doi: 10.32620/oikit.2025.105.06

УДК 629.735.33
Serhii Borysovych Kochuk, Rafael Trujillo Torres*, Artem Oleksiiovych Nikitin

Requirements Analysis for VTOL Fixed-Wing UAVs in Photogrammetric Applications

National Aerospace University «Kharkov Aviation Institute», Kharkiv, Ukraine,
** Hydra Technologies, Jalisco, México*

This article investigates the requirements, operational considerations, and configurations of vertical take-off and landing (VTOL) fixed-wing unmanned aerial vehicles (UAVs) for photogrammetric applications. As one of the most common civil uses of UAVs, photogrammetry requires platforms offering flexibility, endurance, and cost efficiency. The research identifies end-user demands and defines system-level requirements that shape UAV design, production, and deployment. It stresses that establishing these requirements early is crucial to avoid expensive modifications later in the project lifecycle.

A systems engineering approach analyzes UAV deployment, incorporating technical, economic, operational, social, and regulatory factors. The study explores the photogrammetry value chain, current applications, mission profiles, and operational risks in commercial settings. Special attention is paid to the legal and regulatory framework, which poses significant constraints for developers and operators integrating advanced UAVs into civil aviation systems.

The paper reviews UAV configurations suitable for photogrammetry, emphasizing VTOL designs that blend rotary-wing hovering with fixed-wing efficiency. It compares tilt-rotor, tail-sitter, and hybrid approaches, evaluating their advantages and limitations in endurance, payload capacity, maneuverability, and cost.

Findings indicate that tilt-rotor configurations provide excellent maneuverability and versatility but are often constrained by size. Tail-sitters offer weight and portability advantages yet face challenges in maintaining hover stability while capturing ground imagery. Cost is a key factor, with most commercial photogrammetry using UAVs priced USD 1,500–2,000 — a threshold exceeded by many VTOL fixed-wing models.

Key words: unmanned aerial vehicles; vertical take-off and landing (VTOL); photogrammetry; drone; unmanned aerial systems.

Introduction

Unmanned aircraft vehicle (UAVs) commonly known as drones, are aircraft that operate without a human pilot on board [1]. Recently the terms remotely piloted aircraft (RPA) or remotely piloted vehicle RPV as synonyms of unmanned aircraft System UAS. The exploratory research stage is generally referred to as the definition of user requirements. In many industries, this stage is essential because it often leads to new ideas or enabling capabilities that mature into the initiation of new projects[2]. Requirements form the foundation of a project by defining the basis for design, manufacturing, testing, and operations. Each requirement carries a cost, and therefore it is essential to establish a complete but minimal set of requirements early in the project lifecycle. Requirement changes at later stages of development can have a significant financial impact and may even result in project cancellation. [3]. This study adopts a systems engineering approach to identify the scope of the system of interest, considering economic, social, operational, and regulatory factors that influence future UAV developments. In section two analysis of the value chain of the photogrammetry industry and the current applications, in section three is analyzed the operational conditions of the system. In section four a brief review of the current status of the regulatory framework of the UAS or RPAS and its inclusion in civil aviation. In section five is presented the VTOL fix wing concept or so-called hybrid drone as a potential enabling technology in the UAS commercial industry and current photogrammetric applications, challenges and limitations. Finally, the conclusions and recommendations for future work are presented.

1. Photogrammetric Applications

The use of drones in the civil sphere can be classified into three major areas: a) commercial, b) Public and safety and c) research. this document deals with commercial applications. Nowadays the UAS civil operations are classified according to their application showed in table 1. The operation of drones as a work tool in different productive sectors has created over 127 billion dollars' industry market [4].

Table 1

Classification of civil UAV operations

Category	Description	Example
Surveillance / Photogrammetry	Short range imagine capture and analytics	Infrastructure inspection /traffic accident reconstruction
	Long range imagine capture and analytics	Precision agriculture / BIM Models
	Using photo and video applications without analytics	Inspection Real time
Entertainment / advertising	Marketing purposes	Light Swarm Show / Drone Racing / Advertisements
Signal emission	Providing multimedia bandwidth by emitting signal / video / sound	Facebook Aquila project
Mobility	Passenger Transport	Taxi / Personnel Shuttle Services
	Last-Mile Delivery / Parcel Shipping	Healthcare Logistics / Autonomous Delivery Systems

In general, the commercial drone industry value chain can be divided into three major groups. Figure 1 illustrates the value chain and the elements that create value:

- Hardware
- Operations
- Services

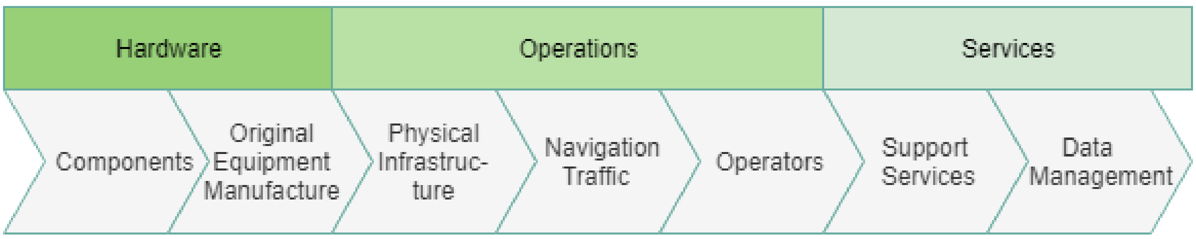

Fig. 1. Value Chain drone industry

In photogrammetric applications, the main value for the end user is to obtain accurate information in a short time in order to make decisions. Therefore, all developments in photogrammetry aim to enhance the value delivered to the application.

The introduction of UAVs as photogrammetric tools has significantly transformed data acquisition procedures in geodesic and surveying companies. The rapid expansion of UAV-based photogrammetry has been enabled by technological advances such as miniaturization of electronic components, light-weight payloads, and smartphone integration. UAV photogrammetry combines flexibility, low acquisition costs, and reduced operating expenses, making it a transformative technology in diverse fields such as urban infrastructure management, agriculture, and energy exploration.

A UAV photogrammetric platform typically consists of a remotely controlled or semi-autonomous aircraft equipped with a photogrammetric system[5], the platform is equipped with a photogrammetric measurement system, including small or medium size still-video or video camera, thermal or infrared camera systems, airborne lidar system, or combination of the mentioned elements, therefore this kind of applications in the UAV industry can be understood as a new tool modifying the insights in the market. The common applications of photogrammetric drones are:

- thermography inspections
- structural inspections
- volume calculation
- surveying
- 3D cloud points
- 3D Texture model
- digital surface and terrain cloud
- orthomosaic
- contour lines

The role of the unmanned aerial vehicle (UAV) as a photogrammetric tool should be understood within the broader context of the photogrammetric system. This holistic perspective clarifies the UAV's function in the value chain of the industry. While the aircraft itself is important, processing software ultimately defines the business model in photogrammetry. In recent years, such software has become increasingly relevant, as field data acquisition protocols often dictate the operational procedures of the UAV.

Figure 2 illustrates a generic workflow commonly used by geodesic companies.

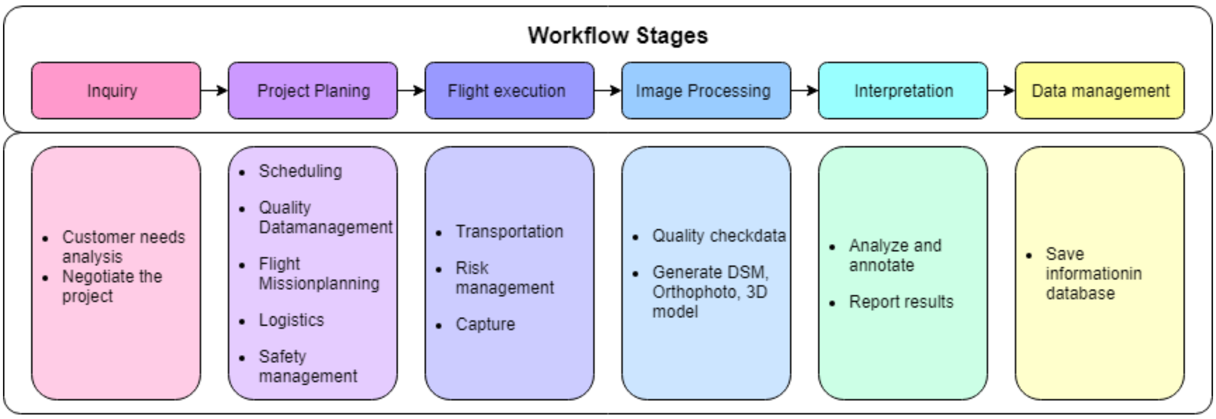

Fig. 2. Generic Process Workflow in Photogrammetric Drone Operations

The commercial drone industry has been characterized by rapid change, with new alliances emerging among hardware manufacturers, software developers, cloud service providers, and payload suppliers. These collaborations have strengthened the value chain and improved the overall user experience. This dynamic environment has required geodesic companies to adapt continuously, and over the past years, a standardized operational model for photogrammetric drone missions has become evident.

2. Concept of Operations CONOPS

The mission profile is fundamental to UAV conceptual design as it describes the flight trajectory and actions carried out in flight. [6], From a systems engineering perspective, the analysis of CONOPS provides a comprehensive understanding of the intended operation of the system, allowing for requirement definition and function allocation within the conceptual design process. In order to analyze UAS operations, the mission was decomposed into stages, as illustrated in Figure 3. A user journey map was created based on interviews, user guides of the main image processing software, and on-site observations. Figure 4 illustrates the stages and main functions. However, this generic mission journey map can vary and should be adapted to the specific mission and the organizational work culture of each company

Fig. 3. Mission Stages in Photogrammetry Applications

Mission Planning: According to the project schedule and quality management plan, the operator coordinates the mission flight path and analyzes potential risks in the mission area, using commercial mapping APIs and other available field data. The outcome of this process is a safety management plan and a mission flight path, which are then uploaded to a computer or mobile device for execution in the field.

It is recommended that the system of interest (SOI) be managed by the mission planner and uploaded onto the hardware. The ground control station should consist of a mobile device, tablet or a heavy-duty laptop.

Transport to Mission Location: The operator transports the mission equipment to the designated location, usually assisted by one or two colleagues and accompanied by the necessary signaling and safety devices. The mission equipment (UAV, ground control station, and tools) should be carried by two people, ideally in a transport case that fits into a car trunk or rear seats. The UAV itself should be trans-ported in a backpack for ease of handling.

Flight Execution: The operator and assistant execute the safety management plan and identify real-time risks in the field, taking into account weather conditions and the operational context. Once execution is confirmed, the operator selects the take-off area according to the mission flight plan. If conditions prevent take-off at the planned location, a new take-off point is selected and updated in the mission planner. During the mission, the operator constantly monitors the UAV’s position with the assistance of colleagues. After the UAV returns to the home point and lands, the system’s integrity and the captured image files are verified.

The mission should be recorded in the flight logbook, documenting any errors or unexpected events that occurred during flight. The UAV system should not require tools for assembly; after each mission it must be ready, or nearly ready, for subsequent operations. The system should also provide an indicator that allows the operator to verify the payload’s functionality. The use of catapults or additional external devices for take-off should be avoided, as the system must be capable of taking off and landing within a small area (2–5 m^2).

Desirable system functions include: automatic return-to-home capability, obstacle avoidance, real-time display of the payload’s field of view, and the ability to hover for inspection tasks. Flight endurance should exceed 30 minutes, with 60 minutes being preferable. Typical missions range from 40 to 2,000 hectares, requiring a minimum image overlap of 60%. Maintaining accurate adherence to the planned flight path is critical. The system should also be capable of storing mission paths for repeated execution in the future.

Post-Mission Operations: Following mission completion, the UAV and its payload are recovered, and the acquired data are transferred to the operational facility. Data extraction is typically performed through storage devices such as microSD cards or USB interfaces, enabling subsequent processing and analysis. To ensure operational effectiveness, the information should be easily retrievable and transferable to a computer for further use and dissemination among colleagues. Furthermore, the UAV storage case should be designed with dimensions compatible with standard office shelving systems, allowing practical handling and storage.

3. The mission profile definition

Mission profiles for photogrammetric UAVs can be categorized into three primary types: free-flight missions, circular missions, and grid or S-pattern missions. Free-flight missions provide maximum flexibility, allowing operators to control UAV direction and altitude to adapt to uncertainties. Circular missions involve semi-autonomous paths around a target, typically used for 3D scans. Grid missions are fully autonomous, designed to capture systematic images for large-scale mapping, orthomosaics, and terrain modeling., classification and description of Mission show in table 2.

Since different applications require specific missions, mission profiles can be classified according to the flight path into three main groups: free-flight, circular, and S-pattern missions.

Free-flight missions: In this type of mission, the operator maintains control of the UAV at all times. There is no predetermined flight path, and the operator can adjust direction and altitude at any time to account for uncertainties in the mission environment. Hover time and proximity to the object of inspection are important factors. It is desirable for the operator to be assisted by distance sensors and first person view (FPV) technology to maintain situational awareness within the workspace. Figure 4a illustrates this mission profile.

Table 2

Mission classified in according to the operational flight path

Mission	Applications	Description
Free flight	Thermography	The UAV is employed as an inspection tool in scenarios where direct physical inspection is difficult, unfeasible, or poses elevated risks due to operational uncertainties. In such missions, the operator must retain the ability to assume manual control of the UAV at any time while continuously monitoring flight parameters. Typically, a second operator—an inspection specialist—manages the onboard camera in real time and evaluates the object of interest. These missions are generally carried out at close range.
	Structural inspections	
	Thermography inspection	
	Surveying	
Circular missions	Surveying	This type of mission is used to obtain 3D scans of buildings or objects for subsequent analysis. During these missions, the operator is assisted by an observer and relies on GPS data displayed on the screen, since visual line-of-sight (VLOS) may be lost. Such missions are typically conducted at close range, generally not more than 300 meters from the operator.
	Volume calculation	
	3D cloud points	
	3D Texture model	
Grid	Digital surface and terrain cloud	This type of mission is usually fully autonomous. To meet the requirements of image processing software, a standard flight pattern is necessary, and the camera must be triggered at fixed time intervals or distances. This function is typically programmed in the camera or the mission planner. The UAV must follow the planned path precisely to avoid data loss. In most cases, the operator is assisted by one or two observers and GPS tracking displayed on the screen. These missions are generally long-range but preferably remain within VLOS.
	Orthomosaic	
	Contour lines	
	Thermography	
Double Grid	3D cloud points	Similar to the previous mission type, the double-grid mission is commonly used for reconstructing urban or semi-urban areas. Its purpose is to achieve higher image overlap and produce more accurate 3D models. This mission requires greater flight endurance, and in practice, its completion often demands either two UAVs or multiple batteries.”
	Digital surface and terrain cloud	
	Volume calculation	
	Contour Lines	
	3D texture model	

Circular missions: In this type of mission, the flight path is executed around the object of interest, and the mission is carried out in a semi-autonomous mode. It is desirable for the flight to be supported by collision-avoidance systems. Figure 4b illustrates the corresponding flight path.

S-pattern missions: In this type of mission, the object of interest is a large region, and the flight characteristics are determined by the requirements of the image processing software. The UAV operates in a fully autonomous mode, and it is desirable that the operator does not intervene except in emergency situations or for safety procedures. It is important that the UAV follow the planned flight path with minimal deviations and that the payload be triggered at the correct times or coordinates. Figures 4c and 4d illustrate the corresponding flight paths.

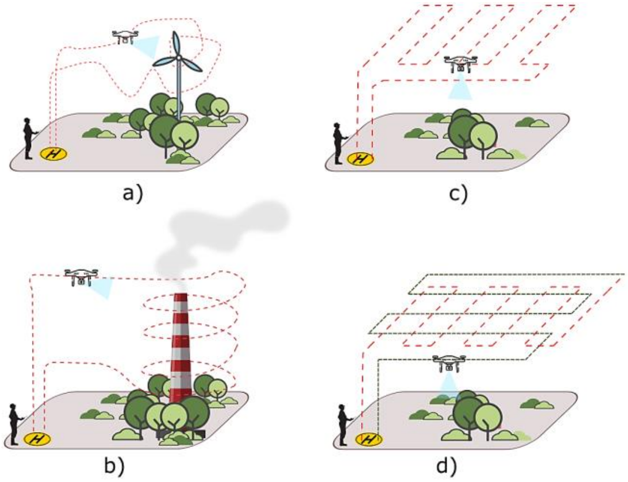

Fig. 4. Mission Profiles

In general, mission scenarios can be classified into two types:

- Open field missions – Typically used in precision agriculture, mining, surveying, and construction. The main obstacles in these environments are terrain features or transmission towers.
- Urban missions – Conducted in cities for applications in construction, surveying, and real estate monitoring. These missions are characterized by greater uncertainties and the presence of multiple obstacles, making S-pattern missions more challenging to execute.

4. Risk in operations and reliability

The concept of removing the aircraft pilot has made photogrammetric operations safer by protecting human lives and reducing operational costs. However, this concept also introduces new challenges. According to [7], the reliability of UAS must be ensured for the following reasons:

- If a UAS fails, the mission fails. In photogrammetric applications, this can result in the loss of critical information and, consequently, additional costs that reduce the profitability of company operations.
- If a UAV crashes, injuries or fatalities may occur.
- Any loss or malfunction of the system can result in the loss of the service provided, damage to facilities, and significant repair or replacement costs.

Risk is a central issue in technology management [8]. From a holistic perspective, risk is related to system reliability, potential failures, pilot training, and safety procedures. To maintain system reliability, it is necessary to understand its operational behavior. One of the most common tools for mitigating risk is to identify the origin of failures. Risks can generally be categorized into three groups according to their nature, as illustrated in Figure 5, which shows both the classification and the sources that can gen-erate risk.

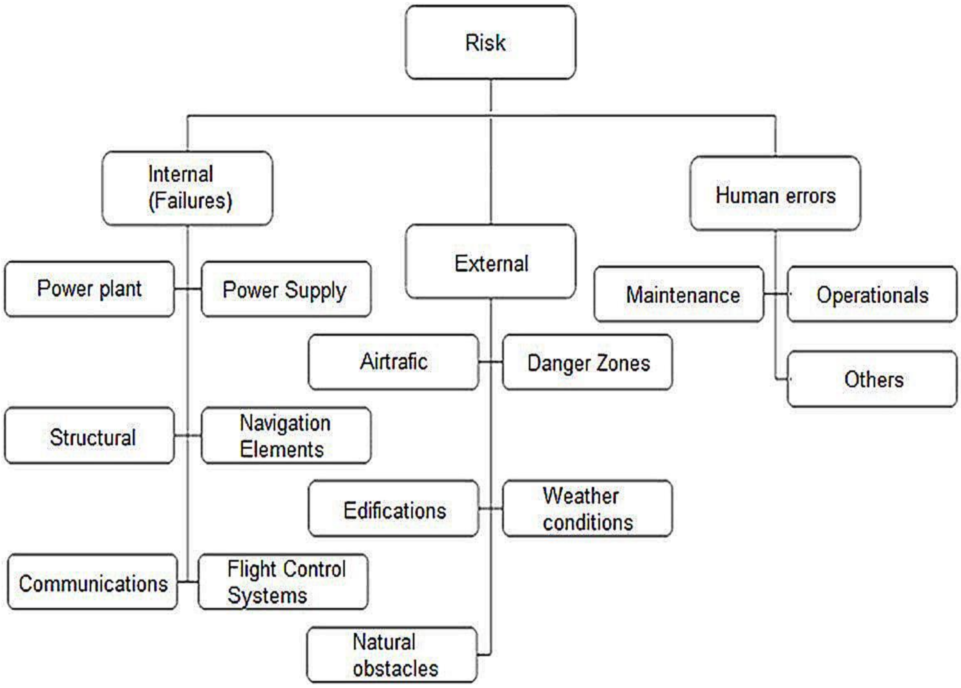

Fig. 5. Operational risks in Unmanned Aircraft Systems Operation

Reliability must be considered from the system's conceptual design phase. Poor design increases operational uncertainties; however, it is essential to balance risk perception with the overall cost of the final system.

Therefore, design for reliability directly affects the UAS specifications. As a consequence, during conceptual design formulation and system architecture definition, reliability functions must be allocated at the component level.

In particular, the fault-tolerance function should be assigned to the control system, since this property significantly enhances aircraft reliability. This means that the UAV must demonstrate the ability to continue operating without compromising safety, even in the event of a failure of a control component or the loss of part of the airframe. Consequently, in the conceptual design stage, fault-tolerant control plays a critical role in defining what is meant by 'without compromising safety,' as well as in determining the control strategy, the positioning of control compo-nents, and the overall allocation of system functions.

5. Regulatory Framework

Most of the countries are now grappling with the regulatory issues related to drones, as they would with any innovation that has implications for public safety therefore countries are struggling to append UAS into their aviation regulatory framework. The challenge for regulate UAS includes the need to ensure that drones are operated safety, without harming public and national security, and in a way that would protect areas of national, historical, or natural importance also countries made efforts to address concerns regarding property and privacy right of land-owners or other person impacted by the operation of drones [8]. Regulatory framework changes by country context, however most of the countries have similar elements differing with wide ranges on the level of restrictiveness of each element that are often dictated by the whether country favors promotion of new technology or safety-first approach [9]. In the context of photogrammetric implies a commercial use licensing aircraft registration, labeling and insurance are required for the operation of the drone those requirements practically have become standard for countries with drone commercial regulation.

Several countries impose requirements according to country jurisdiction such as Flight authorization information, UAS Operator Qualification, Radio Communications, Safety features and spatial restrictions. Spatial restrictions has been a subject of interest and debate depending on the legislation of civil aviation, having as a main point the restriction flying close to airports, other spatial restriction are flights over sensitive locations and historical monuments or historical parks. The spatial restriction which drastically reduce the operation in commercial UAS is the Visual Line of Sight (VLOS). Maintain VLOS is requirement within 18 countries [9]. Efforts have been made to regulate Beyond Visual Line of Sight BVLOS in some countries, over all those who intend to use the UAS for parcel delivery.

The regulatory framework is being constantly evaluated and it is important to monitor international and local regulation, along with technology trends and security and safety incidents. Operational limitations based on Federal Aviation Administration FAA Part 107 for photogrammetric applications [10] are summarized in table 3 however at the author’s discretion it can be taken as a standard basis of operations.

Table 3

Operational Regulatory Requirements

Operational limitation	Regulatory requirement
Operator	Operator must hold a remote pilot certificate or be under the direct supervision of someone holding a Remote Pilot Certificate who is designated as the Pilot in Command
AUV Registration	Aircraft must be registered
Seen and avoid	VLOS only. First Person view cannot satisfy ”seen-and-avoid”
Operations	Daylight and civil twilight only
Visibility	Daylight and civil twilight only
Nonparticipating person	May no operate over any persons not directly participating
Maximum altitude	Below 120 m AGL (Above Ground Level)
Airspace	May only operate in uncontrolled airspace without air traffic control permission
Accident reporting	Any accident resulting in serious injury, loss of consciousness, or property damage of at least $500 must be reported to the FAA within 10 days.

6. VTOL fixed wing UAV

In photogrammetric applications, fixed-wing aircraft are typically employed for missions requiring coverage of large areas. Multirotor endurance is limited due to the high energy demand of sustained flight, yet this configuration has proven more versatile for a wide range of operations. Market data indicate that most operators worldwide prefer multirotor platforms, with acquisition cost being the most influential factor, followed by maintenance expenses, availability of spare parts, and portability. In recent years, however, photogrammetric drone operators seeking to reduce operational costs have increasingly demanded systems that combine the extended range of fixedwing aircraft with the versatility of rotary-wing platforms.

This demand has posed a significant design challenge for drone developers. A natural engineering response has been the development of fixed-wing VTOL UAVs (Figures 6c–f), commonly referred to in the commercial drone sector as hybrid drones.

Fig. 6. Unmanned Aircraft Vehicles for photogrammetric purposes:
a) Fixed-wing Ebee SenseFly [11], b) Multirotor Matrice 200 DJI [12], c) VTOL Tail seater Quantix AeroVironment [13], d) VTOL Tail seater Wingtra [14],
e) VTOL Simplistic Configuration CW-10 JOUAV [15], f) VTOL Simplistic Configuration Transi-tion Alti UAS [16]

The term VTOL specifically denotes aircraft capable of climb and dive vertically, without the need for forward motion during take-off or landing [17].

The principal operational advantage of VTOL platforms is their ability to sustain a fixed position and altitude relative to the ground, a flight condition known as hovering. Fixed-wing VTOL UAVs have emerged as a promising technological trend, as they integrate the key benefits of both fixed-wing and rotary-wing configurations. Consequently, they combine vertical take-off and landing capability with high cruising speeds and improved endurance. Such characteristics broaden the operational envelope, enabling a wider variety of missions or enhancing the efficiency and performance of conventional ones.

Hybrid UAVs are generally classified into two primary categories: Tail-Sitters (Figures 6c, d) and Convertiplanes (Figures 6e, f). Tail-Sitter aircraft launch and recover vertically on their tails, transitioning to horizontal flight by tilting the entire airframe through differential thrust or control surface deflection. Convertiplanes, by contrast, are aerial vehicles capable of taking off, cruising, hovering, and landing while preserving a horizontal reference line meaning the main body configuration remains constant through-out flight. A range of transition mechanisms is employed to accomplish the shift between vertical and horizontal flight modes.

The currently most versatile configuration in the civilian photogrammetry market, due to its lightweight design and ease of transport, is the Tail-Sitter (Win-tra, Figure 6d; AeroVironment, Figure 6c), with these companies leading this configuration. However, a key limitation of the Tail-Sitter design is its inability to hover and capture terrain imagery simultaneously. In contrast, hybrid drones with extended propulsion systems can perform this maneuver and generally exhibit superior flight performance. Nevertheless, this configuration involves a more complex airframe, requiring additional components to be assembled pre-flight, resulting in increased weight and reduced transportability [18].

The Tail-Sitter configuration employs a single propulsion system for both hovering and forward flight, whereas the extended propulsion configuration utilizes separate engines for hovering and forward flight. Consequently, during certain flight phases, the extended propulsion design includes inactive or “deadweight” elements, which reduce the overall system efficiency [19]. This design approach, often referred to as the “simplistic” VTOL architecture, involves adding a multirotor system to an existing fixed-wing aircraft [20–22]. All simplistic VTOL aircraft are, therefore, modified versions of preexisting fixed-wing platforms.

This modification inherently introduces a fundamental design conflict in the architecture of fixed-wing VTOL systems. The integration of multirotor propulsion modules, although indispensable for enabling vertical take-off and landing as well as hover capability, inevitably alters the aerodynamic and structural characteristics of the baseline fixed-wing platform. On the one hand, the additional lifting units and their supporting structures increase overall system mass and drag, which directly diminishes endurance and cruising efficiency compared to a conventional fixed-wing aircraft of similar dimensions. On the other hand, when the aircraft operates in hover or low-speed flight regimes, the distributed propulsion units demonstrate markedly lower efficiency than an equivalent pure multirotor system designed exclusively for hovering tasks. This trade-off, therefore, results in a situation where neither of the two operational modes — fixed-wing cruise nor multirotor hover — can achieve the performance levels of a specialized aircraft optimized for a single regime. The resulting compromise has direct implications for mission planning, payload capacity, and operational economics, necessitating a careful balance between design complexity, mission versatility, and achievable performance envelopes.

From the perspective of applied research and industrial practice, these trade-offs must be analyzed not only from a technical standpoint but also within the broader framework of anticipated operational demands. Based on the author’s evaluation of potential market trajectories, accumulated practical experience in the photogrammetric UAV sector, and evolving concepts of operation, it is evident that hybrid VTOL platforms are increasingly positioned as a dominant solution for medium- to large-scale mapping missions. Emerging customer requirements emphasize the ability to combine rapid deployment, autonomous operation in constrained environments, and long-endurance survey capability in a single aircraft. In this regard, Table 4 consolidates and systematizes a set of mission specifications reflecting these emerging trends in fixed-wing VTOL UAV development. The parameters presented therein are derived from both observed operational practices and predictive assessments of industry needs, thus providing a robust basis for the derivation of future system-level requirements. This table should therefore be regarded not merely as a descriptive summary, but as a structured framework for guiding research, design optimization, and standardization efforts in the next generation of photogrammetric UAVs.

Table 4

Terms of reference VTOL UAV fixed wing design for photogrammetry applications

<table>
<tr><td colspan="3">Aircraft vision statement</td></tr>
<tr><td colspan="3">To develop a compact, backpack-portable fixed-wing VTOL UAV delivering safe take-offs, precise landings, and efficient photogrammetry for mining, construction, and agriculture, with an acquisition cost of USD 1,500–2,000.</td></tr>
<tr><td colspan="3">Required mission specifications</td></tr>
<tr><td>Parameter</td><td>Value</td><td>Units</td></tr>
<tr><td>Flight endurance</td><td>50 – 60</td><td>minutes</td></tr>
<tr><td>Service ceiling</td><td>4</td><td>Km</td></tr>
<tr><td>Cruise speed</td><td>15 – 20</td><td>m/s</td></tr>
<tr><td>Maximum speed</td><td>25 – 33</td><td>m/s</td></tr>
<tr><td>Maximum take-off weight</td><td>2.5 – 4</td><td>Kg</td></tr>
<tr><td>Stall speed</td><td>10 – 12</td><td>m/s</td></tr>
<tr><td>Fixed wing rate of climb</td><td>3 – 5</td><td>m/s</td></tr>
<tr><td>Helicopter mode rate of climb</td><td>2 – 4</td><td>m/s</td></tr>
<tr><td>Hover ceiling altitude</td><td>4</td><td>Km</td></tr>
<tr><td>Landing area</td><td>5 – 7</td><td>m^2</td></tr>
<tr><td>Payload weight</td><td>500 – 800</td><td>gr</td></tr>
<tr><td colspan="3">Photogrammetry requirements</td></tr>
<tr><td colspan="3">• High-resolution camera
• Multispectral camera
• A camera mounted in damping base
• USB interface
• Ground sampling distance: down 1.5 cm/pixel
• Coverage at 120 m above ground level: 150 ha – 300ha</td></tr>
<tr><td colspan="3">Mission profile sequence</td></tr>
<tr><td colspan="3">The mission profile is illustrated as shown in Figure 7 and decomposed in the following sequence
• Take-off and climb
• Hover
• Hover to cruise transition
• Cruise fixed-wing configuration
• Cruise to hover transition
• Descent and landing</td></tr>
</table>

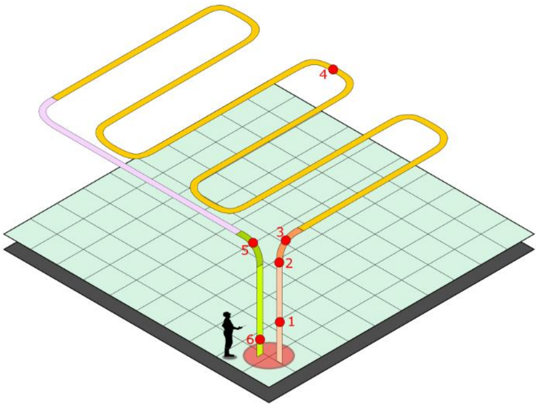

Fig. 7. Mission Profile

7. Case studies of practical applications

Practical experience in the field of photogrammetric drones and operational concepts was applied, for example, by the individual entrepreneur Zhezhera I. V. in the company Engineering Solutions [23] across several projects. One notable case was the survey of the chimney of the Kharkiv Coke Plant, where a thermal analysis of the chimney surface was obtained. This analysis was critical for a comprehensive assessment of natural and man-made conditions, as well as for evaluating the feasibility of reconstruction activities (Fig. 8-9).

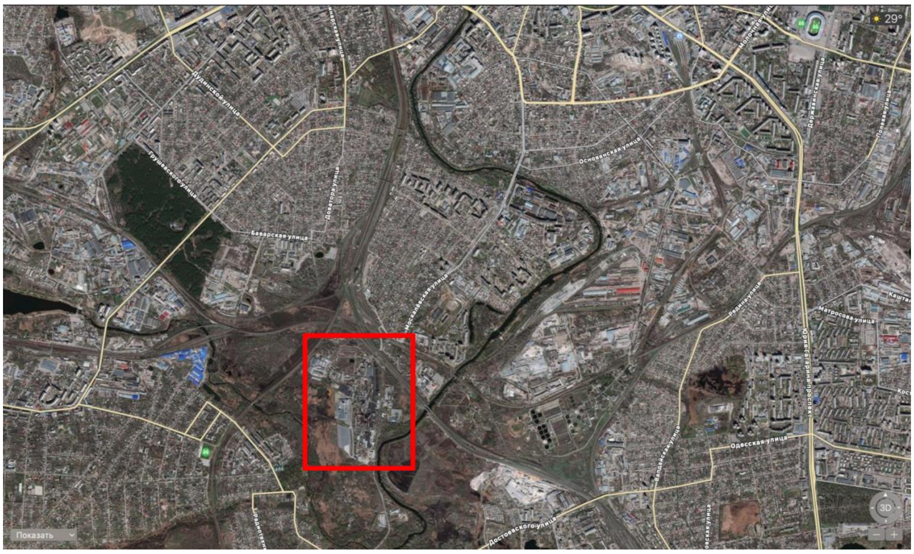

Fig. 8. Location of the Kharkiv Coke Plant work site

Industrial facility inspections often take place in hazardous urban environments, exposing workers to significant risks and technical challenges. Traditional approaches, such as using climbers with handheld thermal sensors, have notable drawbacks. These include limited accessibility to dangerous or high-temperature sites, reduced detail in thermal mapping, and dependence on operator expertise. Such methods also require extended fieldwork, resulting in higher costs and prolonged project timelines. In contrast, aerial thermal imaging with UAVs enables complete surface coverage and accurate detection of heat anomalies. The integration of specialized software allows for precise localization of abnormal zones, significantly improving the reliability and efficiency of inspection operations.

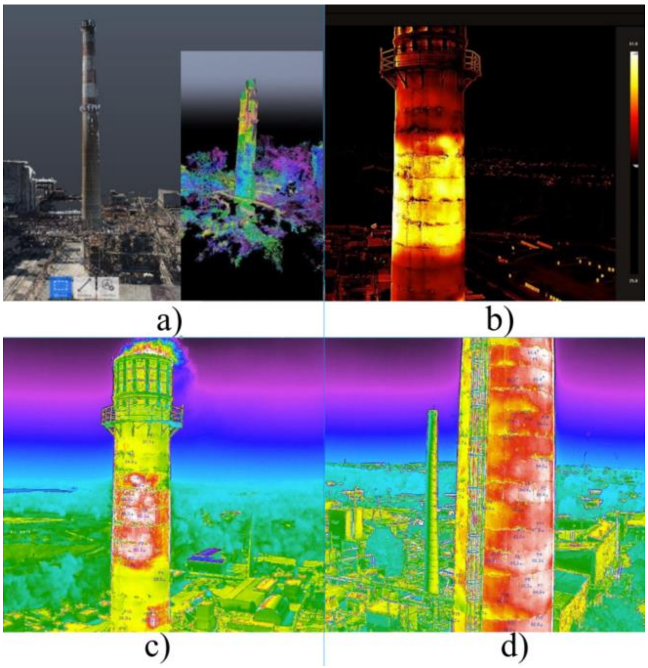

Fig. 9. a) Construction of a dense point cloud in RGB and IR channels. b) Image of Thermal Analysis Tool. c) Thermal image of chimney. d) Thermal image of a chimney at a relative height of 33 m

The comparative images (Figure 9 a-b) demonstrate thermal anomalies located on the pipe surface. Two ring anomalies are clearly visible in the upper part of the pipe. The upper ring anomaly, with a width of ~ 5.65 m, is located in the height range from 71.55 to 77.2 m from the ground surface. The lower ring anomaly, with a width of ~ 9.1 m, is located in the range from 42.9 m to 52 m from the ground surface.

As a result of the survey, thermal and visible models of the chimney of the Kharkiv Coke Plant were obtained, which allowed us to detect the presence of multiple cracks in the seams, holes, as well as anomalous thermal spots that can be formed by thinning (corrosion) of the structural wall of the pipe.

As part of another study, the goal was to obtain topographic and geodetic materials and data on the situation and relief of the area necessary for a comprehensive assessment of the natural and man-made conditions of the geological survey area and to substantiate the possibility of designing the central section of the Mykhailivske limestone deposit in the Voznesensky district of the Mykolaiv region (Fig. 10).

As a result of the shooting, 1850 photographs were obtained, which were used in the processing process. The obtained photographs have a reference in the WGS-84 coordinate system, hardware integrated during shooting. Based on this reference, an initial software alignment of the photographs is performed, after which a search for identifying marks is performed on each photograph. Next, based on the alignment data, a dense point cloud is constructed (see Figure 8), necessary for constructing a height map (see Figure 11 b) and an orthophoto mosaic (see Figure 11 c).

Fig. 10. Section of the Mykhailivske limestone deposit in the Voznesensky district of the Mykolaiv region

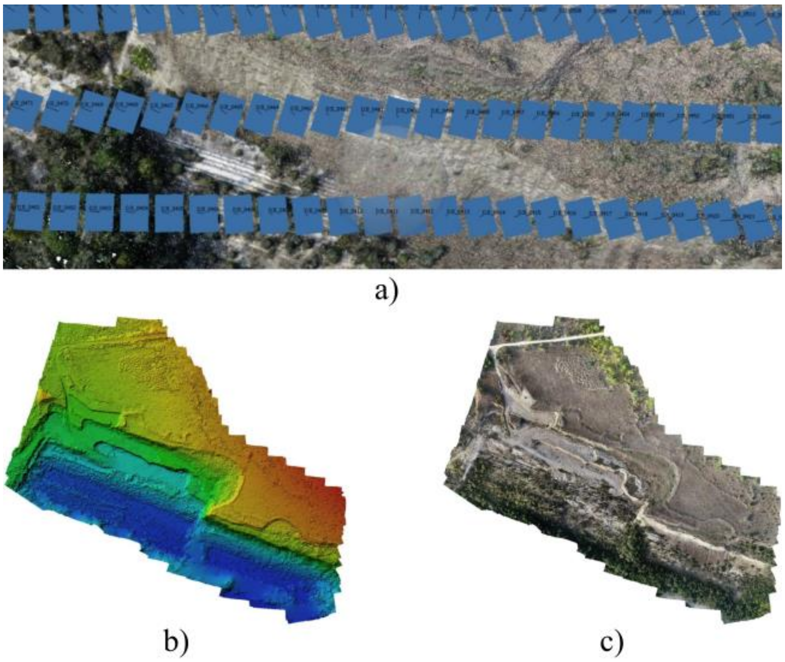

Fig. 11. a) Dense point cloud map. b) Elevation map of the Mykhailivske limestone deposit. c) Orthophotomosaic of the Mykhailivske limestone deposit

As a result of the engineering and geodetic studies conducted, compliance with the requirements of current building codes, rules and instructions was confirmed, which can serve as the basis for the development of project documentation.

8. Conclusions

VTOL tilt-rotor aircraft configurations, due to their advanced maneuvering capabilities, hold significant potential for commercial drone applications. Key unmet needs in the photogrammetry industry include expanding the area that can be scanned with a single battery, increasing endurance, and enabling take-off and landing in confined or unprepared areas [24, 25]. Several companies have already developed photogrammetric VTOL drones, with the augmented propulsion configuration being widely adopted. However, this configuration is limited in terms of overall dimensions and transportability.

A more versatile alternative in terms of weight and portability is the Tail-Sitter configuration; nevertheless, it cannot simultaneously achieve hover flight and capture ground imagery. Another critical requirement is acquisition cost, as industry studies indicate that over 70% of photogrammetry operations are performed with drones priced between USD 1,500 and 2,000 [26, 27], a range that current VTOL fixed-wing drones exceed.

The information presented in this article is intended to be informative, serving as a reference for future VTOL UAV design efforts, and supporting researchers and developers engaged in VTOL UAV development. It is also recommended that continuous updates on current remote-piloted aircraft regulations be maintained to ensure compliance and relevance.

References

1. Introduction To Unmanned Aircraft Systems / D. M. Marshall, R. K. Barnhart, S. B. Hottman, E. Shappee, M. T. Most // CRC Press. – 2012. – Ed. 1. – P. 45-49. DOI: 10.1201/b11202.
2. El-Diraby, T. Employing an Exploratory Re-search Stage to Evaluate Green Building Technolo-gies for Sustainable Systems / T. El-Diraby, A. Redmond, M. Papagelis // Proceedings of the Inter-national Conference on Civil, Structural and Trans-portation Engineering: ACM Press. – 2015. – P. 291-1 - 291-9.
3. Integrating life cycle assessment in the product development process: A methodological approach / L. M. Luz, A. C. Francisco, C. M. Pie-karski, R. Salvador // Journal of Cleaner Production. – 2018. – Vol. 193. – P. 10-13. DOI: 10.1016/J.JCLEPRO.
4. Unmanned Aerial Vehicles (UAVs): A Survey on Civil Applications and Key Research Challenges / H. Shakhatreh, A. Sawalmeh, A. Al-Fuqaha, Z. Dou, E. Almaita, I. Khalil, N. Othman, A. Khre-ishah, M. Guizani // IEEE Access. – 2019. – Vol. 7. – P. 48572-48634. DOI: 10.1109/ACCESS.2019.2909530.
5. Sauerbier, M. The practical application of UAV-based photogrammetry under economic aspects / M. Sauerbier, E. E. Siegrist, H. Eisenbeiss, N. Demir // International Archives of the Photogramme-try, Remote Sensing and Spatial Information Scienc-es. – 2012. – Vol. XXXVIII-1/C22. – P. 45-50. DOI: 10.5194/ISPRSARCHIVES-XXXVIII-1-C22-45-2011.
6. Rivera, F. An object-oriented method for the definition of mission profiles for aircraft design / F. Rivera, S. Jayaram // 32nd Aerospace Sci-ences Meeting and Exhibit. Ed. by Aerospace Scienc-es Meetings. American Institute of Aeronautics and Astronautics. – 1994. – P. 1-3. DOI: 10.2514/6.1994-867.
7. Unmanned Aircraft Systems: UAVS Design, Development and Deployment / R. Austin // John Wiley and Sons, Ltd., Publication. – 2010. – P. 250-264. DOI: 10.1002/9780470664797.
8. Chamata, J. Factors Delaying the Adoption of Civil Drones: A Primitive Framework / J. Chamata // The International Technology Manage-ment Review. – 2017. – Vol. 6, Iss. 4. – P. 125-132. DOI: 10.2991/itmr.2017.6.4.1.
9. Jones, T. M. International Commercial Drone Regulation and Drone Delivery Services / T. M. Jones // RAND Corporation, Santa Monica, Calif. – 2017. – P. 5-20. DOI: 10.7249/RR1718.3.
10. Eyes in the sky: bridge inspections with un-manned aerial vehicles. Final

Report SPR 787 / D. T. Gillins, C. Parrish, M. Gillins, C. Simpson // SPR. – 2018. – Iss. 787. – P. 1-179.

11. O'Sullivan, M. How LafargeHolcim Uses Drones to Manage its Stockpile Inventory & Opti-mise Efficiency / M. O'Sullivan, D. Gentilhomme, E. Rosset. – Access mode: https://www.sensefly.com/drone/ebee-mappingdrone/l – 15.12.2021.

12. 3D City modelling using multirotor drone for city heritage conservation / N. Mohd Noor, A. A. A. Abdullah, A. Abdullah, I. Ibrahim, S. Sabeek // Planin Malasya Journal. – 2019. – Vol. 17, Iss. 1. – P. 338-349. DOI: 10.21837/PMJOURNAL.V17.I9.610.

13. Mhmood, A. H. Optimal H-infinity PID Mod-el Reference Controller Design for Roll Control of a Tail-Sitter VTOL UAV / A. H. Mhmood, H. I. Ali // Engineering and Technology Journal. – 2021. – Vol. 39, Iss. 4A. – P. 552-564. DOI: 10.30684/ETJ.V39I4A.1861.

14. Zhou, M. Review of vertical take-off and landing fixed-wing UAV and its application prospect in precision agriculture [Text] / M. Zhou, Z. Zhou, L. Liu, J. Huang, Z. Lyu // IJPAA. – 2020. – Vol. 3, Iss. 4. – P. 10-15. DOI: 10.33440/j.ijpaa.20200304.130.

15. Radoglou-Grammatikis, P. I. A compilation of UAV applications for precision agriculture [Text] / P. I. Radoglou-Grammatikis, P. G. Sarigiannidis, T. D. Lagkas, I. D. Moscholios // Computer Networks. – 2020. – Vol. 172. – P. 1-18. DOI:10.1016/j.comnet.2020.107148.

16. Transition Flight Modeling of a Fixed-Wing VTOL UAV [Text] / B. Yuksek, A. Vuruskan, U. Ozdemir, M. A. Yukselen, G. Inalhan // Journal of Intelligent & Robotic Systems. – 2016. – Vol. 84. – P. 83-105. DOI: 10.1007/s10846-015-0325-9.

17. Crane, D. Dictionary of Aeronautical Terms [Text]: dictionary / D. Crane. – Second Edition. – Aviation Supplies Academics. – Inc. – 1991. – 615 p.

18. Kamal, A. M. Design methodology for hybrid (VTOL + Fixed Wing) unmanned aerial vehicles [Text] / A. M. Kamal, A. R. Serrano // Aeronautics and Aerospace Open Access Journal. – 2018. – Vol. 2, Iss. 3. – P. 165-176. DOI: 10.15406/aaoaj.2018.02.00047.

19. Development of Unmanned Cargo VTOL Aircraft [Text] / R. Czyba, Z. Gorol, M. Lemanowicz, M. Pawlak, A. Sikora // Modelling in Engineering 2020: Applied Mechanics. – 2021. – Vol. 1336. – P. 31-42. DOI: 10.1007/978-3-030-68455-6_3.

20. Öznalbant, Z. Design and Flight Test Study of a VTOL UAV [Text] / Z. Öznalbant, M. S. Kavsaoglu // Conference: 53rd AIAA Aerospace Sci-ences Meeting. – 2015. – P. 1-16. DOI: 10.2514/6.2015-1903.

21. Costandin, M. Non-linear Model and Trajec-tory Control of A Novel VTOL Vehicle II [Text] / M. Costandin, B. Costandin, P. Dobra // 2018 Interna-tional Conference on Unmanned Aircraft Systems (ICUAS). – 2018. – P. 806-815. DOI: 10.1109/ICUAS.2018.8453369.

22. Ferrarese, G. Modeling and Simulation of a Quad-Tiltrotor Aircraft [Text] / G. Ferrarese, F. Giu-lietti, G. Avanzini // IFAC Proceedings Volumes. – 2013. – Vol. 46, Iss. 30. – P. 64-70. DOI: 10.3182/20131120-3-FR-4045.00037.

23. Engineering Solutions Company – Access mode: https://engineering-solutions.com.ua/#projects – 15.08.2025.

24. Luna, M.A. Fast Multi-UAV Path Planning for Optimal Area Coverage in Aerial Sensing Applications [Text] / Luna, M.A.; Ale Isaac, M.S.; Ragab, A.R.; Campoy, P.; Flores Peña, P.; Molina, M. // Sensors. – 2022. – Vol.22, Iss.(6). – 2297. DOI:10.3390/s22062297.

25. Erez, H. Scheduling Spare Drones for Persistent Task Performance under Energy Constraints [Text] / Erez, H., Noa, A., and Sarit, K.// In Proceedings of the 17th International Conference on Autonomous Agents and MultiAgent Systems (AAMAS '18). International Foundation for Autonomous Agents and Multiagent Systems. – 2018. – P. 532–540.

26. UAV photogrammetric workflows: a best practice guideline [Text] / A. Federman, M. Santana Quintero, S. Kretz, J. Gregg, M. Lengies, C. Ouimet, J. Laliberte // ISPRS – International Archives of the Photogrammetry, Remote Sensing and Spatial Infor-mation Sciences. – 2017. – Vol. XLII-2/W5. – P. 237-244. DOI: 10.5194/isprs-archives-XLII-2-W5-237-2017.

27. Wang, J. Interstate Competition and State Regulation Variations in Commercial Drone Industry [Text] / J. Wang // Academy of Management Pro-ceedings. – 2018. – Vol. 2018, Iss. 1. – P. 100-120.
DOI: 10.5465/AMBPP.2018.13059ABSTRACT.

Надійшла до редакції 26.08.2025, розглянута на редколегії 26.08.2025

Аналіз вимог до безпілотних літальних апаратів з вертикальним зльотом і посадкою (VTOL) у фотограмметричних застосуваннях

У цій статті досліджуються вимоги, експлуатаційні аспекти та конфігурації безпілотних літальних апаратів (БПЛА) з вертикальним зльотом і посадкою (VTOL) для фотограмметричних застосувань. Як одне з найпоширеніших цивільних застосувань БПЛА, фотограмметрія вимагає платформ, що забезпечують гнучкість, довговічність та економічну ефективність. Дослідження визначає вимоги кінцевих користувачів та системні вимоги, які формують проектування, виробництво та розгортання БПЛА. У ньому наголошується, що раннє встановлення цих вимог має вирішальне значення для уникнення дорогих модифікацій на подальших етапах життєвого циклу проекту.

Системний інженерний підхід аналізує розгортання БПЛА, враховуючи технічні, економічні, експлуатаційні, соціальні та регуляторні фактори. У дослідженні досліджується ланцюг створення вартості фотограмметрії, поточні застосування, профілі місій та операційні ризики в комерційних умовах. Особлива увага приділяється правовій та регуляторній базі, яка створює значні обмеження для розробників та операторів, які інтегрують передові БПЛА в системи цивільної авіації.

У статті розглядаються конфігурації БПЛА, придатні для фотограмметрії, з акцентом на конструкціях VTOL, які поєднують можливості висіння гвинтокрилів з ефективністю фіксованого крила. Порівнюються підходи побудови БПЛА з поворотним ротором, типу tail-sitter та гібридними підходами, оцінюючи їхні переваги та обмеження щодо витривалості, вантажопідйомності, маневреності та вартості.

Результати дослідження показують, що конфігурації з поворотним ротором забезпечують чудову маневреність та універсальність, але часто обмежені розміром. Тип tail-sitter пропонує переваги у вазі та портативності, але зіштовхується з проблемами підтримки стабільності зависання під час зйомки поверхні землі. Вартість є ключовим фактором, оскільки більшість комерційних

фотограмметричних моделей з використанням БПЛА коштують 1500–2000 доларів США — поріг, який перевищують багато моделей літальних апаратів з вертикальним зльотом і посадкаю (VTOL) з фіксованим крилом.

Ключові слова: безпілотні літальні апарати; вертикальний зліт і посадка (VTOL); фотограмметрія; дрон; безпілотні авіаційні системи**.**

Відомості про авторів:

Сергій Борисович Кочук – доктор філософії (технічних наук), доцент кафедри мехатроніки та електротехніки, Національний аерокосмічний університет «Харківський авіаційний інститут», Харків, Україна, e-mail: s.kochuk@khai.edu, ORCID: 0000-0003-1429-2246.

Рафаель Трухільйо Торрес – інженер вбудованого програмного забезпечення, Hydra Technologies, Халіско, Мексика, електронна адреса: rafael.trujillo.torres@gmail.com, ORCID: 0000-0002-3177-9649.

Артем Олексійович Нікітін – асистент кафедри мехатроніки та електротехніки, Національний аерокосмічний університет «Харківський авіаційний інститут», Харків, Україна, e-mail: a.nikitin@khai.edu, ORCID: 0000-0001-6830-0710.

About the authors:

Serhii Kochuk – Doctor of Philosophy (Engineering), associate professor of Mechatronics and Electrical Engineering Department, National Aerospace University «Kharkiv Aviation Institute», Kharkov, Ukraine, e-mail: s.kochuk@khai.edu, ORCID: 0000-0003-1429-2246.

Rafael Trujillo Torres – Embedded Software Engineer, Hydra Technologies, Jalisco, México, e-mail: rafael.trujillo.torres@gmail.com, ORCID: 0000-0002-3177-9649.

Artem Nikitin – assistant of Mechatronics and Electrical Engineering Department, National Aerospace University «Kharkov Aviation Institute», Kharkiv, Ukraine, e-mail: a.nikitin@ khai.edu, ORCID: 0000-0001-6830-0710.