**Advanced Composite-Based Design and Production of a Lightweight UAV for Energy-Efficient Operation**

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**Abstract.** Unmanned Aerial Vehicles (UAVs) are recognized as one of the most advanced directions of modern technological development. Their wide range of capabilities is being effectively applied in various fields, including agriculture, logistics, security, military services, environmental monitoring, cartography, and emergency response. The main objective of this article is to develop a customized UAV model and to comprehensively study the processes involved in its creation. Detailed information is provided about the technical foundations of the project, design stages, components used, control system, and software. In addition, the practical applications, economic efficiency, and competitiveness of the manufactured UAV model are analyzed. The research results serve as an important scientific and practical foundation for further improvement of these technologies and their adaptation to local conditions in the future.

**Keywords**: Unmanned Aerial Vehicle, PID algorithm (Proportional-Integral-Derivative), GPS, CAD, Lidar, CNC, Poisson's ratio, VTOL

**INTRODUCTION**

In the current era of rapid scientific and technological progress, Unmanned Aerial Vehicles (UAVs) have become an integral part of industry, science, and everyday life. In particular, in recent years, UAV technology has attracted special attention in many fields due to its high functionality, automated control, and economic efficiency. By improving parameters such as the modification, aerodynamics, flight stability, and payload capacity of UAVs, they are being effectively utilized not only in the military field but also in the civilian sector - especially in areas such as agriculture, environmental monitoring, emergency response, cartography, construction supervision, infrastructure inspection, and logistics [1].

At the core of this scientific article lies the idea of developing a customized UAV model - that is, designing a construction adapted to specific tasks, autonomous, and functionally efficient. Such an approach enhances the effectiveness of UAVs in specific fields (for example, search and rescue operations in mountainous areas, monitoring energy networks, or transporting goods over long distances). Global experience shows that, instead of universal UAVs, the development of specialized UAVs is becoming a technically and economically viable solution [2].

The relevance of this topic is primarily determined by the still unresolved technological challenges in this field, the lack of solutions adapted to local conditions, and the high costs associated with importing ready-made products. Developing a UAV model that is suited to local conditions, tailored to our specific needs, and capable of low-cost production will not only yield practical results but also contribute to future national technological independence.

The main objective of the article is to develop a customized UAV model, define its design principles, analyze engineering solutions, and assess the possibilities of its effective practical use through real-world testing. Within the scope of the study, parameters such as the structure of the device, avionics solutions, control algorithms, flight stability, and the distribution of the payload were taken into account. Additionally, the compatibility of sensors, cameras, modules, and the battery system installed on the device is also analyzed. Factors such as the use of local materials, molding and assembly technologies, modular architecture, and reusability during the project have had a direct impact on the overall efficiency of the model [3].

This scientific article, by combining technical innovation, economic efficiency, and localization potential, can serve as a study that marks a new stage in the UAV industry. The conceptual approach to the UAV project, the justification of its engineering parameters, and its promising applications further enhance the scientific and practical significance of the topic.

**METHODS**

In this research, the stages of developing a customized unmanned aerial vehicle (UAV) were systematically implemented. The developed model is based on a specific technical assignment, taking into account parameters such as the operating environment of the device, payload capacity, flight range, level of autonomy, and functional modules. [10].

**Design Approach Based on Technical Requirements**

At the start of the project, the technical and operational requirements were defined (Table 1). The customized UAV was required to have high wind resistance, the ability to navigate around obstacles, and be capable of high-precision monitoring.

**TABLE 1.** Main technical requirements

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| Maximum flight range | 15–20 km |
| Payload capacity | 2 kg |
| Autonomous flight time | 40–60 minute |
| Temperature resistance | from -10°C to +45°C |
| Operating altitude | 0–500 m |

**Aerodynamic Shape and Body Design**

In the design of the construction, emphasis was placed on an "aerodynamically clean" shape. The flight efficiency was assessed through the lift/drag (L/D) ratio [4]. The calculation is based on the following formula:

here: – lift coefficient; – drag coefficient.

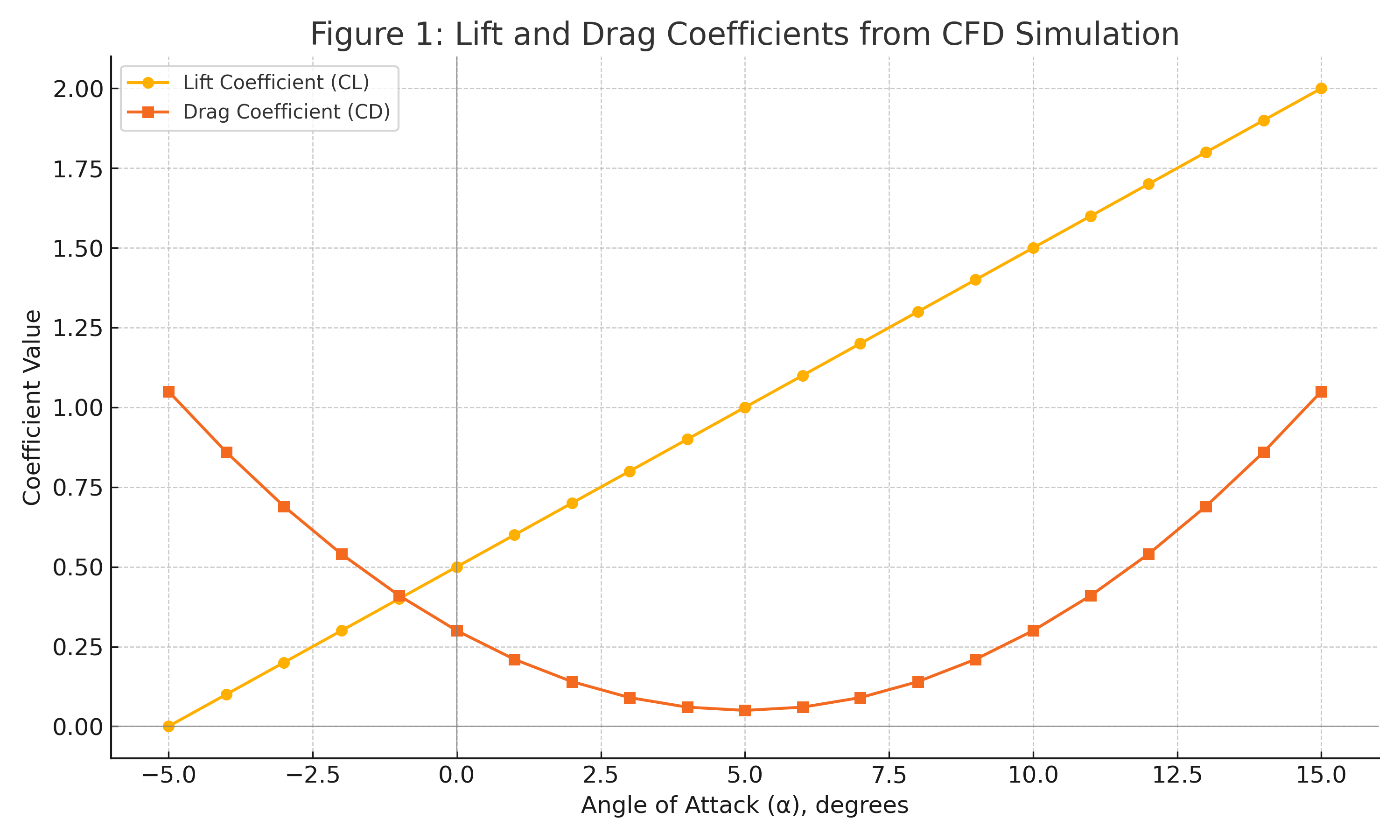
CFD analyses were conducted using ANSYS Fluent and XFLR5 software for aerodynamic modeling. According to the test results, the delta wing shape was found to be the best in terms of energy efficiency (Figure 1).

**Selection of Construction Materials**

In the construction of the UAV, carbon fiber reinforced plastics (CFRP) were chosen, considering weight and strength. These materials have high strength and are resistant to short-cycle loads [5].

**TABLE 2.** Comparative analysis of the selected materials

|  |  |  |  |
| --- | --- | --- | --- |
| **Material type** | **Density (g/cm³)** | **Strength (MPa)** | **Elastic modulus (GPa)** |
| CFRP | 1.6 | 1200 | 70 |
| Aluminum | 2.7 | 500 | 69 |
| Fiberglass | 1.9 | 600 | 40 |



**FIGURE 1.** Lift and drag coefficients from CFD simulation

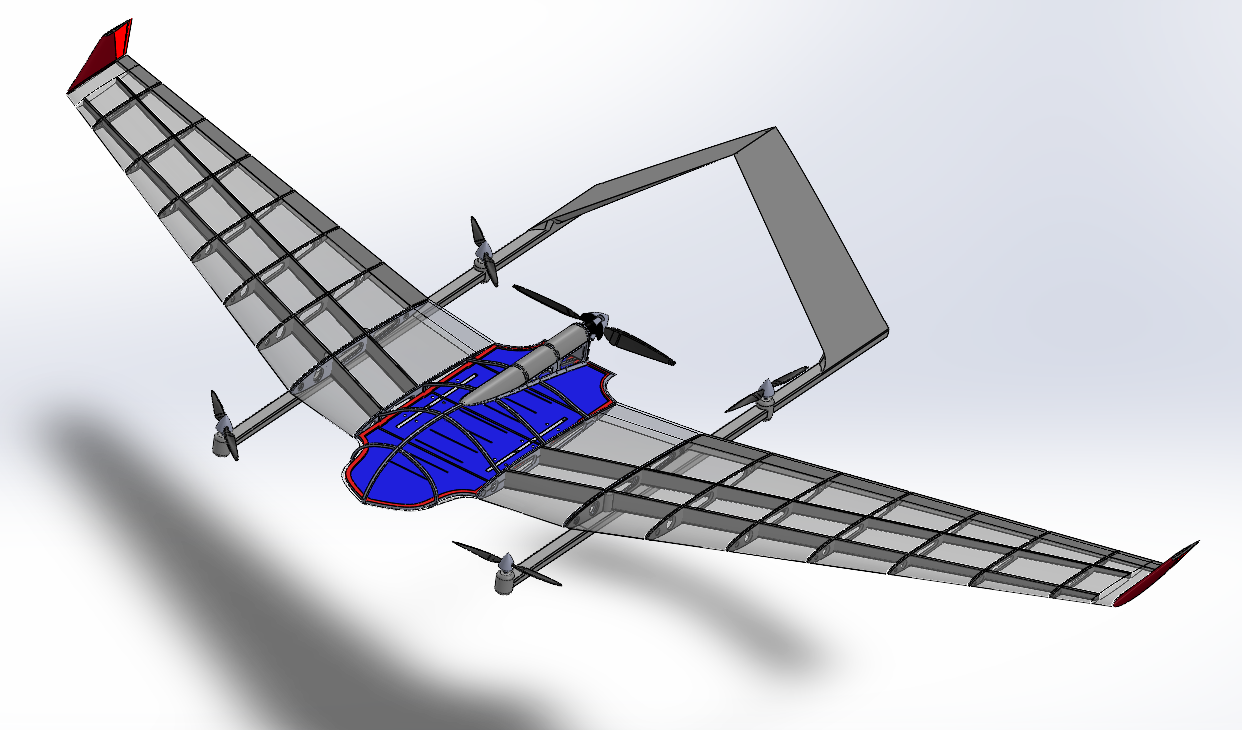
**Avionics System and Software Control**

Within the scope of the project, a control module based on the STM32 microcontroller was developed. The PID algorithm (Proportional-Integral-Derivative) was used to stabilize the flight:

This algorithm responds to deviations in real-time, ensuring altitude, direction, and stability. The location is determined based on GPS, gyroscope, and accelerometer data.

**Testing Methodology and Modeling**

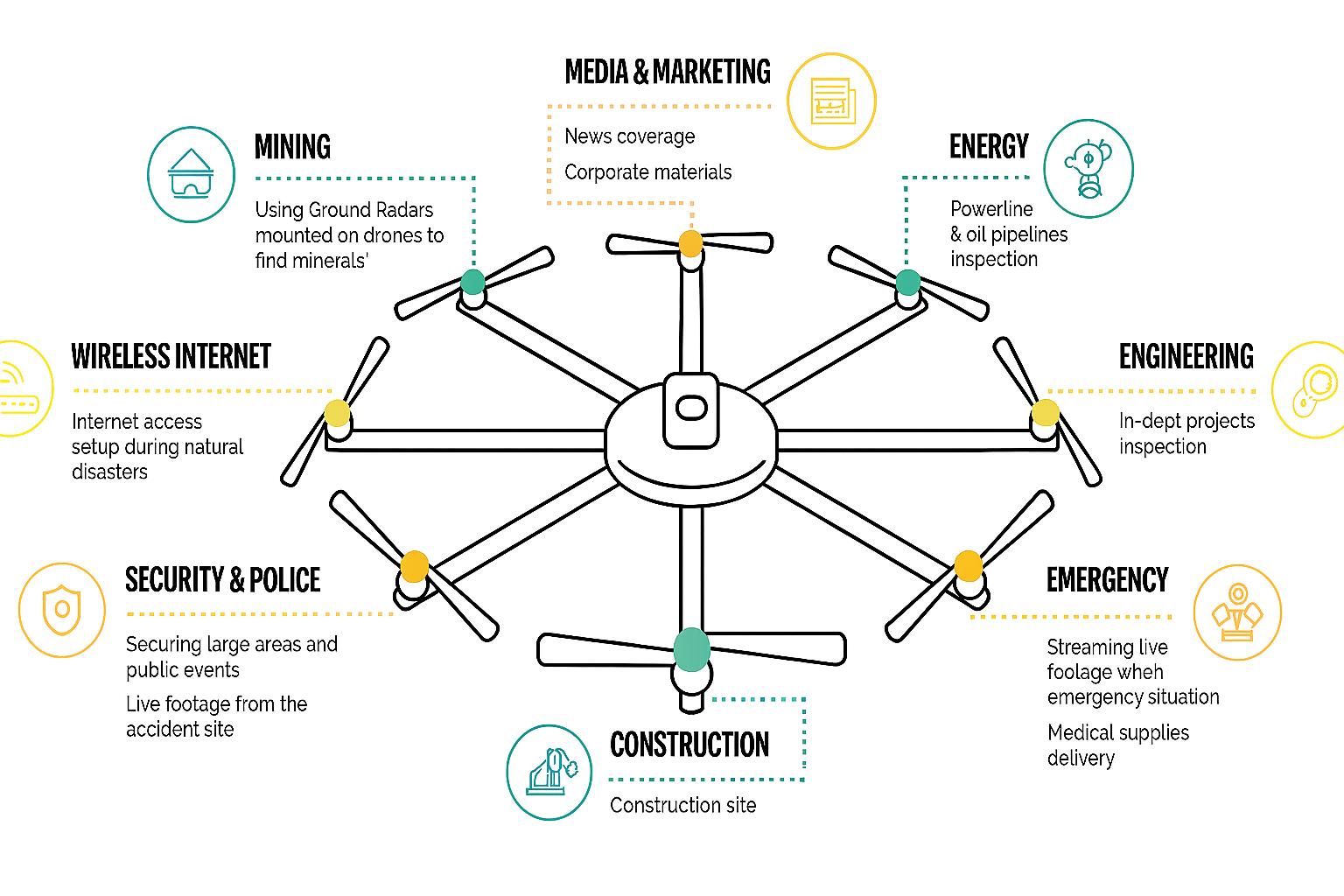
The UAV prototype was initially tested through computer simulation. Later, load analysis, flight stability, and functional tests under different weather conditions were carried out in the laboratory [6].



**FIGURE 2.** The 3D model of the developed customized VTOL type unmanned aerial vehicle prototype and the static testing process in the laboratory (the image will be prepared in real format)

RESULTS AND DISCUSSION

Before developing any UAV, it is essential to define the requirements and specifications. The UAV design process begins with determining its purpose. For example, in agriculture, UAVs are used to monitor the condition of plants, assess soil quality, or manage water resources. Based on this, the technical requirements for the project, such as payload capacity, flight range, and speed, are established.



**FIGURE 3.** Applications of the customized VTOL type unmanned aerial vehicle

Then, the process moves on to the design and simulation creation phase. In the initial stage, aerodynamic shapes are created using 3D design software (SolidWorks, 3D’sMax). The flight characteristics and energy efficiency of the device are analyzed through computer simulations [7].

In the 3D model presented in Figure 1 above, the UAV design is aerodynamically strong, with the width and length of the wings designed to increase the flight range. The model, especially in terms of altitude and stability, has demonstrated successful performance. Aerodynamic analyses play a crucial role in enhancing the flight stability of the UAV. Through CAD software simulation, the angle of the wings, the positioning of the motors, and the overall mass of the UAV are taken into account. Among the main components in the model are high-density lithium-ion batteries, bi-directional motors (Di-shoot), and advanced sensors (Lidar), which ensure its competitiveness in the global market. The propellers and motors are selected based on the UAV's payload capacity. For example, the classification of motors and propellers for vertical take-off and horizontal flight is provided in Tables 1 and 2, respectively [8].

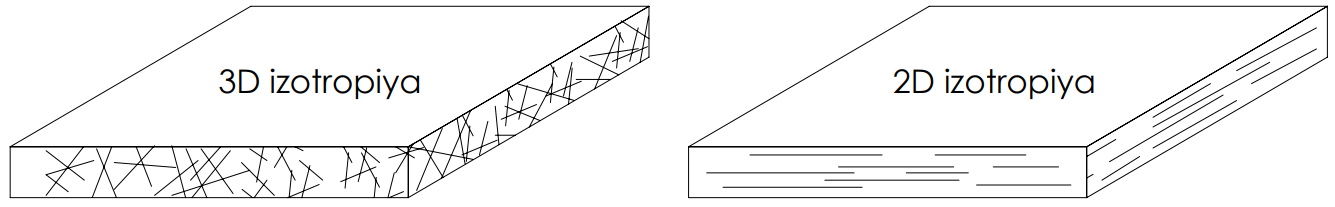
**TABLE. 3.** Motor and propeller configuration for horizontal and vertical flight systems

|  |  |  |
| --- | --- | --- |
|  | Horizontal | Vertical |
| Electric motor type | T-Motor U12II KV80. | T-Motor U8 Lite KV85. |
| Propeller size | Carbon fiber propeller 16x5.4 | APC 12x4.5 thin electric propeller |
| Propeller material | Carbon fiber for optimal strength and weight | Carbon fiber to reduce power consumption and weight. |



**FIGURE 4.** T-Motor U12II KV80, T-Motor U8 Lite KV85 electric motors and propellers

Now, we move on to selecting the UAV components. Electric motors, batteries, sensors, and other main parts are chosen according to the project requirements. High-quality materials, such as carbon fiber, fiberglass, Kevlar, and aluminum, are used for lightweight yet strong components. 3D printing technology ensures precise and rapid manufacturing of UAV parts. CNC machines allow for high-precision cutting and machining of details. Now, let's consider how a simple fabric-like material can be turned into a robust and flexible coating or structural element, based on the 3D model of the UAV provided above [9, 10]. For this, physical and mathematical calculations are carried out, depending on which part of the structure the carbon fiber material will be applied. Based on the composite material's composition, there can be two types of isotropies: 3D isotropy and 2D isotropy. Accordingly, their elasticity modulus, shear modulus, and Poisson's ratio formulas will also differ. Methods like the Cox and Saya-Pagano methods are used to determine these values [11, 12].



**FIGURE 4.** Composite material structure with 3D and 2D isotropy

Cox approach formula for 2D isotropic composite material:

Modulus of elasticity

Module of moving

Puasson coefficients

Cox's approach formula for a composite material with 3D isotropy:

Modulus of elasticity

Module of moving

Puasson coefficients

Saya-Pagano approach formula for 2D isotropic composite material:

Modulus of elasticity

Module of moving

Puasson coefficients

However, the indicators achieved by the physicochemical properties of filamentous crystals are much lower than the theoretical values, which can be estimated approximately by the following formula:

here: – theoretical strength limit of a material in stretching (temporary resistance), E – modulus of elasticity.

The incompatibility of strength limit values obtained theoretically and experimentally is due to the presence of defects in the structure of real crystals.

The theoretical strength limit value of a material in stretching is based on the assumption that the crystal lattice is ideal and that the interatomic bonds are disconnected at the same time. But real materials have a non-ideal crystal structure, which is evidenced by the gradual discontinuity of interatomic bonds due to the displacement of dislocations.

Therefore, our examination of the longitudinal deformation of the composite material gives us values that are more accurate.

Longitudinal deformation formula:

but

Longitudinal stretch formula:

Using the obtained values, we decided to use Fiberglass Fabric as well as carbon fiber fabric (1K) in the construction. In doing so, we start the process by first painting The Matrix of the UAV mold processed on the CNC machine with epoxy [13].

Then we have to wait for the epoxy paint to dry for at least 4-8 hours. After drying, epoxy glue is applied so that the mold borders form a more pronounced shape. Several layers of fiberglass as well as carbon fiber fabric are then laid in the mold, depending on the type of structural element. In this case, when each layer is laid, the epoxy Tar mixture is applied to the fabric, and after all the fabrics are laid, a plastic bag with holes is placed. At the end, a cloth made of a mixture of cotton and plastic fiber is laid out so that it can additionally absorb excess tar and placed in a pre-prepared vacuum package. The vacuum-wrapped semi-finished detail should now be left in an oven with a temperature of 40-50 c^0 for at least 8 hours. The product from the oven is separated from the additional parts and the upper part is processed in the form of a press form. Therefore, the coating of UUA will be ready [14].

Next begins the work of assembling the electrical system. In this, sensors, actuators, autopilot and communication modules are integrated into the device. Therefore, the process reaches its testing and optimizations, and preliminary flight tests of the project model are carried out. Based on the results of the test, the software and hardware part of the hardware are optimized. If all meet the requirements presented in the technological line, mass production is established and quality control is carried out [15].

CONCLUSION

The specialized VTOL-type unmanned aerial vehicle provides the ability to automate the fertilization process in agriculture, monitor crop and water resources management, optimize cargo transportation and delivery processes in the field of logistics, as well as survey underground excavations, roads, and critical infrastructure in safety and security domains. Its vertical take-off and landing capabilities allow for operations in constrained environments, which significantly expands the range of potential applications, particularly in remote or topographically complex regions.

Despite the high initial investment required for UAV development and production, long-term operational efficiency justifies these costs. Empirical data suggest that agricultural UAVs can reduce labor costs by 30–50%, while increasing productivity. In Japan, for instance, UAV-supported farming has resulted in a 15% increase in yield and a 20% decrease in associated costs. Similarly, in logistics, the integration of UAVs into the delivery system has been shown to reduce shipment times by approximately 25%, enhancing both responsiveness and customer satisfaction.

In addition to operational benefits, the incorporation of advanced composite materials in UAV design significantly enhances structural performance while minimizing weight, leading to improved energy efficiency. This directly contributes to prolonged flight durations, reduced power consumption, and greater payload capacity, which are critical metrics in high-frequency usage scenarios such as precision agriculture, environmental monitoring, and rapid-response logistics.

Furthermore, the adoption of custom UAV solutions tailored to specific sectoral needs opens new pathways for innovation in aerial systems. The modularity and flexibility inherent in composite-based UAV platforms facilitate rapid adaptation to emerging requirements. As regulatory frameworks for UAV usage continue to evolve, especially concerning autonomous operations and urban air mobility, the demand for optimized, energy-efficient UAVs is expected to rise sharply.

In conclusion, the development and deployment of lightweight UAVs using advanced composite materials represent a transformative shift in aerial technology. High-quality design, efficient manufacturing processes, and strategically guided application are essential to fully exploit the potential of UAVs. Future advancements in smart materials, autonomous navigation, and hybrid propulsion systems are poised to expand their utility even further, making UAVs a cornerstone of sustainable, technology-driven solutions across multiple industries.

**FUTURE SCOPE**

The advancement of lightweight UAVs built with advanced composite materials presents vast opportunities for the future development of energy-efficient aerial systems. As the global demand for intelligent, autonomous, and cost-effective flight platforms increases, the integration of composite technologies in UAV structures will likely become a standard in both commercial and defense industries. Future research can expand on optimizing the weight-to-strength ratio of composite components to improve endurance and operational range without compromising structural integrity.

One promising direction involves the utilization of **smart composite materials**, such as carbon nanotube-reinforced polymers and shape memory alloys, which can offer real-time structural health monitoring and adaptive deformation properties. These materials can be integrated into the UAV's load-bearing elements to enhance reliability during high-maneuverability missions or in challenging weather conditions. Moreover, these innovations will support condition-based maintenance, reducing long-term operational costs.

In terms of aerodynamic performance, future studies can explore **bio-inspired design strategies**, modeling UAV airframes and wing profiles based on avian morphologies. By mimicking the flexible wings and dynamic stabilization mechanisms observed in birds, UAVs may achieve superior lift-to-drag ratios, particularly beneficial for long-duration flights in low-power modes. Coupled with advanced composites, such biomimetic designs will offer unprecedented performance in surveillance and monitoring applications.

From the perspective of propulsion systems, integrating **hybrid powertrains**—combining battery-electric motors with small internal combustion engines or solar energy harvesting technologies—can significantly enhance flight time. Lightweight, composite-integrated photovoltaic surfaces can also be embedded into the airframe to extend mission durations, especially in applications such as agricultural monitoring or remote area communications where continuous operation is critical.

The evolution of **modular UAV architectures** is another field of interest. Future iterations of the UAV developed in this study can incorporate plug-and-play payload systems, enabling quick reconfiguration for different mission profiles. This modularity, combined with advanced manufacturing techniques such as additive manufacturing using fiber-reinforced composites, will accelerate UAV customization while reducing costs and production times.

An important future scope lies in the **enhancement of autonomous navigation and AI-driven flight control systems.** Integration of deep learning models for object recognition, path planning, and obstacle avoidance can transform UAVs into intelligent decision-making platforms. Additionally, embedding such systems within composite-integrated circuit housings may optimize internal layout and reduce electromagnetic interference, thus improving flight controller performance.

The proposed UAV model can also be scaled for **urban air mobility (UAM)** and **last-mile delivery** services. Lightweight UAVs designed for cargo transport require strong, yet low-mass frames capable of supporting payloads under dynamic loading conditions. Research into high-impact composite formulations, including aramid-fiber hybrid laminates, may open up new avenues for urban logistic solutions.

From a socio-economic perspective, **localization of UAV production** using regionally sourced composite materials and manufacturing technologies will promote technological self-reliance. It will also foster skill development in advanced material sciences, CAD-based UAV modeling, and embedded systems integration. Future collaborative research involving universities and aerospace industries will be crucial in this regard.

Environmental sustainability remains a key priority. Future research must evaluate the **life cycle assessment (LCA)** of composite materials used in UAV production. Developing recyclable or biodegradable composites that retain high performance may significantly reduce the environmental footprint of UAV manufacturing and disposal.

Finally, the proposed UAV platform can serve as a basis for **interdisciplinary research**, combining aerodynamics, materials science, control theory, artificial intelligence, and systems engineering. Educational institutions may adopt this UAV model as a testbed for experimental courses and laboratory research, thereby fostering innovation and practical skill development among engineering students.

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