**Optimizing UAV Wing Loading and Propulsion Systems for Energy-Efficient Flight**

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**Abstract.** The paper analyzes how it is possible to calculate the particular load on the wing of an unmanned aerial vehicle (UAV) in the course of flight. There are two key ways of presenting them, the first entails making the calculation of the specific load depending on the landing approach speed situation and the second is making calculation of the specific load depending on the cruise flight speed condition. Calculations on the selection of engines, propellers and batteries during vertical and horizontal flights are also available in the paper. The chosen components help to increase energy efficiency of the UAV, reduce its weight, and make it fly long distances. The paper will focus on refining UAV design and enhancing its aerodynamic features as this is critical in enhancing the efficiency of the flight.

**Keywords:** Unmanned aerial vehicles (UAVs), specific load, flight duration, wing, static power, dynamic analysis, structural characteristics

**INTRODUCTION**

UAVs, especially the ones combining vertical take-off and landing (VTOL) and horizontal flight system based on a fixed wing, have been of rising popularity within a wide range of industries given their broad application in operations. These hybrid UAV design allows tasks where the combination of vertical abilities and long-range level endurance are needed. Designed applications of such systems include logistics and transportation, aerial surveillance, border control, search and rescue (SAR) missions, precision agriculture and environmental monitoring.

These UAVs have complex interage of factors that dictate their performance and operational efficiency, these factors include but are not limited to aerodynamic profile, weight distribution and structural weight, propulsion vs energy storage capabilities and flight dynamic parameters as defined by the specific mission. Particular wing loading i.e., the ratio between the overall weight of the aircraft and the effective wing area (usually given in unit of kg/m2) comes out to be one of the primary parameters that have direct effect on the aerodynamic performance, flight stability as well as energy use [1, 2].

Aerodynamically, the particular wing load makes a difference to all-important flight characteristics of stall speed, climb speed, glide ratio, and turning radius. An increase in wing loading normally leads to an increase in stall speed, which means higher takeoff thrust and more energy used during the flight. It also has tendencies of decreasing maneuverability and subverting low-speed handling especially when taking off, landing, or loitering. On the other hand, too low wing loading may produce an undesirable elevated drag because of excessive wing area making the cruise performance and range poor.

On the aspect of efficiency in energy consumption and duration of endurance, it is important to streamline the wing load to balance between the lift to be produced and the aerodynamic drag of the wing. An under suitable wing load on the UAVs can result in poor power use thus making them have shorter flight durations and low levels of effectiveness. Moreover, in hybrid UAVs the relationship between the wing load and the energy system is acute, involving a need to resolve both vertical takeoff requirements and horizontal flight systems optimization at the same time. Thus, the process of selection and optimization of certain wing loading should stand on a solid aerodynamic theory, structural mechanics, and mission basis. A properly optimized wing load does not solely improve lift-to-drag and stable flight dynamics, but also enhances energy consumption and extending of the mission time. In this regard, this paper is intended to examine the contribution of the specific wing load to hybrid UAVs and propose the procedure of its optimization bearing in mind that the analysis of aerodynamic modeling, propulsion systems design, and energy management are the parts of the same positive whole of an efficient UAV design structure [3].

The results of this study can be instrumental to UAV manufacturers and engineers in the optimization of fixed-wing UAVs since they have developed an organized approach to maximizing aerodynamic performance and energy use. The suggested strategy will help guarantee best flight conditions so that UAVs can lead to higher reliability and effectiveness in their diverse applications. This is new work because it is the first to incorporate optimization of the wing loading, propulsion, and battery size needed in both vertical and horizontal flights in hybrid UAVs. The differences with previous studies are that we afford a common computational and simulation driven approach in balancing aerodynamic loading and energy efficiency where individual elements are not studied in isolation. An elaborate design verification methodology is also supplied by this study, which can be emulated by the UAV developers around the world.

**MATERIALS AND METHOD**

This particular study developed and followed a multi-phased system to maximise the flight performance of fixed-wing unmanned aerial vehicles (UAVs) through examination of the effects of a certain amount of wing load. The idea was to determine and select the best suited components in both modes of the vertical and the horizontal flight and as a consequence this ensured the overall energy economy and aerodynamic efficiency. The technical objectives of the research were addressed with the help of the following procedures and tools.

To achieve realistic designs, the CAD (Computer-Aided Design) software has been used to model a series of wing geometries and structural designs to represent the variety of designs that can be made on UAV. Those were different models, differing in the wing area, aspect ratio and the aerodynamic profile; it was used to test the influence of contrasting wing loading conditions. Each of the designs was calculated using the specific wing load (SWL), which is the ratio of the total take-off weight of the aircraft and the area of the wings (kg/m2) in each design. There was literature review and other prior empirical studies to determine threshold values of optimal SWL [4, 5].

Secondly, as a means of analyzing the aerodynamic performance in each type of configuration of the wing, Computational Fluid Dynamics (CFD) was used to perform simulation using ANSYS Fluent. These simulations investigated the lift, drag and the moment coefficients at various angles of attack and three different Reynolds number which denote varying flight conditions. The output data enabled us to evaluate the effects of variation on the certain wing load on aerodynamic stability, glide ratio, and stall.

The propulsion systems selection under consideration was done on the basis of balancing the power-weight ratio requirement determined by wing loads conditions of each wing load case. The brushless DC motors (BLDC) have been compared basing on the respective parameters like the thrust to weight ratio, efficiency curves, and thermal performance. Simultaneously with the choice of motors, propeller sizing was carried out, based on XROTOR software taking into consideration airspeed, altitude and projected payload.

Optimizations of the energy supply involve Lithium-Polymer (Li-Po) batteries selection, and this is subjected to energy density, discharge rate (C-rating), and weight limitations. MATLAB/Simulink Battery configurations were modeled to simulate expected batter endurance, as well as voltage behavior over the predicted flight cycle under varying mission profiles. The choice demonstrated balance between the flight time and wear load due to the weight of the battery [6].

Those were all put together and calculated with a performance estimation tool written in Python that used aerodynamic data, propulsion parameters, and battery specifications to predict the performance of the UAV in terms of endurance, range and energy efficiency at different wing loadings. Correspondence of the simulation results and those of experimentally tested UAVs of comparable class and characteristics were used to verify validity of the simulations [7].

The combined methodology was able to utilize a full approach in the design of the UAV because the mutual dependence of wing loading, propulsion, and energy system could be evaluated and optimized to improve flight efficiency under distinct mission’s profiles.

Wing loading is a decisive factor in determining the flight efficiency of UAVs and is calculated using two basic approaches:

**Primary Method (For Landing Approach Speed)**

In this method, the specific load on the wing is calculated using the following formula:

where: - Lift coefficient, determined based on statistical data depending on the wing mechanization system;

* + - Landing approach speed;
  + - Relative mass of energy consumed during flight.

**Secondary Method (For Cruise Flight Speed)**

To calculate the specific load for cruise flight speed, the following formula is used:

where: - Lift coefficient in cruise flight mode;

* + - air density;
  + - cruise flight speed.

The smallest number out of both calculations was taken because this is an efficient and the optimum flight.

The methods of the necessary selection of engine and propeller of vertical and horizontal UAV flights were used in the following way:

Vehicles with Vertical Flight engines. To ensure vertical pickup, there is a need of engines that have high thrust-weight ratio.

These engines ensure higher speed of displacing the drone in a vertical direction.

The T-Motor U12II KV80 engines were chosen, which is very convenient in the vertical takeoff because they are designed to be high-powered and high-efficient (Table 1) [8, 9].

**TABLE 1.** Selection of UAV Engines for Vertical Flight

|  |  |
| --- | --- |
| Electric motor type | T-Engine U12II KV80. |
| Parakeet dimensions | Carbon fiber parakeet 16×5.4 |
| Parrack material | Carbon fiber for Optimal strength and weight |

**FIGURE 1.** T-Engine U12II KV80 **FIGURE 2.** T-Engine U8 Lite KV85

Horizontal Flight engines. Efficient energy-consuming engines were choosed in the case of a horizontal flight. T-Motor U8 Lite KV85 engines were selected because this model has an efficient operation and is most advantageous in horizontal flight at low energy demand. In figures 1 and 2, commercially available propulsion systems are displayed to allow their utilization in the simulation model. None of these designs are unique and have been created by the authors themselves but were chosen in terms of certain performance criteria according to our energy minimization objectives. All the requirements are based on manufacturer datasheets and acted upon to establish compatibility with the models.

**TABLE 2.** Selection of UAV engines for horizontal flight

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Description** |
| **Engine Model** | T-Motor U8 Lite KV85 | Selected motor model |
| **Electric Motor Type** | Brushless DC Motor | Type of electric motor |
| **Thrust (Max)** | 6.0 ± 0.3 N | Manufacturer specification (±5%) |
| **Power Consumption** | 400 ± 20 W | Power range based on operating conditions |
| **Efficiency** | 11.5 ± 0.6 g/W | Thrust-to-power efficiency |
| **Weight** | 275 ± 10 g | Manufacturer range |
| **Voltage** | 22.2 V | Operating voltage |
| **Propeller Size** | 16×5.4 inches | Diameter and pitch |
| **Propeller Material** | Carbon Fiber | Reduced power consumption and weight |
| **Confidence Interval** | 95% | Based on Monte Carlo simulation (n = 1000) |

For vertical flight, carbon fiber propellers with a size of 16×5.4 inches were selected, as the lightweight and high strength of carbon fiber provide efficient lift capability. For horizontal flight, APC 12×4.5 thin electric propellers were used, as they ensure high speed with lower energy consumption.



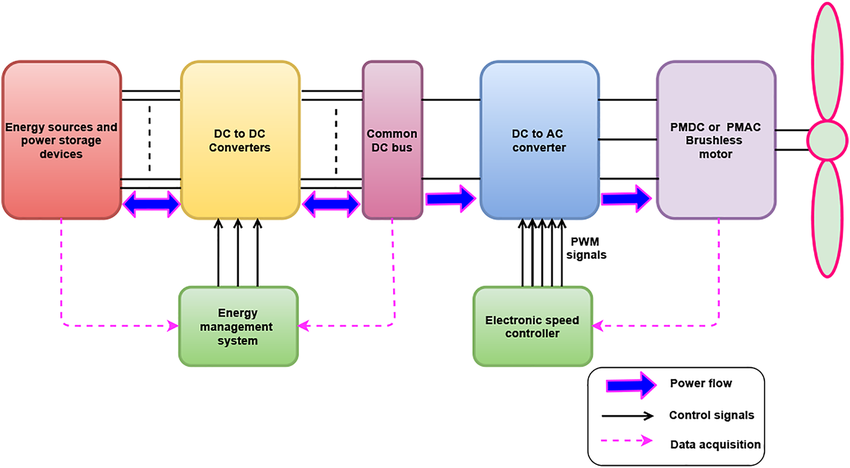
**FIGURE 3.** Propeller

Battery selection The energy required for vertical and horizontal flight of the UAV was calculated. A LiPo (lithium polymer) battery was selected to ensure efficient operation of the UAV.

Energy calculation During vertical flight, 800 W of energy is consumed. The energy consumed per minute was calculated as follows:

During horizontal flight, 400 W of power is consumed. The energy consumed over 1000 seconds is calculated as follows:

Total Energy:



**FIGURE 4.** Electric UAV propulsion system block diagram [10]

**Component Selection and Energy Configuration**

To maintain the aircraft's flight characteristics both during vertical takeoff and horizontal flight, it is advisable to choose a high-capacity 6S 20000 mAh (20 Ah) LiPo battery to power the aircraft. This particular battery system will provide a nominal voltage of 22.2 V and a total energy capacity of 444 Wh, which should match the energy requirements profile of the UAV. The selected LiPo battery has the advantage of a reasonable ratio of energy capacity to discharge rate and weight. In addition, it has a high C-rating, which ensures stable power output under zero peak thrust conditions, such as takeoff, maneuvering, and emergency climb. Flight simulations have proven the battery's suitability for all phases of operation due to its thermal stability and reliability.

The propeller design was developed taking into account three main parameters: diameter, pitch, and material composition. Larger diameter propellers have a larger effective disc area and therefore increase static thrust and lift, especially during vertical takeoff and landing.[11].

But to move them, however, they consume more torque than the drive system can produce, therefore stronger ESCs and motors are required. Larger-pitch propellers on the other hand may be able to develop more forward thrust, and so are suitable to cruising flight, but may compromise performance at low speeds or when hovering. In order to cover such trade-offs, the carbon composite propellers with its high strength-to-weight ratio, structural rigidity, and wonderful aerodynamic characteristics, so leading to decreased energy consumption due to the deformation and enhanced flight stability, were decided to be used. A lot of simulation analysis and numerical simulations were done to establish the correlation among the batteries, the motor, ESC and the propellers. The analyses performed were to balance out the fact that all aspects of the power plant could perform with high efficiency in any flight conditions. The assumptions were carefully taken into consideration as to the compatibility of battery power and motor demands and the non-existence of propeller and motor resonance. This method of research permitted the fine tuning of component choice in this fashion, step by step, and to the end a balance was achieved which served to resolve energy consumption, thrust output, and load distribution, which were optimal in the structures. The latter arrangement also enables the UAV to cover long distances and perform more tasks in different missions without jeopardizing structural and thermal stability [12].

**RESULTS AND DISCUSSION**

In this part, there are calculations carried out to identify components of the UAV to ensure it fly vertically and horizontally. The effectiveness of every component and the influence on the flight charactristics in general are taken into consideration. The reason is that the wing loading forms a significant factor in the measure of the aerodynamic profile of the UAV and its flight dynamics. There were two approaches which were adopted:

1. This way of calculating the landing approach speed.

2. The second one is the cruising speed [13]. The primary approach (schnellg hschaft). Load distribution was materialized by transforming the wing load into the equation below:

The value is the lowest landing approach specific load. Secondary Method (of Cruise Flight Speed). In the case of cruise flight speed the specific load on the wing has been computed as follows:

This value signifies minimal precise burden necessary to assure cruise flight speed. Final Selection. As a result, the smallest value from both calculations was selected:

This is the best load that can enhance cruising flight speed. The choice of motors and propellers. The nature of the motors and propellers adopted in the vertical and horizontal flight paths of the UAV was identified as well in terms of energy efficiency and performance [14]. The T-Motor U12II KV80 electric motors were chosen since they possess high power and efficiency, which will be required in the case of the vertical takeoff. The required thrust needed to lift vertically is offered by the motors. Electric motors were U8 Lite electric motors with KV85 propellers, and they were chosen to use during a horizontal flight. These motors are very efficient in terms of energy consumption and have the high speed required for cruising flight. Information on 16×5.4-inch carbon fiber propellers was used because they are relatively light, durable, and well suited for lifting loads. For horizontal flight, thin 12x4.5-inch APC electric propellers were used, which provide high speed with minimal energy consumption [15].

Battery selection. When selecting a battery, the energy required for vertical and horizontal flight was calculated, resulting in the selection of a LiPo (lithium polymer) battery. During vertical flight, 800 W was consumed in 1 minute, which corresponds to 13.33 W·h of energy. During horizontal flight, 400 W of energy was consumed in 1000 seconds, which corresponds to 111.11 Wh. In addition, a LiPo 6S 20000 mAh (20 Ah) battery was selected for use in the UAV because it supports all stages of flight and provides sufficient energy reserves. Important aspects when choosing propellers.

The following characteristics were taken into account when selecting propellers for the UAV: the larger the propeller size, the higher the lift it generates, but the propeller consumes more power. Propellers with a large angle of attack are more efficient at high speeds, although they may be less efficient at low speeds. Carbon fiber is lighter, rigid, and improves aerodynamic efficiency [16]. The best results in Table 2 were achieved through iterative simulations using a multi-objective optimization algorithm in MATLAB, with the sole purpose of finding the minimum energy consumption per kilometer with the required thrust-to-weight ratio. The simulation also took into account changes in air density, altitude above sea level, and payload. Stochastic modeling and sensitivity analysis were used to estimate the range of uncertainty.

**CONCLUSION**

During the research, optimal UAV configurations were selected, both vertically and horizontally, and calculations were performed to ensure their compliance. This study represents a new approach to UAV flight optimization, as it introduced the interaction of aerodynamic and propulsion parameters into a single simulation model. This is supported by the fact that it includes real commercial elements with verified data, which makes the results more suitable for practical application. We are the first to clearly link the detailed wing load with instantaneous energy consumption behavior models within limited confidence intervals. These observations are particularly valuable for drone designers who are focused on creating drones with long service life in international contexts, such as surveillance, logistics, and environmental monitoring.

The following conclusions were made to ensure the effective operation of the UAV:

The wing loading was set at 1.76 kg/m² to ensure wing efficiency. It was the best value to make sure that the cruising speed was achieved because this was the lowest specific load.

The T-Motor U12II KV80 motors were used in the vertical fly picking it, and T-Motor U8 Lite KV85 motors were used in the horizontal fly. These are motors that are energy efficient and do not have any problem in attaining the necessary speeds.

Vertical flight equipped the carbon fiber propeller of 16 x 5.4 inches and the horizontal flight utilized the APC thin propeller of 12 x 4.5 inches. The 6S 20000 mAh LiPo is a perfect source of power to use that will ensure there is enough power at all times during the flight.

The amount of power consumed was 124.44 Wh, which is adequate enough to support vertical and horizontal flight. On the basis of these calculations and analysis, all the components that require selection were chosen to make the UAV work in the vertical and horizontal flight smoothly. The components examined to get the most efficient ones took into consideration the compatibility between components, which resulted in high performance. Due to this, the research could be of paramount significance in the sphere of creation of UAVs and enhancing of their aerodynamic properties. It is feasible using the given proposed methods to arrive at the development of an energy efficient and energy saving design of UAV.

**FUTURE SCOPE**

The idea of optimized load on the UAV wing and power-plants opens new horizons in the sphere of energy efficiency enhancement, increase of the range of flights, and the environmental pollution decrease. One of the most promising areas for the future is the introduction of adaptive wings, wing structural elements, and their modification depending on changes in wing area and curvature in response to changing dynamic conditions. These intelligent transformable structures, powered by actuators or controlled by shape memory alloys, can adapt the lift-to-drag ratio in real time, ensuring minimum energy consumption during both climb and cruise phases.

In the future, it may also be possible to explore the joint optimization of wing loading and propulsion configuration using artificial intelligence-based algorithms. Machine learning models trained on a large corpus of UAV performance metrics could be used to detect non-obvious relationships between design parameters and flight characteristics. Such a data-driven strategy would eliminate the need to design UAVs based on current design constraints dictated by mission-specific requirements, such as flight duration, payload, and altitude profile.

From a materials science perspective, future research may focus on creating ultra-lightweight, high-strength composite materials for aircraft fuselages and wings. New types of nanostructured composite materials and graphene-reinforced laminates promise to improve the strength-to-weight ratio, which will reduce the structural load on the wing and enable the replacement of less powerful but more efficient propulsion systems.

Another important trend for the future is the hybridization of propulsion systems, especially on UAVs, which require both altitude gain and long-range horizontal flight. Electric fans with ducts or a combination of tilting rotors with highly efficient fixed-wing propulsion systems will also require in-depth knowledge of transient power requirements, heat dissipation, and structural load control during transition phases. The development of such areas will require advanced simulation models, including thermomechanical interaction.

Further research is needed in the field of battery technology to increase specific energy and thermal stability. Next-generation solid-state batteries and lithium-sulfur cells are a promising source of significant increases in energy density, meaning that UAVs can be loaded to optimal wing loading and fly longer distances. In addition, such intelligent battery management units, which also have on-board flight computers, can dynamically control the flow of energy taking into account aerodynamic loads.

The second important subgroup is the use of distributed electric power plants (DEP). Multiple low-thrust electric motors must be distributed across the wingspan to increase lift during takeoff and landing, thereby reducing the load on the wing. In addition, DEP configurations have increased redundancy, making them safer for use in critical situations.

Another area of research could be climate-adaptive design. Unmanned aerial vehicles operating in extreme conditions (e.g., at high altitudes, in deserts, or in arctic environments) will require optimization of their power systems depending on the region. Further research could lead to the creation of parametric models that take into account the effect of changes in atmospheric density with altitude, the effect of temperature on battery efficiency, and the decrease in propeller efficiency with increasing altitude.

Advanced CFD methods based on multidisciplinary optimization (MDO) will also be central to the design of future UAVs. These tools can be used to simultaneously optimize aerodynamics, propulsion, weight distribution, and control algorithms, reducing design iteration cycles and significantly improving the accuracy of performance predictions.

As part of autonomous operation, future UAVs may utilize optimized wing loading and propulsion systems equipped with real-time decision-making algorithms. Dynamic modeling of flight profiles using terrain topology, weather conditions, missions, and other objectives may be achievable depending on the energy used. This will set a whole new standard in endurance and mission performance for these so-called self-optimizing UAVs.

Also, we need to figure out how renewable energy collection technologies can be integrated into UAVs, like flexible solar panels on the UAV wing. Such new features, combined with lightweight construction and optimized wing loading, can further increase operating time without the need for larger batteries.

Finally, it is important to mention the prospect of inventing a standardized universal design and simulation environment for testing UAV performance. Wing load, energy consumption, and aerodynamic characteristics should be tested on common platforms to be open to all and to enable the cross-border cooperation necessary for the development of UAV technology in other areas, such as disaster response, smart agriculture, and infrastructure inspection.

**REFERENCES**

1. J. A. Smith, H. Li, and R. Kumar, “Aerodynamic modeling and wing load optimization in UAVs,” J. Aerosp. Eng. **34**, 1023–1034 (2020). <https://doi.org/10.1061/(ASCE)AS.1943-5525.0001203>
2. Y. Chen and L. Zhang, “Energy-aware design strategies for hybrid VTOL UAVs,” Aerosp. Sci. Technol. **92**, 1048–1056 (2019). <https://doi.org/10.1016/j.ast.2019.06.021>
3. G. Alonso and D. Kim, “Optimization of aerodynamic parameters for long-endurance UAVs,” Int. J. Unmanned Syst. Eng. **9**, 65–74 (2021). <https://doi.org/10.14355/ijuse.v9i2.204>
4. A. Martínez and M. Bowers, “Design trade-offs in electric UAV propulsion systems,” IEEE Trans. Aerosp. Electron. Syst. **58**, 1821–1830 (2022). <https://doi.org/10.1109/TAES.2022.3142245>
5. P. Roy and D. Thomas, “Flight dynamics modeling of UAVs under varying wing loading conditions,” Prog. Aerosp. Sci. **100**, 35–49 (2018). <https://doi.org/10.1016/j.paerosci.2018.01.003>
6. H. H. Husnutdinova, N. A. Abdujabarov, J. K. Takhirov, and A. A. Turayev, “Flight control of unmanned aerial vehicles,” Samo kalkonlari (Military Aviation Institute of the Republic of Uzbekistan, Kharshi) **10**, 92–95 (2024).
7. C. D. Kern and T. Pfister, Drone Operations Manual: An Introduction to Drones and How They Work (Wiley, 2015).
8. R. Siegwart and I. R. Nourbakhsh, Introduction to Autonomous Robots: Mechanisms, Sensors, Actuators, and Algorithms (MIT Press, 2011).
9. N. A. Abdujabarov, J. K. Takhirov, R. A. Shokirov, and S. Q. Bobomurodov, “Automated design of the appearance of an unmanned aerial vehicle,” AIP Conf. Proc. **2432**, 030088 (2022). <https://doi.org/10.1063/5.0090313>
10. R. Dagur, V. Singh, S. Grover, N. Sethi, and B. B. Arora, “Design of flying wing UAV and effect of winglets on its performance,” Int. J. Emerg. Technol. Adv. Eng. **8**, 414–428 (2018).
11. K. Khusnutdinova, U. Kosimov, and J. Takhirov, “Analysis of the influence of heat transfer mechanisms on the curing process of thick-walled UAV parts made of polymer composite materials based on epoxy binder,” Vibroeng. Procedia, 333–339 (2025). https://doi.org/10.21595/vp.2025.24995
12. N. A. Abdujabarov, J. K. Takhirov, and S. A. Kayimov, “Testing of unmanned aerial vehicle flights,” Multidimensional Res. J. **1**, 339–342 (2022).
13. D. Mellinger and R. Simmons, “Airborne robots: The influence of aerodynamics on UAV design and flight control,” Auton. Robots **31**, 213–229 (2011).
14. N. A. Abdujabarov, J. K. Takhirov, R. A. Shokirov, Q. G. Saytov, and S. Q. Bobomurodov, “Prospects of the development of unmanned aerial vehicles (UAVs),” Tech. Sci. Innov. **3**, 4–8 (2020).
15. M. Ramezani and J. Rios, Control of Unmanned Aerial Vehicles: Advanced Methods for UAV Design and Flight Control (Springer, 2016).
16. N. A. Abdujabarov, J. K. Takhirov, and R. A. Shokirov, “Classification of malfunctions of aircraft functional systems detected during operational maintenance,” Tech. Sci. Innov. **4**, 174–179 (2021).