, – s. 1-13.

¹⁴ Набиев, Р.Н., Абдуллаев, А.А. Методы поиска при наблюдении за стратегическими объектами с использованием беспилотных летательных аппаратов // Естественные и технические науки. – Москва: –2025. №4 (203), –с. 258-268.

¹⁵Nəbiyev,R.N. Konvertoplan tipli pilotsuz uçan aparatın ağırlıq mərkəzinin müəyyən edilməsi / R.N.Nəbiyev, A.A.Abdullayev, Q.İ.Qarayev [və b.] // Milli Aviasiya Akademiyası Elmi Məcmuələr, – Bakı: – 2022. №4, cild 24, – s. 1-8.

12) ISUDEF-24 International Scientific and Practical Conference, National Aviation Academy, Azerbaijan, Baku, May 22-23, 2024;

13) E3S Web of Conference. International Scientific Conference Energy Management of Municipal Facilities and Environmental Technologies (EMMFT-2024).

14) Artificial Intelligence: From Theory to Practice I International Conference (AICON-2024), Nakhchivan, Azerbaijan, September 17-18, 2024;

15) Proceedings of the 11 th International Scientific and Practical Conference «Theory and practice of science: key aspects». Roma, İtaliya, Scientific Collection «InterConf+», № 56(244), 19-20.04.2025;

16) Proceedings of the XVI International Scientific and Practical Conference, World of conferences (WOC), Viana, Avstriya, 03-04.04.2025.

The results have been widely used in the teaching process of relevant subjects taught to students of the NAA and cadets of higher military schools studying avionics and flight equipment.

Publication of the work. Based on the results of the research conducted on the topic of the dissertation, 52 works have been published. Of these, 34 are scientific journal articles, 16 are materials of international scientific-practical and scientific-technical conferences of various levels, 2 is an authorship (patent-invention) certificate.

Organization where the dissertation work was performed: The dissertation work was performed at the Scientific-Research Aviation Institute of the Azerbaijan NAA, in the “Aviation Electronics” department and the “Aerospace Devices” department of the Academy.

The total volume of the dissertation is indicated by the mark, with the volume of the structural sections of the dissertation separately indicated. The dissertation work was written in accordance with the requirements set by the Higher Attestation Commission under the President of the Republic of Azerbaijan.

The dissertation work is placed on 354 pages in total. The dissertation work consists of an introduction, six chapters, including

84 figures, 24 graphics, 19 tables, a conclusion, a list of 380 references, a list of abbreviations and symbols. The volume of the dissertation work (excluding gaps in the text and figures, graphics, tables, appendices and a list of references) is 428876 (introduction – 29887, chapter I – 136333, chapter II – 92175, chapter III – 40845, chapter IV – 32583, chapter V – 40643, chapter VI – 52587, conclusion – 3819 symbols).

The applicant expresses his deep gratitude to his scientific advisor, “Honored Engineer” Doctor of Technical Sciences, professor R. Nabiyeu, Head of the “Aviation Electronics” Department at the Scientific Research Aviation Institute of the Azerbaijan NAA, for his valuable advice and recommendations in setting the scientific problems contained in the dissertation, in the formation of the obtained scientific results, and in their discussion, for his constant attention, and for the presentation of the work for defense at a level in accordance with modern requirements.

The author also expresses his sincere gratitude to the leadership of the Azerbaijan National Aviation Academy and the employees of the “Aviation Electronics” Department at the Scientific Research Aviation Institute for the working conditions created in the implementation of the work, and for the technical and moral support they provided.

MAIN CONTENT OF THE DISSERTATION

The introduction substantiates the relevance of the topic, lists the goals and objectives of the research, research methods, the main provisions put forward for defense, the scientific novelty of the research, the theoretical and practical significance of the research, its approval and briefly explains the content of the dissertation.

Chapter One. In this chapter, the stages of development of UAVs (multirotation and glider type), factors that drive their development, their production technologies, requirements for their design and construction (having a large payload and a modern autopilot system), mathematical model of their movement, areas of application and factors that drive the development of this direction in our country are analyzed and modern aspects of its development are

determined, as well as an analysis of information obtained from modern scientific literature and electronic sources on the study of UAV systems¹⁶⁻¹⁸.

The fact that the new generation of multirotation, as well as hybrid-based UAVs, designed with the application of high technologies, has fully automated control has led to the expansion of their use in the service activities of power and non-power structures. Also, this chapter extensively studies the working principles of each element that will make up the automatic control systems of UAVs and the existing flight modes.

The mathematical foundations of the control of multirotation-based quadcopter-type UAVs, the mathematical model of the quadcopter, the dynamic feedback method, controlled surface systems, the establishment of dynamic feedback, the solution of linear control and stabilization issues, as well as the results of digital modeling have been studied and investigated.

The development trends of VTOL-type UAVs and the main requirements for the development of this type of aircraft in the modern era have been determined.

Classification of UAV systems. A broad classification has been carried out by dividing UAVs into various subsystems based on tactical and technical indicators, such as take-off weight, flight duration and flight altitude, operational range (control at maximum distance from the UAV, autonomous flight range), the nature of the task performed (“monotonous”, “toxic”, “dangerous”), energy source and propulsion systems^{1, 2, 19}.

High operating altitude is considered the main flight characteristic for UAVs in order to ensure secrecy, conduct electronic

¹⁶Nəbiyev, R.N., Abdullayev, A.A. Multikopter tipli pilotsuz uçuş aparatlarının inkişaf mərhələləri, konstruksiyası və lahiyələndirilməsi problemləri // – Bakı: MAA-nın Elmi Əsərləri, –2016, №2, –s. 15-29.

¹⁷Набиев, Р.Н., Абдуллаев, А.А. Этапы развития, конструкция и проблемы проектирование БПЛА типа мультикоптер // Milli Aviasiya Akademiyasının Elmi Məcmuələri. – Bakı: – 2016, №4, cild 18, – s. 10-17.

¹⁸Набиев, Р.Н. Требования к беспилотным летательным аппаратам на мультиротационной основе / Р.Н. Набиев, Гараев Г.И., Абдуллаев А.А. [и др.] // Авиакосмическое приборостроение, - Москва:- 2018, № 9, - с. 3-11.

optical reconnaissance over a large area, as well as make detection difficult. In particular, when flying at high altitudes, UAVs with internal combustion engine-type propulsion systems generate low acoustic noise and temperature correlation. These effects also reduce the probability of detection of these types of UAVs by radar^{20, 21}.

VTOL-type UAVs. VTOL-type UAVs, which have different configurations due to their aerodynamic characteristics, are characterized by two sharply different flight modes. As a hybrid aircraft, the VTOL-type UAV combines the features of taking off and landing vertically and hovering in the air using the helicopter's rotor blades, as well as ensuring flight along the required trajectory and horizontal flight due to the aerodynamic force generated at the speed provided by the aircraft's thrust engine, a fixed-wing UAV with lifting force²²⁻²⁴.

Advantages include:

- faster and longer range than helicopters;
- allows vertical take-off and landing from a limited area compared to airplanes, which allows for greater efficiency when suspended in the air;
- unlike fixed-wing UAVs, rotary-wing or rotorcraft UAVs, which have a lower wing load, are less sensitive to air turbulence.

Disadvantages of VTOL-type UAVs:

- the complexity of performing an emergency landing in the event of engine failure;
- the large load on the engines in the suspended mode;
- has lower performance compared to glider-type aircraft in terms of speed and long-range flight;
- loss of efficiency of the propellers providing lift during horizontal flight;

¹⁹Набиев, Р.Н., Абдуллаев, А.А. Обзор этапов развития, конструкций и проблем проектирования БПЛА типа мультикоптер // Современная наука: актуальные проблемы теории и практики. Серия Естественные и технические науки, – Москва: – 2017, №3-4. – с. 16-21.

²⁰ Nabiyev, R.N. Structural drafting of conver-tiplane-type unmanned aerial vehicle / R.N.Nabiyev, A.A.Abdullayev, Q.I.Qarayev // Norwegian Journal of development of the International Science, – 2022, №94, – p. 45-51.

- the weight of the structure (engine rotation mechanism);
- the low efficiency.

Also, in Chapter I, the issues of combating UAVs, means and methods of combating them, as well as the difficulties of combating UAVs, were thoroughly studied ¹.

The second chapter is methodological and practical in nature. Here, information on the operational properties, technical characteristics (energy capacities per specific weight and volume) of batteries and fuel cells (FCs) is comparatively analyzed, and information is provided on energy sources that ensure long-term operation of UAVs, as well as portable electronic devices and devices used in various fields of human activity ²⁵⁻²⁷.

The disadvantages of lithium-based batteries as an energy source include:

- their tendency to wear out when not used;
- the fact that the wear process begins not from the date of commissioning, but from the date of manufacture;
- their high price compared to other types of batteries;
- Lithium-polymer batteries are sensitive to mechanical damage, overload and temperature changes, as well as the possibility of ignition due to short circuits.

Also, deep discharge causes a decrease in the capacity of batteries (electrolyte oxidation), an increase in their internal resistance, and prevents the full accumulation of energy during recharging.

If this situation is repeated several times, the battery becomes completely unusable after 2-3 years ^{9, 28}.

²¹ Nəbiyev, R.N., Abdullayev, A.A. Müasir innovasiyaların tətbiqi ilə hazırlanması planlaşdırılan multikopter tipli PUA-lara qoyulan tələblər // Bakı Mühəndislik Universiteti, “Azərbaycan Beynəlxalq nəqliyyat sistemində: hədəflər və perspektivlər” mövzusunda Beinəlxalq elmi-praktiki konfrans. – Bakı: – 02-05 oktyabr, – 2018, – s. 176-180.

²²Nəbiyev, R.N., Abdullayev, A.A. Konvertoplan tipli pilotsuz uçuş aparatlar haqqında: Cari vəziyyət və perspektivlər // MAA-nın Elmi Məcmuələri, - Bakı: - 2020, №3-4, cild 22, - s.14-26.

²³Абдуллаев, А.А. Тенденция развития беспилотных летательных аппаратов конвертопланового типа // Тенденции развития науки и образования, Научный журнал, – Самара: – 2020, №63/07, часть 1, – с. 84-90.

The main characteristics and application areas of lithium-based batteries. In this type of batteries, the energy capacity varies between 100÷180 Wh/kg or 250÷400 Wh/liter, the voltage is 3.6÷4.2 V, the lower limit of the discharge voltage is 2.5÷2 V and the operating temperature range is (-20...+60) °C. In small-sized batteries, the discharge current value is 2 C, and in powerful batteries, this value is approximately 10÷20 C.

Many manufacturers have developed ABs operating at minus 40 °C. The self-discharge of lithium-based batteries is 4-6% in the first month, and in subsequent months this rate decreases significantly, reaching 10-20% per year. Compared to other AAs of the same size, lithium-based batteries have 20-30% more energy capacity, less “memory effect”, and the ability to charge at any time without waiting for a full discharge. Due to their multiple operation characteristics, lithium-based batteries are “ordinary” and “quick-discharge”. The former are used in places where a small current is required (in mobile phones, laptops, etc.), and the latter are used in places where a large current is required (in UAVs, hybrid cars, etc.)²⁹.

Directions for the application of hydrogen in aviation. The engines used in UAVs are divided into the following types according to the principle of operation: battery-powered (AB), fuel cell (YE), internal combustion engines (ICE) and hybrid (AB- ICE, AB-YE, hydrogen-based ICE). Battery-powered UAVs have low noise and an average flight time of 2-3 hours. When using UAVs with a ICE,

²⁴ Nəbiyev, R.N., Abdullayev, A.A., Qarayev, Q.İ. Pilotsuz uçuş aparatlarında hidrogen əsaslı yanacaq elementlərindən istifadənin xüsusiyyətləri // Azərbaycan Dövlət Neft və Sənaye Universiteti. 1st International Conference: Modern Information, Measurement and Control Systems: Problems and Perspectives (MIMCS' 2019), – Bakı: – 01-02 July, 2019, – p. 212.

²⁵ Nəbiyev, R.N., Abdullayev, A.A. Litium-polimer əsaslı akkumulyator batareyaları // AzTU, “Azərbaycanın nəqliyyatı: nailiyyətlər, problemlər və perspektivlər” mövzusunda Respublika Elmi konfransı. -Bakı: -16-17 aprel, -2019, - s. 103-106.

²⁶ Nəbiyev, R.N., Abdullayev, A.A. Akkumulyator batareyaları və yanacaq elementləri // AzTU, “Ölçmə və keyfiyyət: problemlər, perspektivlər” mövzusunda Beynəlxalq Elmi-texniki konfransı.– Bakı: - 21-23 noyabr, - 2018, - s. 235-237.

²⁷ Nəbiyev, R.N. Enerji mənbəyi qismində hidrogenin xüsusiyyətlərinin təhlili / R.N.Nəbiyev, A.A.Abdullayev, Q.İ.Qarayev // MAA -nın Elmi Məcmuələri, - Bakı: - 2019, cild 21, №4, - s. 16-30.

these indicators increase, resulting in an increase in the probability of safe flight (detection), etc., due to the weight of the aircraft, wing length, noise generated and heat released.

For this reason, the use of hybrid or ICE -type power sources in UAVs weighing up to 10-15 kg is not common. The technical characteristics of different types of power sources (AB, internal combustion, hybrid and fuel cell) have been compared. It has been established that the fuel cell has a higher efficiency and specific energy capacity per weight than other types of power sources^{30, 31}.

Factors limiting the use of hydrogen-based energy sources: the very slow oxidation reaction of the fuel at room temperature; the low power of the energy obtained per unit time; the large size of the device; the reaction that produces energy occurs at high temperatures; requires the use of an expensive catalyst at low temperatures; the low specific energy density relative to volume; the toxicity of some fuels (methanol alcohol);

Their price is directly dependent on the processing and production technology; the high cost of the fuel cell and the cost of the energy received; part of the energy received is spent on converting the fuel from a liquid state to a gas; the complexity of using a polymer electrolyte; their dangerous operation³⁰.

Selection and justification of an energy source for ensuring long-term flight in UAVs. Methane (or propane) is stored in a liquid state (at a temperature of minus 164 °C) and has a specific energy density of 9.2 kWh/kg.

The energy density of methanol in its compressed liquid state (given its weight in a composite cylinder) is approximately 1 kWh/kg higher than the energy density of other gases.

The technical characteristics of different types of power sources are compared in Table 1.

²⁸Abdullayev, A.A. Akkumulyator batareyaları və yanacaq elementləri // Azərbaycan Milli Aerokosmik Agentliyin xəbərlər jurnalı, - Bakı: – 2021, cild 24, №3, –s. 61-69.

²⁹Набиев, Р.Н. Анализ особенностей водорода в качестве источника энергии / Р.Н.Набиев, А.А.Абдуллаев, Г.И. Гараев // Авиакосмическое приборостроение, – Москва: – 2021, № 3, – с. 41-58.

In general, as a result of the comparative analysis, it can be noted that increasing the service life of AB has led to the expansion of their application in portable electronic devices.

The results of the analysis show that the energy capacity parameters of LIAB and LPAB are higher in relation to weight and volume ²⁸.

Table 1.

Technical specifications of various types of batteries

S/s	Parameters	LAB	NMHAB	NCAB	NHAB	LIAB	LPAB
1	Nominal voltage, V.	2,1	1,25	1,2	1,25	3,6	2,7
2	Specific energy capacity by weight, W*h/kg	30÷60	60÷75	40÷45	50÷55	130	150÷200
3	Specific energy capacity by volume, W*h/dm ³	-	180÷200	80÷100	100÷120	260	250÷350
4	Self-discharge, % (monthly)	5	30	20	-	10	~10
5	Maximum required pressure, mPa	-	0,15	0,15	12	-	-
6	Energy capacity consumption, %	98	96-98	72	90-92	98	98
7	Service life, years/ filling-discharging	5/650	5/500	5/500	7/1000	5/500	5/500

A device that automatically determines the polarity during battery charging. At the end of the chapter, a developed device that automatically determines the polarity during battery charging is presented.

Thus, it is shown that the design architecture of the device consists of five resistors, two rectifier diodes, six optotransistors and two bipolar transistors of the same type.

³⁰Abdullayev, A.A. Accumulator batteries and fuel elements // – Japan. Tokyo summit 4th International Conference on Innovative Studies of Contemporary Sciences. Tokyo, – july 29-31, – 2021, – p. 187-197.

³¹ Nabiyev R.N., Abdullayev A.A. Creation of convertible-type unmanned aerial vehicles // 4th International New York conference on evolving trends in interdisciplinary research & practices.– Manhattan, New York City. - May 2-4, 2021, – p. 504-513.

The features of the circuit that are different from other similar ones are shown: the circuit uses three resistors, two rectifier diodes, four optotransistors and four bipolar transistors of two types, two of one type and two of another, and these transistors are connected in two branches with two transistors of the opposite type connected in parallel with the emitter-base junctions in each branch. It is noted that the polarity of the battery is determined by the collector circuits of the transistors, and the polarity of the mains voltage is determined by the base circuits of the transistors ⁹.

The device that automatically determines the polarity during battery charging can be used for safe charging of power sources. The device consists of a step-down transformer of the mains voltage, two controlled rectifier bridge circuits and a control circuit.

The rectifier bridge circuits are assembled on the basis of thyristors. The control circuit includes a control circuit of thyristors assembled on the basis of optotransistors and a circuit that automatically determines the polarity of the battery, as well as the mains voltage, assembled on the basis of four transistors.

The device is connected to an industrial frequency network and ensures safe charging of batteries regardless of the direction of connection of their poles. As a technical result, it is possible to note an increase in the reliability of safe charging of batteries.

The structural diagram of the charging device that automatically determines the polarity of the battery is given in figure 1.

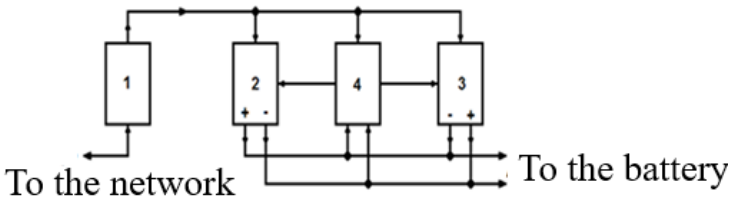


Figure 1. Structural diagram of a charging device that automatically determines the polarity of the battery

The device consists of a step-down transformer of the mains voltage 1, two controlled rectifier bridge circuits 2, 3 and a control circuit 4.

The scheme works as follows: - transformer 1 reduces the value of the mains voltage to the level required to charge the battery.

Depending on the direction of connection of the battery, the control circuit 4 selects one of the two controlled rectifier bridge circuits 2, 3 and, depending on the polarity of the mains voltage, controls the thyristors in the branches of the selected controlled rectifier bridge circuit.

The inputs of the controlled rectifier bridge circuits 2, 3 are connected in parallel, and the outputs are connected in anti-parallel.

The selected rectifier operates during the charging process.

Chapter Three. This chapter studies the power supply of a VTOL UAV with a hybrid power source and a hybrid propulsion system for flight.

The use of a battery, fuel cell, and an electric generator in combination with an internal combustion engine as an energy source in a VTOL UAV with a brushless electric motor, the features of the development of a hybrid power source and hybrid propulsion system based on these, as well as the issues of ensuring long-term flight of a VTOL UAV, were considered.

Scientific research conducted in this direction analyzed the structural schemes of power systems consisting of series, parallel, and series-parallel connections of hybrid power sources and hybrid propulsion systems.

As a result of the analysis, a matrix consisting of a fuel cell, a battery (AB), and an internal combustion engine-generator type hybrid energy sources was constructed and their optimal connection schemes were determined.

When using four hybrid propulsion propeller-motor units (PMU) in the lifting system of a VTOL-type UAV, the system becomes more complex and its weight becomes relatively heavy. In a VTOL-type UAV weighing more than 15 kg, it is possible to ensure long-term vertical flight or hovering by using four brushless electric motors as lifting engines and one ICE as a traction engine. During

the flight, it is possible to recharge the AB using the generator function of the internal combustion engine^{3, 32}.

The selection of elements constituting the hybrid power system of the designed VTOL-type UAV, as well as a preliminary assessment of the take-off weight based on the thrust of the lifting and repulsive engines, was carried out. Based on the elements constituting the hybrid aircraft prepared on the basis of various schemes and the calculated parameters, a conceptual block diagram of the VTOL-type UAV was developed. A conceptual functional diagram of the VTOL-type UAV with a hybrid energy source was developed.

The development of aircraft directly depends on the energy supply of the glider and the ratio of the mass, power and propulsion systems to the overall dimensions, the aerodynamic characteristics of the wing, as well as the aerodynamic quality coefficient of the wing of the aircraft.

The energy consumed during flight depends on the shape of the glider chosen for the aircraft and the angle of attack, which is a quantity that indicates how many times the lift coefficient created by the wing is greater than the drag coefficient, and during design, it is required to use a structure that allows the aircraft to save energy during flight. Also, when designing aircraft, it is necessary to take into account the aerodynamic characteristics of the wings and solve the issues of stability regulation.

In recent years, the production of small-sized ("nano", "micro" and "mini") gliders (aircraft), helicopters, multicopters and VTOL UAVs using brushless electric motors as power units and a battery as a power source has been rapidly developing. The production and operating costs of such aircraft are significantly lower than those of medium and large-sized UAVs, and to ensure their longer flight, hybrid power sources based on two or more different types of power sources are used.

³²Набиев, Р.Н., Абдуллаев, А.А. Исследование основных аэродинамических параметров планера беспилотного летательного аппарата конвертопланового типа // Авиакосмическое приборостроение, – Москва: – 2022, № 4. – с. 17-33.

Compared to internal combustion engines (ICE), UAVs are relatively environmentally friendly, have low noise, heat radiation, etc. advantages, and during their application, the amount of toxic waste released into the environment is reduced, energy consumption efficiency, and ultimately flight efficiency increase.

Although small-sized UAVs have high maneuverability and intelligence characteristics, their flight duration is short. The flight duration with a lithium polymer battery (AB) with a specific energy density of 100 Wh/kg is 20-25 minutes. By connecting an additional AB, it is possible to increase the flight duration to 40 minutes, but in this case the weight of the payload decreases.

Analysis of UAV power systems. (ICE 1 + G) - In the AB type "sequential" connection, the electric motor (EM) is powered by only one source - AB, and AB is charged by a voltage converter operating on the electric energy generated by the generator from the ICE + G system (figure 2).

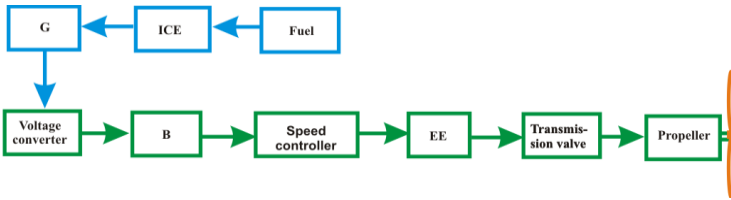


Figure 2. "Series" connection scheme of the hybrid power source (HPS)

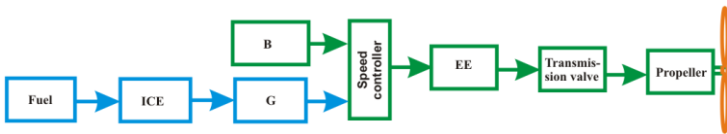


Figure 3. "Parallel" connection scheme of the HPS

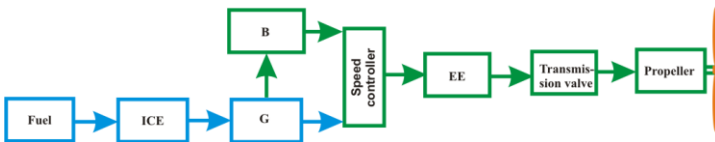


Figure 4. "Mixed" connection scheme of the HPS

The speed controller, which is implemented from the power supply AB, regulates the power transmitted to the collectorless EMs that drive the UAV blades. The advantage of the "sequential" connection is the simplicity of the design, the disadvantage is the use of a complex mechanism to perform the switching process between energy sources. (ICE 1 + G) - In the AB type "parallel" connection, the EM can be powered from two sources at the same time (figure 3). In this case, the main power supply of the EM is carried out through ICE + G, and if this is not enough under heavy loads, the AB is connected to the system "parallel".

The disadvantage of the scheme is the lack of the function of charging the AB from an electric generator ³³.

In the "parallel" connection of the (ICE 1 + G) - AB type, it is possible to eliminate the disadvantages inherent in the previous two connection schemes, while maintaining the advantages of them. In this case, a "mixed" connection is used, and the thrust for long-term flight is created mainly by (ICE 1 + G), while the battery is charged (figure. 4).

In case of heavy loads, the electric motor (EM) is switched on and provides additional thrust. In this case, the power supply of the electric motor can be carried out both from the electric generator and from the battery. This allows for more efficient charging of the battery and the electric generator, regardless of the traction force ³³. If the internal combustion engine and the generator are powered by a fuel cell and a voltage converter, respectively, without the "mixed" connection in figure 4 - using the battery charging from the generator of the internal combustion engine (ICS), the technical characteristics of the system correspond to the scheme shown. In this case, hydrogen is used as the fuel.

Due to the fact that the oxidation-reduction reaction occurs at high temperatures (600...1000 °C), the use of a catalyst made of expensive and rare metals to reduce the temperature to 60-100 °C, as well as the fact that part of the energy received is spent on cooling the system, as well as the high probability of explosion of composite tanks filled with hydrocarbon gas at high pressure, it is not advisable

to use fuel cell-battery-based hybrid energy sources as energy sources in micro and mini-type UAVs.

Analysis of hybrid propulsion systems. The "sequential" and "parallel" connection schemes of the hybrid propulsion system (HPS) of the UAV are characterized mainly by the constructive arrangement of the ICS and the electric motor (EM) (according to figure 5). In the "sequential" connection scheme, the blades are directly attached to the carrier axis, and the torque of the internal combustion engine is transmitted to the carrier axis through a mechanical coupling (figure 5).

In this case, the axes of the internal combustion engine and the electric motor are located in one straight line, the rotor of the EM is assembled on the carrier axis, and its energy supply is carried out from the battery. The EM is connected to the system to provide the required power during heavy loads. In the "parallel" connection scheme of the HPS of the UAV, the torques formed by the ICS and the EM are transmitted to the carrier axis through gears. In this case, the axes of the internal combustion engine and the electric motor are not located in one straight line (figure. 6). In both connections, it is possible to obtain a ICE + G configuration by adding a generator to the ICS circuit and ensure charging of the battery during the flight.

The schemes analyzed above serve one propeller motor group (PMQ). If four lifting PMQs are used in a VTOL-type UAV, the application of the indicated schemes may lead to a complication of the system and an increase in the weight of the UAV. By using four EMs to ensure vertical flight and one ICS to ensure horizontal flight, it is possible to achieve a reduction in the weight of the UAV and an increase in the horizontal flight time.

In order to ensure long-term flight, a constructive generalization of the schemes analyzed in figure 5 and figure 6 was carried out. It is possible to choose the energy capacity of the batteries that supply the EMs of the lifting system with energy so that in the event of failure of the thrust ICS that provides horizontal flight during the flight, the battery is connected to the circuit and a safe landing of the aircraft is ensured. In other words, it is possible to reduce the weight of the

UAV by optimizing the weight of the battery selected for bringing the UAV to a safe area and landing it.

To ensure long-term vertical flight or hovering, intensive charging of the battery during flight may be required. In this case, charging of the battery is performed using a generator (figure 7).

It is also noted that when designing an aircraft, it is necessary to take into account the aerodynamic characteristics of the wings and solve the issues of stability control.

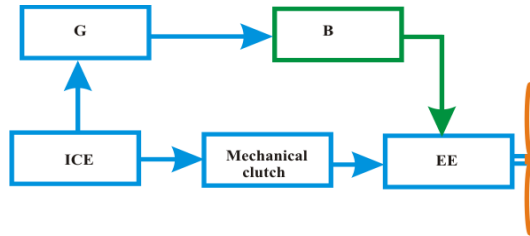


Figure 5. "Sequential" connection of the propulsion system of an ICE - a battery-based hybrid power source

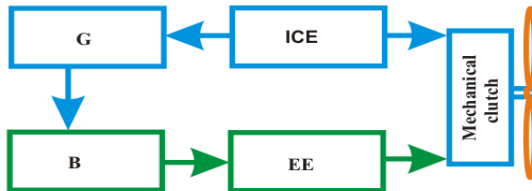


Figure 6. "Parallel" connection of the propulsion system of an ICE - a battery-based hybrid power source

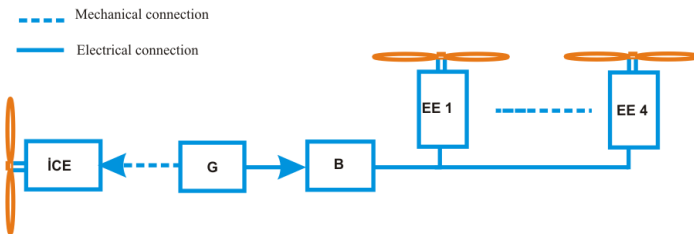


Figure 7. Connection diagram of the propulsion system of a hybrid power source of a planned VTOL UAV

As can be seen from the block diagram, the commands given by the pilot-operator (speed, direction, etc.) are received in real time by the UAV's air data terminal and transmitted to the central flight computer (CFC) (figure 8).

The data received from the navigation system (GPS, accelerometer, gyroscope, pitot tube and barometer) are calculated and summarized in the CFC. The UAV's transition to vertical take-off and landing and horizontal flight modes is controlled by the CFC. To ensure vertical flight, four brushless electric motors are used, the power supply of which is provided by a lithium polymer battery and the number of revolutions of which is regulated by a speed controller.

The speed controllers regulate the lifting force of the electric motors in accordance with the command given by the CFC. The central flight computer controls the thrust of the internal combustion engine, which provides horizontal flight, the operation of the generator, as well as the operating modes of the electric motors, depending on the selected configuration of the hybrid energy source

11

The main aerodynamic parameters of the VTOL-type UAV glider have been studied. The goal here is to determine the optimized aerodynamic characteristics of the aircraft by computer modeling of the VTOL-type UAV, which provides vertical and horizontal flight, combines the flight-technical characteristics of an airplane and a helicopter, has a fixed "flying wing" glider structure, and design the aircraft based on these results.

Meeting the condition of autonomous flight of the UAV is one of the most important and complex solutions. Therefore, the main requirement for the UAVs being designed is to meet the condition of ensuring free flight.

The main autonomy is provided by the flight control processor of the aircraft, inertial navigation, pressure, etc. sensors. If the condition of full autonomy is met, the aircraft is characterized by quickly responding to any scenario and demonstrating the aircraft's resistance to external influences (limitations).

In order to eliminate the problem of providing aircraft-type aircraft with runways, the design and development of aircraft that do

not require runways remains a priority issue for aviation specialists.

The demand for aircraft that take off as helicopters and combine the aerodynamic properties of a glider as an airplane is growing. Due to their complex design, the preparation and operation

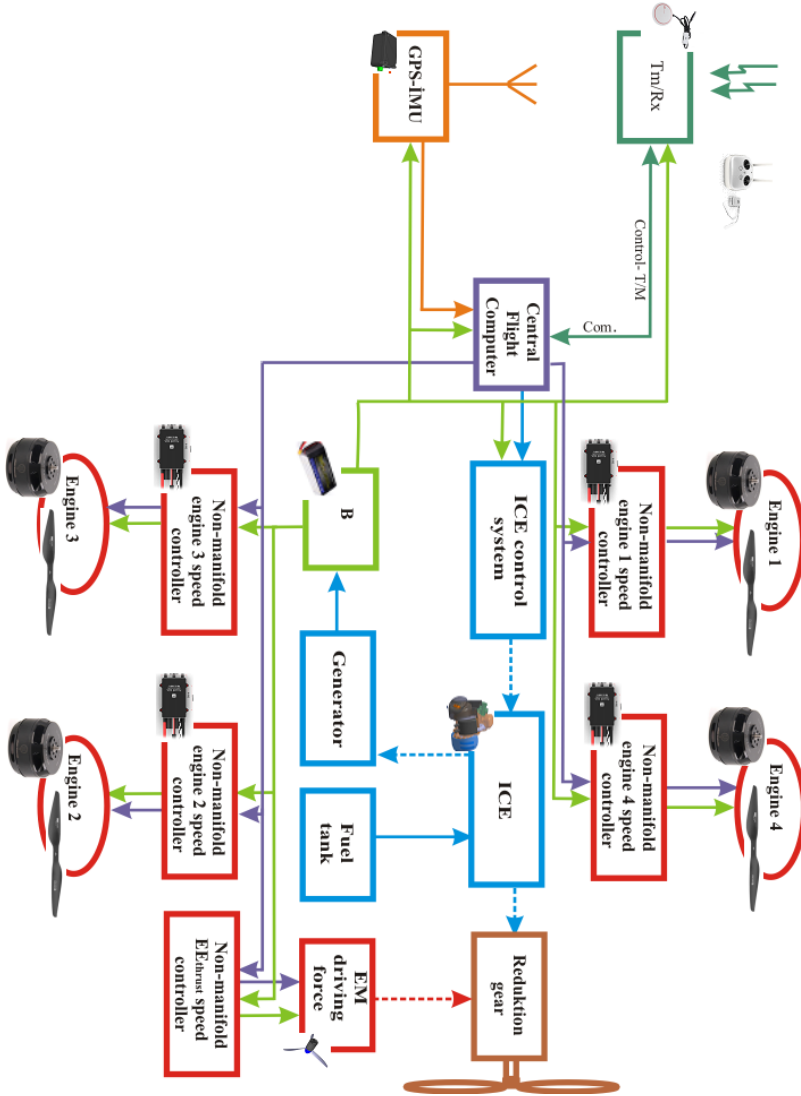


Figure 8. Block diagram of the designed convertible-type hybrid UAV

of this type of UAVs is not simple, and great professional skills are required from the pilot-technical staff during operation.

Thrust and lift engines increase the maneuverability of aircraft. Depending on the position of the engines (vertical, horizontal) and the sequence of operation, both lift and thrust are generated. The lift of the aircraft is generated by the lift engines (parallel to the plane of rotation), and horizontal flight (perpendicular to the plane of rotation) by the thrust engine.

As a result, the aircraft continues to fly in airplane mode. During the reverse process, the aircraft switches to vertical flight (multicopter) mode.

The lift engine creates lift as a result of the differential difference of the rotational moments of the propellers in mutually opposite directions, forward movement as a result of the thrust generated by the thrust engines, and forward flight movement by changing the angles of attack of the ailerons of the aircraft. In the VTOL type UAV, during horizontal flight, it is free from the limitations of helicopters and multi-rotor aircraft (short flight range and low flight speed).

“Flying wing” refers to fixed-wing aircraft, and its structure includes a simple form consisting of a wing, fuselage, and tail section. There are also “flying wing” fixed-wing aircraft models without a separate fuselage. Fuel, batteries, avionics equipment, payload, etc. are mainly structurally placed inside the wing.

The “flying wing” structure also includes handles, suspensions, a cargo compartment, as well as small structural units as vertical and horizontal stabilizers. Design of a “flying wing” glider. Using the “XFLR5” software base, analyses were conducted and the parameters of the “flying wing” profile were calculated.

First, to select the best aerodynamic profile to be used as the “flying wing”, a CFD (computed fluid dynamics) analysis of two different aerodynamic surfaces was conducted and one of the studied wing profiles was selected ¹¹.

For this purpose, the “XFOIL” program database, a subsystem of the “XFLR5” program, was used. The aerodynamic properties of

the aerodynamic surfaces of the “flying wing” were evaluated using the panel code selected from the database.

For the analysis, “S” series aerodynamic surfaces with high aerodynamic surface thicknesses (S5010, $t/c=9.82\%$, S5020, $t/c=8.40\%$) were selected and the Reynolds number was calculated for them in a wide range. “XFLR5” took these poles and, if necessary, interpolated between calculations using different Reynolds numbers, adding a percentage corresponding to the VLM-vortex cage method analysis.

The reason for choosing the S5020 series aerodynamic surface is stated below:

- having a small torsion coefficient ($c/4$);
- the maximum lift coefficient of the wing is $s/4$ orders of magnitude lower than the aerodynamic coefficient of the wing. The lift and drag coefficients increase in the sequence S5010, S5020. The highest value of the angle of attack is approximately 12-13 degrees for S5010. However, a higher lift coefficient is required to provide the lifting power of a VTOL type UAV. The highest value of the angle of attack is recorded at approximately 6-7 degrees for S5020. It allows the glider to fly at a certain angle of attack.

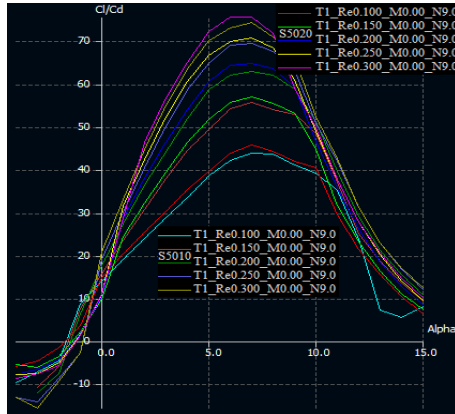
Therefore, it is required to verify the results obtained using the XFLR5 program and the applied solutions as a preliminary model. Nevertheless, the results obtained are sufficient to compare the “flying wing” models.

From the graph depicted in graphic 1, it is clear that the lift coefficients increase and are highest for the wing with a wing configuration of 450 with an angle of attack of 60-120.

To analyze the wing, a one-time sample analysis method is used on the wing.

A mass balance case is provided to determine various aerodynamic properties such as the location of the aircraft's AM, wing lift, force moment coefficient, and drag coefficient. In addition, dynamic stability reports are performed to determine lateral and longitudinal stability.

For this analysis, we have designed four different wing tips (wing tips:- 00, 450, 600, and 900).



Graphic 1. Graphic of the dependence of the coefficient Cl/Cd on the angle of attack

The wingtip provides the lifting force, and in this case a higher lift coefficient is required. A higher drag coefficient at a certain angle of attack ensures that the UAV flies a long distance.

The “prototype” project is now ready. For full modeling, it is possible to conduct various computational tests using the “SolidWorks” and “ANSYS” computer programs and obtain new parameters to further improve the model. For this, the structural design of the UAV was perfectly drawn on the basis of the “SolidWorks” software.

Aerodynamic tests using ANSYS software. The main tasks for conducting aerodynamic tests are as follows: to determine the flow pattern over the “flying wing” profile; to calculate the values of the lift and resistance forces.

To ensure that the aerodynamic design corresponds to the final base configuration, aerodynamic tests were conducted using “ANSYS-Fluent”. To prepare the computer model, an angle of attack of less than 8° is selected.

This was possible by geometrically rotating the UAV around the z axis at an angle of 8° . A suitable aerodynamic and thermal mesh was drawn around the UAV. The mesh was completed using the following parameters ¹¹.

During flight, the pressure distribution across the area of the “flying wing” blades forms a low dynamic pressure field.

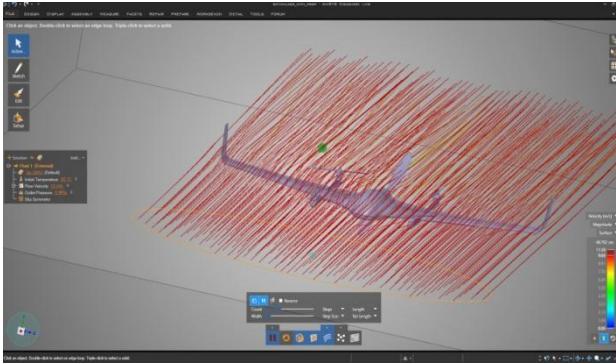


Figure 9. Static pressure for the internal circumferential flow channel a) and pressure along the longitudinal axis and in the fin area b) contours

Figure 9 depicts the velocity distribution in the wing area and the “fuselage” area of the flying wing. Here, the pressure contours (b) along the longitudinal axis and in the wing area are depicted for the internal circumferential flow channel. The velocity in the wing area is almost zero, which leads to a decrease in velocity in two areas. An increase in pressure is observed in this area.

For the velocity profile on the fuselage, it is seen that a large part of the upper surface has a higher velocity than the lower surface. This is sufficient to create lift.

Chapter Four. This chapter is devoted to the structural design of the VTOL-type UAV and the designation of the selected components, and the effect of the selected elements depending on the location on its aerodynamic properties is justified by theoretical and experimental knowledge. Also, in the context of monitoring strategic objects, optimization of the main parameters of the VTOL-type UAV was carried out, and the probability of its detection by visual, acoustic and radar detection means was determined ³³.

³³Nəbiyev, R.N. Konvertoplan tipli pilotsuz uçuş aparatının konstruktiv işlənilməsi / R.N.Nəbiyev, Q.İ.Qarayev, A.A.Abdullayev // Milli Aviasiya Akademiyasının Elmi Məcmuələri, – Bakı: – 2022. №1, cild 24, – s. 1-10.

The functional block diagram of the electrical circuits of the VTOL type UAV, the onboard components included in its structure: power system, architectural design of the fuselage, appearance and location of avionics elements, energy system, functions of control controllers (“FC”), “RC” communication receiver and navigation “GPS” devices, payload (EO camera), “OSD” device providing telemetry data display on the image on the screen, “VideoLink” - (video transmitter), telemetry device “DataLink” for transmitting digital data to a long distance are described and selected^{4, 12}.

In order to increase the efficiency and safety of flights, research works carried out at the design and development stage in the direction of loading, centering and correct location of the center of gravity of aircraft, as well as the characteristics of existing methods and tools were analyzed, and the methodology for using the “scale-mass” method, which is most often used in determining the center of gravity of the UA, was developed on the example of the VTOL type UAV.



Figure 10. A laboratory-prepared workbench for determining the center of gravity of a VTOL UAV

³⁴Nabiyev R.N., Abdullayev A.A. Results of measurements carried out for the purpose of determining the center of gravity of a convertiplane-type UAV // Proceedings of the 6th International Scientific and Practical Conference «Current issues and prospects for the Development of Scientific Research». – Orleans, France. Scientific Collection “InterConf+”. – № 26 (129) October, - 19-20.10. – 2022. -p. 197-202.

The analysis of the mean square deviation and probable error when determining the weight of the prepared VTOL-type UAV and calculating the coordinates of the center of gravity was carried out.

The features of loading the VTOL-type UAV in stationary conditions and using mobile electronic scales to determine the center of gravity were considered. The developed method for determining the center of gravity of the aircraft with higher accuracy was described, and the model of the proposed system was presented.

The results of theoretical and experimental studies carried out to determine the weight and center of gravity of the UAV were analyzed.

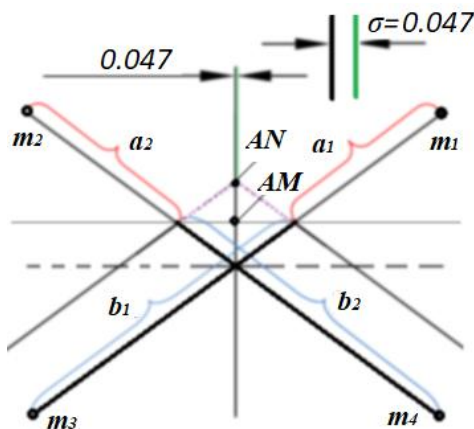
Determining the center of gravity of the VTOL-type UAV. The issue of accurately determining the center of mass and gravity of the aircraft, as well as the development of new methods and technologies in this direction, remains relevant today. It is known that it is possible to determine the coordinates of the center of gravity of gliders in advance based on survey books.

However, these data correspond to the unloaded state, which does not correspond to the final equipment of the glider³⁴. The CG is an "imaginary" point in three-dimensional space where the weight of all parts of the aircraft acts equally and where the axes of rotation of the aircraft's glider (x, y, z) intersect.

When the load on the aircraft changes (for example, replacing the battery, installing a camera on the front of the aircraft, etc.), the location of the CG changes. During the preparation stage, the CG of the aircraft must be located in the designed location. This process is called centering the model. The location of the CG is individual for different aircraft. If a ready-made glider model is used for a newly developed aircraft, then the location of the CG is provided in advance in the operating instructions for this model.

³⁵Nabiyev R.N., Abdullayev A.A. Structural emplacement and layout of elements of the developed convertiplane type unmanned aerial vehicle // Proceedings of the 2nd International Scientific and Practical Conference. Concepts for the development of society's scientific potential. - Prague, Czech Republic, Scientific Collection "InterConf+". - № 109, - 19-20.05. - 2022, - p.325-330.

The stability and controllability of an aircraft are significantly affected by its CG ³⁵. The deviation of the CG from the maximum permissible limits causes the aircraft to partially or completely lose its controllability. The existing methods and tools used to determine the loading and center of gravity of an aircraft, calculate its weight, and also prepare centering data have a number of shortcomings. In certain cases, the safety of flights is reduced as a result of incorrect analysis of the obtained parameters by specialists. Methods and means for determining the center of gravity of aircraft. In recent years, both in civil, military and experimental aviation, overloading of both manned and unmanned aerial vehicles (UAVs) beyond the permissible value, as well as violation of the center of gravity, has led to an increase in flight accidents. In this regard, special attention should be paid to the development and implementation of systems for measuring the weight and center of



Graphic 2. Scheme for determining the CG of an UAV based on experimental weight values using the parallelogram rule

³⁶Nəbiyev, R.N., Abdullayev, A.A., Qarayev, Q.İ. Konvertoplan tipli pilotsuz uçuş aparatının yaradılması və onun əsas parametrlərinin strateji obyektlərin müşahidəsi kontekstində optimallaşdırılması məqsədi ilə ağırlıq mərkəzinin müəyyən olunması // Azərbaycan Respublikası Müdafiə Nazirliyi Milli Müdafiə Universiteti. “Hərb sənətinin actual problemləri”. Ümummilli lider Heydər Əliyevin anadan olmasının 100 illiyinə həsr olunmuş Beynəlxalq Elmi-praktiki konfrans, – Bakı: – 3-4 may, 2023, – s. 275-278.

gravity of the UA before flight ^{5, 15}. Analysis of weighing systems shows that their accuracy is relatively low for controlling the weight of the aircraft.

Therefore, systems that can measure the weight of the UA before flight, as well as store, transmit and display information, are widely used to determine the center of gravity ³⁶.

However, such systems require the installation of special sensors and radio transmitters in the structure of the aircraft. These additional equipment ultimately lead to an increase in the weight of the aircraft. In recent years, a number of authors have paid special attention to the development of new methods and tools for creating measurement systems with more flexible capabilities and application features for determining the weight of the aircraft.

The methodology for measurements carried out to determine the center of gravity of a VTOL-type UAV has been developed, the required tools, preparation for work and experiments have been carried out (figure 10). In order to verify the accuracy of the measurement results, the tests were repeated 10-15 times at different times.

Based on the constructed diagrams, a final graph was constructed using the program, in which the mean square error of the deviation of the aircraft from the axis of symmetry is $\sigma = 0.047$ (graphic 2). The results of the measurements determined that, since the center of gravity was taken differently on the plane of the laboratory table in accordance with the methodology and the intermediate point fell outside the central axis (to the right or left, forward and backward), the measurements were brought to a horizontal position with a level gauge and the measurement errors of the digital measuring scales were checked based on the results of measuring a 1 kg load as a reference load. The measurements were repeated 100 times by changing the position of the scales in a clockwise direction. Based on the results of the measurements, repeated measurements were carried out by shifting the loads in the appropriate direction to ensure centering of both axes of the aircraft. Based on the final results, diagrams of the CG were constructed in the "Auto CAD-2020" program using the parallelogram rule based

on the calculated values of the coordinates of the intersection points of the diagonals.

Chapter Five. This chapter describes the onboard control and measurement system (OBMS) designed to comprehensively record the main technical parameters of a small (micro) UAV in real flight and the element database used for this purpose. During the tests of a small (micro) VTOL UAV in various flight modes, the onboard control and measurement system device writes the data received from the 5 onboard sensor groups and the inertial navigation system to the memory card of the card module, and based on the data received after the flight, the corresponding time charts are built using the “*Excel 2016*” program. With the application of the system, diagnostic testing and condition assessment of the UAV engines were performed. The possibility of ground diagnostics of the micro UAV power elements before and after the flight, as well as monitoring flight events that may occur in the air during the flight, was determined^{6,37}.

Also, during test flights performed in VTOL and airplane flight modes at different times and under different meteorological conditions, the temperature, current consumption and number of cycles of each engine, as well as the angular change and acceleration of the glider along the three coordinate axes, were measured and recorded using the onboard control and measurement system. Time dependence graphs of the recorded parameters were constructed, and based on them, the takeoff, landing and hover modes of the aircraft were studied. Automated recording of the measured parameters of the power elements in the flight preparation, takeoff and landing modes of the VTOL micro UAV was carried out and analyses were conducted on the constructed graphs.

Creation of an onboard control and measurement system for unmanned micro aircraft. Currently, the solution of the issues of recording technical and telemetric data during practical flight and laboratory studies of small-sized (micro) UAVs, as well as transmitting them to the ground in real time, is very relevant. Despite the large-scale work carried out by scientific research, design and construction companies and specialized companies operating in this

direction, a comprehensive solution to the problem of dynamic flight mode has not been presented³⁸.

In order to solve these problems in medium and large-sized UAVs, the required number of sensors and a centralized flight data recorder (FDR) are very easily placed on board.

Data received from the aircraft's energy, energy distribution, INS and power systems are synchronously recorded by the central computer to the permanent memory of the onboard recording system and are used for post-flight flight assessment, as well as for diagnostics of aviation equipment.

Some telemetric data ($v_{horizontal}$, $v_{vertical}$, v_{wind} , H_{flight} , T_{air} , T_{flight} duration, U_{AB} , I_{AB} , GPS number, D flight distance) are transmitted from the board to the ground in real time via a radio transmitter in existing small-sized UAs.

However, there have been no research studies that have a comprehensive approach to recording the main technical parameters of each engine during flight, post-flight assessment of the flight and comprehensive diagnostics of aviation equipment, and solving the problems that need to be solved to prevent the recurrence of the emergency in subsequent flights in a VTOL-type UAV consisting of four lifting engines.

With the help of the BNÖS, it is possible to measure technical parameters in the micro UAV and write them to a removable non-volatile memory card.

Here, the technical parameters include: $I1...I5$ - current consumed by the engines; $T1...T5$ - corresponding temperatures of the engines; $RPM1...RPM5$ - revolutions per minute; $A1...A3$ - accelerometer reading; $G1...G3$ - gyroscope reading⁷.

The technical parameters used are the temperature of the engines used in the micro UAV, the number of revolutions, the

³⁷Nəbiyev, R.N. Bort nəzarət-ölçü sistemi ilə konvertoplan tipli mikro PUA-nın VTOL rejimində tədqiqi \ R.N.Nəbiyev, A.A.Abdullayev, Q.İ.Qarayev \ \ – Bakı: Milli Aviasiya Akademiyasının Elmi Məcmuələri, – 2024, №4, cild 26, – s. 1-7.

³⁸Abdullayev, A.A., Nəbiyev, R.N., Qarayev, Q.İ. Pilotsuz mikro uçuş aparatları üçün bort nəzarət-ölçü sisteminin yaradılması və stasionar rejimdə sınaqları // “Fevral məruzələri” IX Beynəlxalq elmi-praktiki gənclər konfransı materialları, – Bakı: –8–10 fevral, –2024, –s. 156-159.

current consumed, as well as information about the direction of the aircraft axes and the velocity vector. The device includes a card module, an autonomous power supply system, an inertial measurement system, a control controller and a group of sensors.

Each group of sensors has a temperature, number of revolutions and a current sensor. After the flight, the on-board recorder can be used on the ground to determine the suitability of the micro UAV engines for flight based on the data recorded during the flight, as well as to make a decision on its release for the next flight and the safe execution of the flight. It is possible to analyze the technical data recorded on the ground, as well as to determine the cause of accidents that occurred during the flight based on this data after the flight.

The device works as follows: The onboard recorder and the autonomous power supply system with a rechargeable battery are fixed on the board of the micro UAV without violating the characteristics of the glider's mass centralization. A microSD memory card is inserted into the card module.

Here, the autonomous power supply system consists of a rechargeable battery and a voltage converter with a stabilized output voltage. From the moment the device is powered up, the controller software in it performs the functions of receiving data from the inertial measurement system and a group of sensors, and at the same time writing the received data to a non-energy-dependent memory card via the card module³⁹⁻⁴¹.

From the moment the power supply to the device is cut off, the information written to the non-energy-dependent memory card is stored there. It is possible to analyze the recorded technical data on the ground after the flight, and based on this information, determine the cause of the accidents that occurred during the flight. Depending on whether it is single-rotor or multi-rotor, one or N power systems can be used in a micro UAV. A power system is mainly composed of an engine and an electronic speed controller. The device is autonomous, used as a "black box", but does not perform a control function and does not affect the operation of flight controllers.

Most of the technical operational characteristics of the UAV can be determined in a stationary mode in the laboratory, but some of them should be determined only in a dynamic mode during flight. The goal here was to create an on-board control and measurement system for systematically collecting data on the technical parameters of a small VTOL UAV in flight mode (“online”) (synchronously measuring and writing to a memory card) and conducting tests in real flight conditions, that is, in general, to determine the suitability of the micro UAV power system during flight ⁴¹.



Figure 11. VTOL-type UAV with onboard control and measurement system installed

The data collected by the created system serves to increase the reliability and efficiency of the UAV's operation, as well as to ensure the safety of flights. Based on the received flight data on the energy consumption and temperature of each engine, the direction of the aircraft axes and the velocity vector, it is possible to diagnose

³⁹Nabiyev, R.N., Abdullayev, A.A., Garayev, G.I. Study of the designed convertiplane-type micro UAV in stationary and multicopter flight modes with the onboard control-measurement system // ISUDEF-24-International Symposium on Unmanned Systems: AI, Design, and Efficiency, -Bakı, Azərbaycan: - 22-23 may - 2024, -p. 6

⁴⁰Nabiyev, R.N., Abdullayev, A.A., Garayev, G.I. Research of a vertical takeoff and landing micro UAV in the plane mode with the onboard control - measurement system // (EMMFT-2024) E3S Web of Conf.–2024, Vol. 592, 06024 (2024).

⁴¹Paşayev, A.M. Pilotsuz mikro uçuş aparatlarının uçuş-texniki parametrlərinin bort qeydiyyat qurğusu, Patent (İxtira) a 2024 0022, Azərbaycan Respublikası / Nəbiyev R.N., Qarayev Q.İ., Abdullayev A.A.

technical devices, in particular engines and other power elements, to timely detect events that may occur on board the UAV during flight, as well as to control them.

Technical assistants of the BNÖS: A description of the onboard control and measurement system installed on the VTOL-type UAV is shown in Figure 11. The list of modules and elements used in the recording device is given below: ESP32 controller; TTGO T-Display module; microSD card module; 5×ACS758 current sensor; 5×FS-CPD02 sensor; 5×DS18B20 digital temperature sensor; IMU sensor; FS-i6 “Flysky” ground control unit (RCU); voltage converter (12 V to 5 V); 3S LiPo type AB. A digital and programmable sensor was used as a temperature sensor, an electronic optical system consisting of emitting and receiving semiconductor diodes operating in the infrared range was used as a cycle number sensor, and a sensor operating on the “Hall” effect was used as a current sensor.

On-board control and measurement system element base. On-board control and measurement system element base. It consists of a controller, TTGO Display module, microSD card module, inertial measurement module (IMU), voltage converter, batteries and temperature, current and cycle number sensors, as well as RCU. Of these, the main element base of the BCMS includes a controller, display module, card module, 5 sets of sensor groups and IMU. A set of sensors consists of three types of sensors: temperature, current and number of cycles. A description of the electrical connections of a laboratory sample of the BCMS is shown in figure 11^{42, 43}.

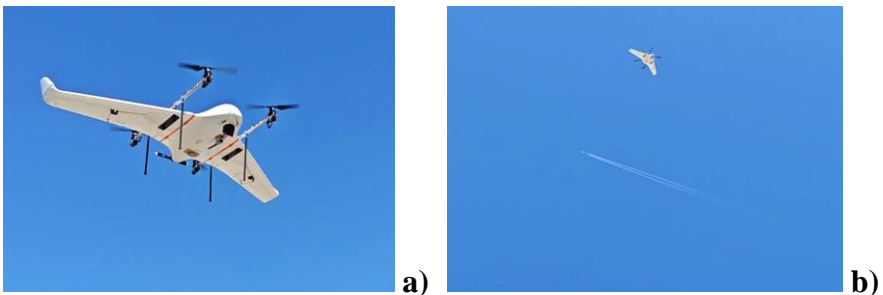


Figure 12. Practical test flights of a VTOL micro unmanned aerial vehicle in VTOL and aircraft flight modes

Study of the VTOL - aircraft flight mode of a VTOL micro UAV with an onboard control and measurement system (BCMS).

It is possible to use the onboard control and measurement system to control the technical parameters of the engines of unmanned micro UAVs, as well as to collect information about these parameters. The developed BCMS allows you to record both the number of revolutions, current consumption and temperature of the engines included in the UAV's power system, as well as information about the aircraft axes and the direction of the velocity vector during ground operation and flight. At the same time, the number of revolutions of the engines during flight is transmitted and recorded by a radio transmitter to the ground control console used as a receiving monitor in the BCMS. Based on the number of revolutions indicated on the console screen, the power system of the aircraft is controlled during real flight, and as a result, the safety of flights. Based on the recorded values of the parameters, the aircraft is diagnosed and a decision is made to release it for the next flight.

Tests conducted in VTOL-aircraft flight mode. In order to verify the flight stability of the VTOL micro UAV based on the hybrid flight concept, test flights were conducted at the airfield and the indicators obtained by the onboard control and measurement system of the power system were studied.

To study the flight of the aircraft in VTOL-aircraft modes, propellers were attached to both the thrust and lift engines of the UAV, and 10 test flights were carried out at different times of the day in favorable meteorological conditions for flight, with a duration of 7...8 minutes (figure 12 a and b). The article presents time graphics constructed based on the results of two flights as an example of recorded and archived data.

⁴²Abdullayev A.A. VTOL mikro PUA-nın uçuşunun müxtəlif uçuş rejimlərində bort nəzarət-ölçü sistemi ilə tədqiqi // Süni intellekt: Nəzəriyyədən praktikaya, I Beynəlxalq Konfrans, –Naxçıvan, Azərbaycan: -17-18 sent-br, -2024, - s. 271-277.

⁴³Nəbiyev, R.N. Bort nəzarət-ölçü sistemi ilə konvertoplan tipli mikro PUA-nın VTOL rejimində tədqiqi \ R.N.Nəbiyev, A.A.Abdullayev, Q.İ.Qarayev \ Milli Aviasiya Akademiyasının Elmi Məcmuələri, - Bakı: - 2024, №1, cild 26, - s. 17-29.

The agreement of the technical parameters of the engines and the output signals of the IMU demonstrates the validity of the study. To show the synchronous change of the values recorded during the flight, time graphics of various parameters were drawn on the same scale (figure 3).

Test. During the test, the air temperature was 22 0C, the pressure was 765 mm.h.s., the wind speed with an azimuth of 1850 was 4-5 m/s, and the instantaneous acceleration was 8-10 m/s.⁸.

Based on the time graphics of the number of engine revolutions, the test period can be divided into four stages (graphic 3):

- 1) Engine operation while the UAV is on the ground;
- 2) UAV gaining altitude or taking off from the ground and hovering;
- 3) UAV transitioning to the airplane flight mode and flying in this mode;
- 4) UAV transitioning from the airplane flight mode to the hovering mode and landing (graphic 3, a).

In the first stage, the number of revolutions increased from zero for the lift engines to a value of less than 5000 revolutions/min, and was equal to zero for the thrust engine. The current consumption increased from zero to 10 A for the lifting motors, but did not reach this value, while it was equal to zero for the traction motor during this period (graphic 3, b). At this stage, no change was observed in the temperature of both the traction and lifting motors (graphic 3, c).

In the second stage, the number of revolutions increased from zero to 5000 revolutions/min for the lift engines during speed or altitude buildup and then remained approximately at this value during hovering. During altitude buildup, the current consumption increased from 10 A to 20 A for the lift engines and was equal to zero for the traction engine (graphic 3, b). Despite the increase in current consumption during altitude buildup, the temperature of the lift engines decreased by 1...2 0C compared to the initial value (graphic 3, c)⁴⁴.

In the third stage, the number of revolutions at the moment of transition decreased from 5000 revolutions/min to zero for the lift engines and increased from zero to 10000 revolutions/min for the traction engine (graphic 3, a). During this period, the current

consumption decreased from 20 A to zero for the lifting motors, and increased from zero to approximately 25 A for the traction motors (graphic 3, b). As a result, the temperature of the lifting motors decreased with a certain delay, adapting to the ambient temperature.

Finally, in the fourth stage, the number of revolutions decreased to zero for the traction motors, and increased from zero to 5000 revolutions/min for the lifting motors (graphic 3, a). The current consumption decreased from 10 A to zero for the traction motors, and increased to values greater than 10 A for the lifting motors (graphic 3, b). The temperature of the lift engines began to increase in proportion to the energy supplied during the hover and descent (graphic 3, c)⁴⁵.

The temperature of the thrust engine increased relatively in proportion to the energy applied to it from the moment the flight transitioned to the airplane mode and then remained relatively constant in the stable flight mode (graphic 3, c).

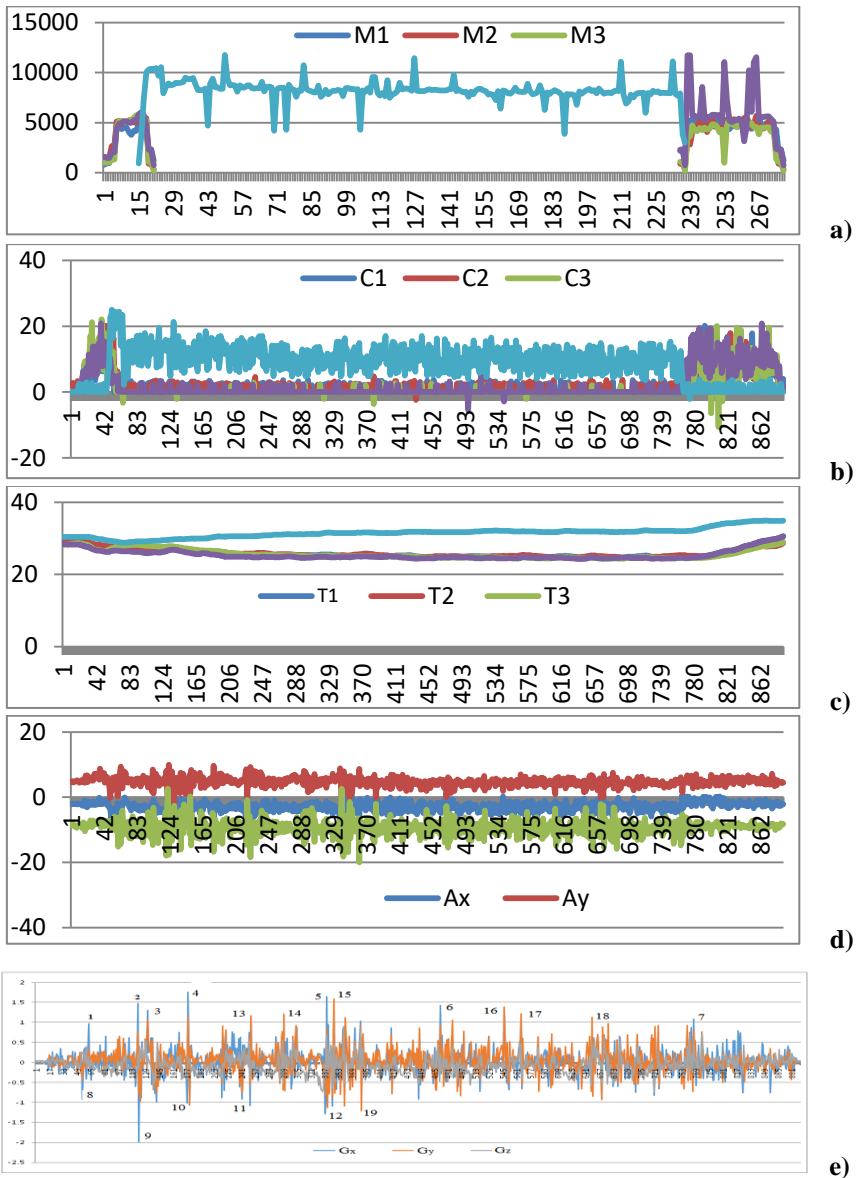
It is clear from the graphics that the number of cycles and the temperature of the engines at all stages of the flight are proportional to their current consumption (graphic 3, a - graphic 3, c).

However, despite the increase in the current consumption of the engines to provide the necessary lifting force during the height gain period, the reason for the decrease in the temperature of the engines compared to the initial value is the acceleration of the air flow created by the blades due to the increase in the engine rotation speed. In general, in the case of both an increase and a decrease in the applied energy, the moment of change in the temperature of the engines is delayed relative to the moment of change in the number of revolutions and current consumption.

This is more clearly seen in transitional modes. For example, at the end of the flight, during descent, the air flow that serves to reduce

⁴⁴ Nəbiyev, R.N. Pilotsuz uçuş aparatları üçün qida mənbələrinin seçilməsi / R.N. Nəbiyev, Q.İ.Qarayev, A.A.Abdullayev // Milli Aviasiya Akademiyasının Elmi Məcmuələri, - Bakı: - 2018. №3, cild 20, - s. 1-11.

⁴⁵ Nəbiyev R.N., Abdullayev A.A. Development trends of unmanned aerial vehicles: Main tasks, prospects and expectations // II International Baku scientific research conference. – Baku, Azerbaijan: Odlar Yurdu University, conference, - 28-30 april, - 2021, – p. 556-579.



Graphic 3. Timelines constructed based on values recorded by the BCMS during test flights conducted in VTOL aircraft flight mode under simple meteorological conditions: Output signals of the motors' speed (RPM, revolutions/min) - a, current consumption (A) - b, temperature ($^{\circ}$ C) - c; accelerometer - d and gyroscope - e.

the number of revolutions of the engines, and accordingly their temperature, sharply decreases, finally becoming equal to zero. As a result, the temperature of the engines increases by 2...3 °C in a short time, before reaching a dangerous level, and over time the temperatures of the engines and the environment become equal.

The horizontal balance and stability of the VTOL micro UAV during the flight is proven by the stability of the gyroscope and accelerometer output signals on the x, y, z axes against wind and wind speed (graphic 3, d and e). In graphic 3, e, it is seen that the gyroscope output signal increases on the x axis at points 1-12 of the wind resistance and on the y axis at points 13-19.

Chapter Six. This chapter analyzes the conditions for using UAVs in the successful implementation of tasks set in the direction of search and rescue, as well as observation of strategic objects, and the data obtained as a result of their application. The importance of applying advanced technologies in determining the location of the UAVs, the activities of the crew, and the ability to act flexibly in emergency situations is justified, and the importance of using UAVs is emphasized and highlighted^{46,47}.

Here, the work of UAVs in complex and difficult conditions was investigated with the application of technological innovations based on the current operational task. It was also noted that UAVs are widely used in the performance of aerial reconnaissance and search and rescue missions, in the delivery of medicines and necessary supplies to the required point for medical assistance within flight restrictions, as well as in monitoring the area in emergency situations^{13, 14}.

The dissertation also determined the criteria for the effectiveness of aerial observation. Applied calculation methods for

⁴⁶Набиев, Р.Н., Абдуллаев, А.А. Ведение электронно-оптического наблюдения с помощью беспилотных летательных аппаратов и оптимизация возможностей применения // – Современная наука: актуальные проблемы теории и практики. Серия Естественные и технические науки. - Москва, - 2025. №5. с 116-123.

⁴⁷Набиев, Р.Н., Абдуллаев, А.А. Оптимизация наблюдательных возможностей беспилотных летательных аппаратов // Естественные и технические науки. – Москва: –2025, №2 (201), –с. 258-268.

calculating the area of the area observed by UAVs in one flight, the cost of conducting observation, and the cost of obtaining information by observing a designated area of the earth's surface were presented.

It is advisable to take the comparison of the costs incurred for observation data obtained from a single area as the main criterion in optimization reports. In this case, all other criteria for the effectiveness of reconnaissance complexes should be fully taken into account. The determination of the prices of the components included in these criteria is carried out taking into account the flight modes and altitudes of each UAV. It has been noted that the determination of the advantages of UAVs is carried out by reporting flight modes and flight altitudes ^{48,49}.

UAV surveillance in the organization of security work.

The time factor is of great importance during natural disasters and search and rescue missions. The use of UAVs during rescue operations increases the efficiency and safety of search (surveillance), as well as reduces the rescue time. The main approach during search and rescue operations is the correct planning of the UAV route and the surveillance algorithm.

In practice, sometimes for these purposes, the principles of survival, mass, flock, etc. can be used.

The main methods of searching for strategic objects have been identified: search-observation in a certain local area; search in the zone of interest; search by flying over objects; conducting aerial observation of the object by flying to a given point; search for the object in given angular sectors; search for the object on a given flight route ^{13, 52}.

Evaluation of the effectiveness of the use of UAVs during the execution of reconnaissance missions. Criteria for the

⁴⁸Nabiyev R.N., Abdullayev A.A. Methods of conducting observation with unmanned flight vehicles // World of conferences. XVI International Scientific and Practical Conference «World science priorities», -Vienna. Austria: -03-04.04.2025, - p.143-145.

⁴⁹Nabiyev R.N., Abdullayev A.A. Basics of drone surveillance // Proceedings of the 11 th International Scientific and Practical Conference «Theory and practice of science: key aspects». Roma, Italiya, Scientific Collection «InterConf+», - 19-20.04.2025, № 56(244). - p. 278-283.

effectiveness of conducting aerial observation ^{50, 51}.

The main criteria for the effective application of the air reconnaissance complex include the relative effectiveness of forces and means and the interests of conducting air reconnaissance:

$$U = \frac{W_K}{W} \quad (1)$$

here, W_K , W - the probability of completing the assigned task with and without the use of aerial reconnaissance data.

However, in practice, it is quite difficult to determine the relative value of the effectiveness of forces and means. Because determining the effectiveness of forces and means for both situations requires a large amount of work. The following criteria are used to determine the effectiveness of reconnaissance means:

- the probability of completing the task by a reconnaissance UAV;
- the cost of completing the task;
- the cost of obtaining the image.

The probability of completing the task by a reconnaissance UAV is determined by the following expression.

$$K_T = K_{IYOE} * K_{MTAQE} * K_{M\text{әә}lum\text{ә}t} * K_{AEE} \quad (2)$$

here: K_T - probability of completing the mission with a reconnaissance UAV, K_{IYOE} - The probability that a UAV will be operationally fit for flight or will operate without failure for the entire flight period ⁵².

K_{MTAQE} - The probability of eliminating the negative effects when approaching the payload application zone or this zone. For military UAVs, $K_{MTAQE} = K_{HHM}$ (the probability of eliminating the effect of enemy air defenses). The probability. K_{MTAQE} is determined by the following expression:

⁵⁰Nabiyev R.N., Abdullayev A.A. The Optimization of the Surveillance Capabilities of UAVs // Tuijin Jishu/Journal of Propulsion Technology. - 2025, ISSN 1001-4055, Vol. 46(2), -p. 1212-1221.

⁵¹Nabiyev R.N., Abdullayev A.A. Basics of electron-optical surveillance with UAVs // The Scientific Heritage, -Budapest, Hungary:-2025, Vol. 159, -p.140-143.

⁵²Nabiyev R.N., Abdullayev A.A. Optimized UAV surveillance strategies for securing strategic objects: a performance-based comparative analysis // Multidisciplinary Science Journal, - 2025, Vol. 7(12), -p. 1-7.

$$K_{MTAQE} = e^{-\sum_{i=1}^N \lambda_i * t_{ni}} \quad (3)$$

here λ_i - the effective impact intensity of the i number of unfavorable factors, λ_{ni} - the flight duration of the UAV in the case of the direct impact of the i number of unfavorable factors.

$K_{M\text{ə}lumat}$ - The period from the acquisition of EO observation images by the UAV to their delivery to the user. During this period, the probability that the information will not lose its relevance is:

$$K_{M\text{ə}lumat} = e^{-\frac{Z_{MA\ddot{O}V}}{Z_{OHP}}} \quad (4)$$

here, $Z_{MA\ddot{O}V}$ - The time for detecting and transmitting data is equal to the sum of the times for detecting, identifying and determining the coordinates of the target in the operator's display area., $\frac{1}{Z_{OHP}}$ object mobility parameter (Z_{OHP} - the average time that an intelligence object remains in a static state at a given location).

K_{AEE} - probability of detecting a single reconnaissance object in the payload's field of view,

$$K_{AEE} = \frac{F_{BS}}{F_S} \quad (5)$$

here, F_{BS} - Area of the area surveyed by UAV in one flight:

F_S - The area of the ground searched for a target during the execution of a combat mission. Cost of performing an observation: defined as the total cost incurred to perform a task ^{14, 52}.

$$MYYD_{1T} = \frac{D_{UA}}{n_T} + D_{\text{ə}X} + D_{YMX} \quad (6)$$

here, D_{UA} - cost of the aircraft, n_T - Estimated number of UAV applications, $D_{\text{ə}X}$ - the additional resources and costs (engine, servo drive, etc.) spent to ensure a flight, D_{YMX} - cost of fuel and material costs (fuels and lubricants, technical gases, etc.).

The cost of obtaining information by observing a designated area of the Earth's surface is a universal specific criterion, which is designed to assess the effectiveness of each reconnaissance UAV's application, taking into account its survivability, cost, and payload capabilities:

$$D_M^- = \frac{MYYD_{1T}}{K_T * F_{\Sigma}^1} \quad (7)$$

herea, F_{Σ}^1 - Total area of the earth's surface observed by UAV in 1 flight.

CONCLUSION

The scientific issues raised in the process of research on the topic of the dissertation were analyzed and studied, and the following main conclusions were obtained:

1. A device that automatically determines the polarity for safe battery charging has been developed and implemented using a device consisting of a mains voltage step-down transformer, two controlled rectifier bridge circuits, and a circuit that determines the polarity of the battery and mains voltage to charge the battery ⁹.

2. A conceptual functional diagram of a VTOL UAV with a hybrid power source has been developed ^{3, 12, 36}.

3. When using an internal combustion engine as a power source, the weight of UAVs increases, and in this regard, it is possible to create effective power sources that can provide long-distance flights by using an internal combustion engine and a hydrogen fuel cell as a hybrid power source in UAVs weighing more than 15 kg. ^{3, 11, 12, 44}.

4. Computer modeling of a fixed "flying wing" VTOL type UAV was carried out based on the "SolidWorks", "ANSYS", "Profili" and "Xflir5" application programs and optimized aerodynamic characteristics were determined. As a result of the design, the design, aerodynamic and stability characteristics of the UAV were determined, and based on the obtained report and structural data, the selected mass elements and the final structure of the UAV with a wingspan of 2.21 m were designed and prepared ^{11, 12}.

5. Based on the weight values measured by electronic scales placed under the supports, the coordinates of the center of gravity of the VTOL type UAV were calculated on the axes connecting the support points diagonally, and using these values, the center of gravity of the UAV was graphically depicted in the "AutoCAD-2020" program. The high efficiency of the "scale-mass" method applied to determine the center of gravity was confirmed. Due to the different coordinates of the centers of gravity on both axes, an intermediate point was established using the parallelogram rule to

find the center of gravity. Based on the optimization performed using the mean square method, it was found that the mean square deviation error of the deviation of the intermediate point from the central axis is: $\sigma = 0.047$ ^{5, 15, 34-36}.

6. For the first time, an on-board control and measurement system was created to comprehensively record the technical parameters of a VTOL micro UAV (I1....I5, T1....T5, RPM1....RPM5, A1....A3, G1....G3) and, based on the analysis of the obtained values, the technical condition of the aircraft's power circuit, especially the engines, was assessed^{6, 37, 38}.

7. Using the developed onboard control and measurement system, test flights of the VTOL micro UAV were conducted in stationary, VTOL and VTOL-aircraft flight modes. During the tests, the technical parameters of the engines - the temperature, current consumption and number of cycles of four lift and one traction engines, as well as information about the direction of the aircraft axes and the velocity vector - were measured synchronously and the time dependence graphics of the corresponding parameters were analyzed in the "online" mode (at the same time written to the memory card) to provide the opportunity to make decisions^{7, 39, 40, 42}.

8. A methodology has been developed for diagnosing the power system of a micro UAV before and during flight^{9, 41, 43, 44}.

9. After the flight, it is possible to determine the suitability of the micro UAV engines and make a decision on its release for the next flight, based on the data recorded in the on-board control and measurement system, and also to determine the cause of accidents that occurred during the flight based on the recorded technical data^{6, 7, 45}.

10. The developed onboard control and measurement system can be modified for use in multi-rotor and other aircraft^{8, 40, 41, 44}.

11. During the execution of observation and search tasks with UAVs, it has been determined that it is important to take into account the geographical relief of the observed area, meteorological conditions and the distance to the UAV, the visual, acoustic and thermal detection indicators of the UAV, the characteristics of aviation equipment having a stable navigation and communication

system during the active operation of radio-electronic warfare means, the flight altitude of the UAV and the technical and operational characteristics of the payload integrated into it, intelligence information obtained from other sources about the object, the probability of detection and location, mobility, speed, size, color, as well as the density of the composition of the observed area in terms of the number of elements^{13, 14, 46, 48-52}.

The main content of the dissertation is reflected in the following works of the author:

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Personal contribution of the applicant in scientific works:

- [1] - Conducting analysis, collecting data, and summarizing results;
- [2,3,4,5,10,11,12,14,16,41,42,43,44,45,47,48,49,51] - Conducting research, collecting data, and summarizing results;
- [6,7,8,9] - Data collection, analysis and research, summarization, conference presentation;
- [19,26,46,50,] - Conducting research and summarizing results, presenting online at the conference;
- [18] - Conducting research and summarizing results, speaking at a conference;
- [28] - Selection of contributors and summarization of results and presentation at the conference;
- [33,35,39,40] - Performing experiments, assembling the scheme, conducting analysis, speaking at the conference;
- [25] - Performing experiments, assembling the scheme, conducting analysis;
- [31,52] - Collecting data, summarizing results, assembling a diagram, and writing a description;
- [20] - Development of a conceptual framework and algorithm, conducting research, and summarizing results;
- [21,23,27] - Conducting research, assembling the structure, selecting the components, and summarizing the results;
- [29] - Conducting research, simulating with software, conducting reports, and summarizing results;
- [30,32,34,37,38] - Assembling the scheme, performing mathematical calculations, performing experiments, analyzing and summarizing the results;
- [13,15,17,22,24] - Freely performed by the author.

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