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CREATING AN INNOVATIVE ECOSYSTEM FOR THE DEVELOPMENT OF UNMANNED AVIATION IN UKRAINE: SYNERGY BETWEEN SCIENCE AND INDUSTRY

TWORZENIE INNOWACYJNEGO EKOSYSTEMU DLA ROZWOJU LOTNICTWA BEZZAŁOGOWEGO W UKRAINIE: SYNERGIA NAUKI I BIZNESU

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ABSTRACT

In this paper we advocate for the establishment of an aviation "innovative ecosystem" in Ukraine, particularly regarding the technology of unmanned aerial vehicles (UAVs). This ambitious strategy necessitates the introduction of new business models, taking advantage of new opportunities for achieving sustainable development goals in the increasingly resource-limited world. Moreover, this initiative faces a notable challenge: navigating the "double transition" of adopting both green and digital transformations across multiple domains. We believe the solution to creating an innovative ecosystem lies in harnessing the intellectual and infrastructural capabilities of top-tier research institutions – which in Ukraine include the National Aviation University (NAU) and the National Technical University "KPI." By combining the efforts of Ukrainian higher education institutions and actively enhancing international cooperation, in particular with the Łukasiewicz Research Network – Institute of Aviation in Warsaw – we argue – Ukraine can expedite the development of "factories" of ideas and innovations by supporting the training, incubation and growth of startups, encourage the formation of micro and small high-tech enterprises and bringing their products to global and regional markets, improving the mechanisms of interaction of the startup teams with venture capital funds and investment companies.

Key words: innovation, ecosystem, unmanned aerial systems, active interaction of research universities, synergy

ABSTRAKT

W niniejszym artykule opowiadamy się za utworzeniem "innowacyjnego ekosystemu" w dziedzinie lotnictwa w Ukrainie, ze szczególnym uwzględnieniem technologii bezzałogowych statków powietrznych (UAV). Ta ambitna strategia wymaga wprowadzenia nowych modeli biznesowych, wykorzystania nowych możliwości dla osiągnięcia celów zrównoważonego rozwoju w coraz bardziej ograniczonym zasobowo świecie. Inicjatywa ta napotyka na znaczące wyzwanie: nawigowanie przez "podwójną transformację", polegającą na jednoczesnym przyjęciu zielonej i cyfrowej transformacji w różnych dziedzinach. Uważamy, że rozwiązaniem na stworzenie innowacyjnego ekosystemu jest wykorzystanie intelektualnych i infrastrukturalnych możliwości wiodących instytucji badawczych – w Ukrainie są to między innymi Narodowy Uniwersytet Lotniczy (NAU) oraz Narodowy Techniczny Uniwersytet "KPI". Poprzez łączenie wysiłków ukraińskich instytucji szkolnictwa wyższego i aktywne zwiększanie współpracy międzynarodowej, szczególnie z Siecią Badawczą Łukasiewicz–Instytutem Lotnictwa w Warszawie, argumentujemy, że Ukraina może przyspieszyć rozwój "fabryk" pomysłów i innowacji. Wspierając szkolenie, inkubację i wzrost startupów, zachęcając do tworzenia mikro- i małych przedsiębiorstw wysokiej techniki oraz wprowadzania ich produktów na rynki globalne i regionalne, poprawiając mechanizmy współpracy zespołów startupowych z funduszami venture capital i firmami inwestycyjnymi

Słowa kluczowe: innowacja, ekosystem, bezzałogowe systemy powietrzne, aktywna interakcja uczelni badawczych, synergia

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Introduction

The development of unmanned aviation during the 20th century and into the early 21st century has proceeded in pace with major scientific and technical advancements – especially the advent of remote and automatic control systems, the introduction of a new elemental base (particularly microcircuits and microchips), advancements in real-time data collection and processing technologies, and the development of innovative composite materials. Nowadays, progress in unmanned aerial vehicle (UAV) technology is increasingly being guided by the principle of open innovation. This approach involves the active exchange of knowledge between various

entities participating in the innovation process and the establishment of sustainable relationships between various scientific and research institutions, manufacturers, and users, all within the framework of innovative ecosystems. Open innovation leads to greater differentiation of products, services, and processes, which ensures stable growth of production volumes and expands the scope of drone use. For example, the technical capabilities of modern UAVs can enhance the work of law enforcement agencies both in maintaining public order and safety, and in conducting search and rescue operations. Since 2019, for instance, the UK has launched a program to involve police drones in traffic monitoring, where drones assist in recording traffic violations and transmit the received information to police units for further documentation and termination of illegal activity. Additionally, many innovative solutions in the field of unmanned aviation have emerged out of the use of drones in military operations, especially in Afghanistan, Libya, and Syria. Open-source data indicates that the leading countries in the field of unmanned military aviation are the United States, Israel, Turkey, and EU member states. In the EU, drone ecosystem creates new jobs, promotes and protects European technological know-how, and creates opportunities for the growth of the EU economy in general.

Analysis of the current landscape in the design and production of UAVs reveals a vibrant scene in Ukraine, with more than 200 medium and small businesses actively engaged in designing and manufacturing UAVs of various capacities. The ongoing military action in Ukraine has stimulated the rapid development of innovations across various sectors, including the creation and use of unmanned aerial vehicles. We strongly believe that, as a country suffering from the military aggression of its northern neighbor and as a candidate country for EU membership, Ukraine not only *can*, but indeed *must* use the current situation as an impetus to accelerate the transformation of its economy by actively implementing innovations and stimulating innovative entrepreneurship. As the Minister of Digital Transformation of Ukraine has emphasized, by the end of 2023, as compared to the previous year the production of drones in Ukraine will increase approximately 120-140 times, underscoring the country's strong commitment to advancing this critical sector.

At the same time, despite the military activity, the civilian sphere of application of UAVs is a priority for Ukraine's economy. The UAV technologies that are rapidly developing in wartime are also widely used in

non-military realms as well. They will be of particular importance in the post-war reconstruction of the independent nation's economy. The practical experiences of UAV use in Ukraine and worldwide have demonstrated their potential to significantly reduce the costs associated with monitoring the environment and natural disasters, precision agriculture, wireless communications, remote sensing, power-line surveillance, highway and border traffic control, search and rescue operations, etc. For instance, the Ukrainian company "DroneUA" has entered the world ranking of the best startups in the field of artificial intelligence for agriculture. As a system integrator of unmanned solutions, it has its own engineering and production divisions as well as an open data processing center. "DroneUA" technologies are currently being utilized across more than 4 million hectares of cultivated land in Ukraine.

The dynamic development of Ukrainian-made and -designed UAVs is poised to make a significant contribution not only to the development of the national economy in particular, but also the economy of the European Union as a whole. Moreover, Ukraine is positioned to make a real contribution to the development of the European UAV market, which experts predict will provide numerous services for various end-users in the civil and defense sectors (Steer 2023). Innovative Urban Air Mobility (UAM) services will be part of the future ecosystem of urban multimodal intelligent mobility, and the ground and air infrastructures supporting these transport services will be widely deployed and integrated.

Although the broader deployment of UAVs offers numerous advantages, such as increased efficiency, cost-effectiveness and enhanced data collection capabilities, it also comes with its share of challenges, such as the regulatory framework, data security, flight safety, and the need for continuous refinement of technical and technological features. These challenges emerge at the intersection of multiple fields of scientific research. The resulting interdisciplinary nature of UAVs research requires the convergence of various R&D directions, including aerospace engineering, informatics and cybernetics, robotics, management and logistics, etc. Understanding the interplay between these R&D directions and forging effective collaborative strategies is critical for the development of UAV technologies. Consequently, identifying an optimal, effective organizational and economic configuration of participants in the innovative process of UAV development is one of the most urgent theoretical and practical tasks.

International experience with creating competitive products shows that innovative ecosystems are an effective form of cooperation between different participants (or "stakeholders"), in the innovation process, the active development of which is confirmed by the annual rating of "The Global Startup Ecosystem Report." Note that the term "ecosystem" is increasingly being used in various contexts by international organizations – in particular, by the European Commission, the OECD, the United Nations Conference on Trade and Development (UNCTAD), the World Economic Forum, international consulting and auditing firms, etc. The growing interest in the functioning of innovative ecosystems stems from the need to navigate the complexities of modern markets through novel cooperative mechanisms, and from numerous instances of successful ecosystem-based business strategies that have yielded synergistic outcomes unattainable by entities in isolation.

The development of effective innovation ecosystems is the primary task of the "Strategy for the Development of the Sphere of Innovative Activity for the Period until 2030," approved by the Cabinet of Ministers of Ukraine (2019). The strategy defines priority innovation sectors, including: Defense Tech, Artificial Intelligence, FinTech, Green Tech, AgriTech, Cyber Security, and Industry 4.0. The onset of the active phase of the war in 2022 in Ukraine has intensified the need for accelerated innovative development of both the military economy (especially in the areas of Military Tech and Cyber Security) and the post-war recovery economy. Innovations have become a matter of national security and this necessitates an appropriate environment – an ecosystem conducive to innovations.

However, it's not just governmental bodies that need to adapt; business organizations, scientific communities, and expert groups also must evolve their approaches to collaboration. adopting practices that significantly enhance the cooperation among key stakeholders. This shift towards more effective collaboration underscores the importance of exploring innovative ecosystems at large, especially those tied to the development of unmanned aerial vehicles (UAVs).

The objective of this article, therefore, is to advocate for the establishment of an innovative ecosystem of UAV technology in Ukraine. First, we review the existing literature to analyze different perspectives and identify the main approaches to understanding innovative ecosystems, especially in terms of UAV development, systematizing the existing knowledge. We elucidate the

benefits of adopting an ecosystem approach over the traditional models of UAV design and development, then propose a coherent definition of the innovation ecosystem and its conceptual model from the point of view of the co-creation of a focal innovation. Lastly, we highlight the pivotal role of research universities in catalyzing UAV innovations in such an ecosystem. Overall, this study offers a foundation for developing an ecosystem strategy and refining practical tools for ecosystem management across various administrative levels – setting the stage for future ecosystem research, providing a strategic foundation for innovation and the sustainable, technologically advanced development of UAVs.

Literature Review

Numerous scholars emphasize that the business ecosystem approach is a synthesis of mechanistic (regulations, instructions, schedules) and organic (values, motives, communities, network interaction) management styles. Therefore, the ecosystem paradigm is increasingly being used in enterprise management, the greening of business activities, technological innovations, and collaborative processes of value creation. Embracing the ecosystem approach requires a review of the traditional business models of various organizations and state institutions, as well as an assessment of the opportunities for cooperation of enterprises from various sectors of the economy, which can potentially unlock additional opportunities to boost competitiveness and create new sources of income. The toolkit of the ecosystem approach makes it possible to analyze various socio-economic entities, ranging from the scale of the world economy as a whole down to the level of small enterprises.

The business ecosystem approach is therefore increasingly being discussed in various fields, particularly in aviation. Drawing on Moore's (1996) definition, we assume that a "business ecosystem" is as follows:

> [a]n economic community supported by a foundation of interacting organizations and individuals – the organisms of the business world. This economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders. Over time, they coevolve their

> capabilities and roles, and tend to align themselves with the directions set by one or more central companies. Those companies holding leadership roles may change over time, but the function of ecosystem leader is valued by the community because it enables members to move toward shared visions to align their investments, and to find mutually supportive roles. (Moore, 1996).

Moore's key point here is that competition among enterprises does not disappear, but rather evolves to a more complex level, when business entities realize their place and relationships in an already existing ecosystem, or develop new ones. As components of ecosystems, companies create innovative opportunities: they cooperate and compete at the same time with the goal of creating new products and meeting customer needs, which results in the enhancement of production and management practices.

The evolution towards Industry 5.0 further reinforces the innovative significance of the business ecosystem approach. Adner (2017: 41) describes the emergence, within the ecosystem, of "coevolution of opportunities and abilities of participants in the process of value creation." This shift from economic competition to mutually beneficial cooperative engagement helps to mitigate resource scarcity. The ecosystem's "equalization structure" is pivotal, whereby a network of partners committed to mutual benefits and shared objectives collaborates to realize an innovative strategy (Reeves & Pidun, 2002).

Many researchers emphasize that innovative ecosystems are a synergistic confluence of state, business, and research environments, collectively fostering knowledge flows, supporting technological development and the commercialization of innovations. For instance, in the project "Development of the Innovation Ecosystem in Ukraine" published in April 2023, the Ministry of Digital Transformation of Ukraine defined the "innovation ecosystem as a synergy of the state, business and research environment with the use of regulatory, educational and financial resources and the introduction of a knowledge transfer mechanism with the aim of transformation into innovative products" (Poberezhets & Rakytska, 2003: 436).

Another important feature of innovative ecosystems is their digital orientation, facilitating digital relations between their participants and the use of digital technologies. In particular, Lee and Trimy (2021: 16) have proposed a revolutionary paradigm: an innovative platform ecosystem that

unites people, objects, ideas, functions, technologies. In their view, an innovative ecosystem is a self-organized mechanism for finding and solving problem situations and creating added value using end-to-end digital technologies (artificial intelligence, Internet of Things, big data analytics, e-learning, etc.).

Pidorycheva's (2020) approach categorizes innovative ecosystems into four distinct models, analyzing each of them in detail:

1) ecosystems organized around a focal (central) firm;
2) ecosystems as "structures" built around a focal value proposition (focal innovation);
3) ecosystems as specific environments that arise at different levels, from local to global;
4) ecosystems as platforms around which stakeholders' activities are organized.

In this article, it is the second, structural approach that we adopt: viewing innovation ecosystems in terms of partners needing to cooperate in order to implement a focal value proposition (focal innovation). The distinctiveness of this approach lies in its reliance upon cooperation mechanisms, thanks to which enterprises and organizations combine their individual offerings into a coordinated solution for customers (Adner, 2017; Adner & Kapoor, 2016; Adner & Feiler, 2019). In such an ecosystem, there is a coordinating firm, but it does not control other participants, only coordinates their joint activities. Coordination truly matters here: if it is insufficient, the partners will fail and the value proposition will not be created. Moreover, the ecosystem is multilateral, that is, the relationships within it cannot be divided into a set of simple bilateral relations.

Many researchers draw attention to the role of higher education institutions in fostering and developing innovative ecosystems (Chychkalo-Kondratska & Levchenko, 2023). Modern universities should act as generators of new ideas, as inclusive educational spaces where there is a synergy of science, education, innovation, and business. Historical examples of this model include Silicon Valley, which developed around Stanford University, the Boston ecosystem, with the centers of MIT and Harvard, as well as Israel's innovative ecosystem, focused on high-class medical technologies, which was formed with the active participation of scholars from Technion University.

Bazhal (2022) has examined the role of research universities and other scientific and educational organizations in the structural innovation transformation of Ukraine's economy, suggesting that in the process of formulating Ukraine's state innovation policy a separate priority direction should be established, related to the creation of next-generation higher education institutions (universities). These institutions are envisioned as innovative entrepreneurial universities and centers, aimed at nurturing cumulative human capital amidst the temporary state of crisis. Kyzim et al. (2021) emphasize the crucial role of educational institutions in the startup ecosystem. They underscore how these institutions support entrepreneurship and innovation, providing valuable resources to startups and providing students with theoretical knowledge in various fields. Such higher education institutions (universities) create opportunities for the development of their own innovative ideas through the creation of startup schools and accelerator programs.

Some research has pertained directly related to aviation, both unmanned aviation and the broader aviation industry. Hrinchenko (2020) believes that the ecosystem approach helps to determine the key factors for the sustainable development of the aviation industry and to develop an appropriate and effective industry policy. Some researchers believe that aviation is the ideal prototype of an "ecosystem," as attracting investment in new technologies will not only allow for mobility to be improved, but also for the harmful impact of the industry on the environment to be reduced (Kalf & Renda, 2020; Kim, et al., 2022).

Telli et al.'s (2023) thorough review of the directions of UAV-related research, carried out on the basis of the Scopus database and analyzing 47,635 references published in the field of UAVs between 2020 and 2023, identified the following main areas of UAV research: technical design aspects, artificial intelligence applications, and the development of control systems and software.

The scholarly literature often highlights the intricate web of interactions and collaborative efforts required among corporations, research entities, and governmental institutions to nurture and sustain an innovation ecosystem. Despite the recognized importance of these interactions, however, there remains a gap in understanding the optimal strategies for generating synergy among science, education, business and the state in the field of UAV development. It is this gap that we address in this article.

Methodology

The informational base for this study comprised legislative and other normative acts on the international, regional and national levels governing the provision of UAV services, regulating their functioning and development, monographs and economic reviews of scientific institutions, Internet resources, and publications in both Ukrainian and foreign periodicals.

To address the objectives of this study and develop a comprehensive understanding of the establishment of an innovative ecosystem for UAV technology in Ukraine, the following methodologies were employed:

Analytical review

An extensive review of existing literature, including scholarly articles, reports, and case studies related to innovative ecosystems, UAV technologies, and the role of research institutions in fostering innovation. This review aimed to identify successful models and practices from around the world that could be adapted to the Ukrainian context. Particular attention was given to the analysis of ecosystems in sectors relevant to UAVs, such as aerospace, defense technology, and digital transformation initiatives.

Stakeholder analysis

A detailed stakeholder analysis was conducted to map out the key players in the UAV ecosystem within Ukraine and internationally. This included universities (such as the National Aviation University and the National Technical University "KPI"), government agencies (e.g., the Ministry of Digital Transformation of Ukraine), private enterprises engaged in UAV design and manufacturing, venture capital funds, and international partners like the Łukasiewicz Research Network – Institute of Aviation in Warsaw. The analysis focused on understanding the roles, interests, capabilities, and potential contributions of each stakeholder to the ecosystem.

Comparative analysis

A comparative analysis was performed to benchmark Ukraine's UAV ecosystem against those in other countries with established and successful UAV innovation ecosystems. This analysis helped identify best practices, key success factors, and lessons learned that could inform the development of Ukraine's UAV ecosystem.

Synthesis and strategic recommendations

The findings from the literature review, stakeholder analysis, and comparative analysis were synthesized to develop a comprehensive understanding of the current landscape and potential pathways for establishing a vibrant UAV innovative ecosystem in Ukraine. Based on this synthesis, strategic recommendations were formulated to address the identified challenges and leverage opportunities for accelerating the development and commercialization of UAV technologies in Ukraine.

This multi-methodological approach enabled a thorough examination of the factors influencing the establishment of an innovative ecosystem for UAVs in Ukraine, offering a robust foundation for actionable strategies to enhance innovation, collaboration, and sustainability in the UAV sector.

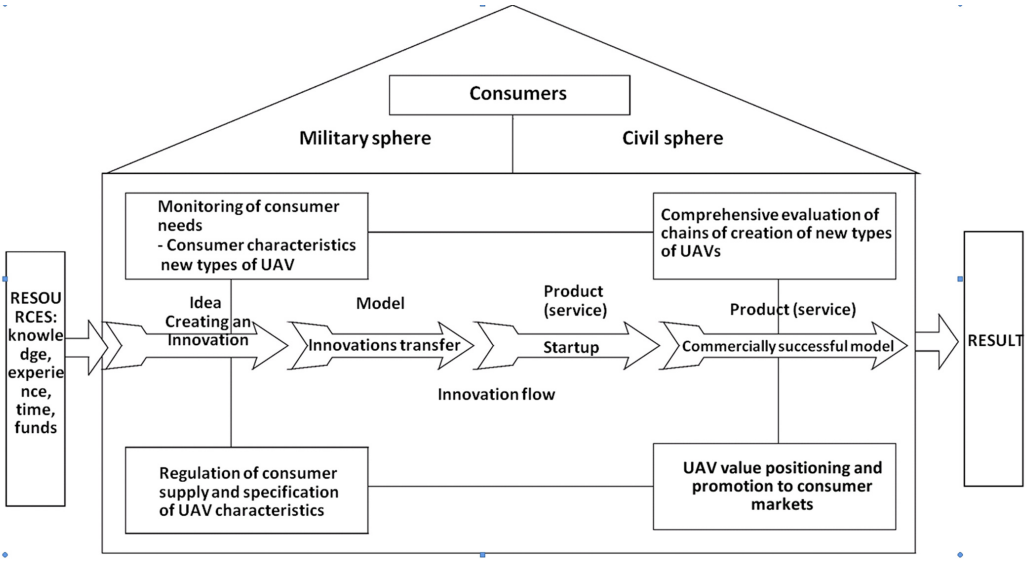
Results and Discussion

The formation of an innovative UAVs ecosystem

Currently, the production of UAVs in Ukraine can be described as artisanal, as it is engaged in by many different small enterprises with limited orientation towards new knowledge and innovations. Adopting the ecosystem approach requires a review of the traditional business models of various organizations and government institutions, as well as a reassessment of the opportunities for cooperation among enterprises from various sectors of the economy, which can potentially provide additional opportunities to increase competitiveness and create new sources of income. The main idea of the approach is that the transformation of scientific knowledge into innovation requires cooperative efforts on the part of all stakeholders in the innovation process (universities, private enterprises, venture funds, etc.). In other words, innovations are fostered collectively, in a certain networked environment formed by legally independent participants between whom there are formal and informal arrangements. The ecosystem approach makes it possible to treat the issue comprehensively, taking into account various internal relationships and interactions with the external environment. It facilitates the integration of various methodological approaches and evaluating alternative ways of implementing UAV design and production strategies.

In an innovative business ecosystem, the dynamic interactions between business, science, education and the state are akin to those in a natural ecosystem, with each entity both influencing and being influenced by others, creating an ever-changing configuration in which each business must be flexible and adaptable to survive. The main factor in the evolution of business ecosystems is the minimization of aggregate public costs for the creation and dissemination of innovations, and its activities are aimed at collective actions in the field of creation of knowledge flows, support for technological development and commercialization of innovations. The ecosystem logic not only generates new ideas in the design of UAVs with a certain set of consumer values, but also allows for the identification of participants who have enough resources, capabilities, competences and capital to implement those ideas.

Figure 1. Conceptual diagram of the formation of an innovative UAVs ecosystem (agreed understanding of the value of joint actions)



Source: original compilation.

Fig. 1 presents a conceptual diagram of the formation of the UAV innovation ecosystem, which assumes that the value proposition (innovation) is determined first, then the types of activities necessary for its creation, and lastly the stakeholders, whose participation depends on whether the focal

innovation will be produced. So, the key idea of forming an innovative ecosystem for UAVs is that cooperation among participants in the innovation process ensures the continuous creation of new ideas based on a complementary combination of resources, opportunities, competencies in various combinations, and thus contributes to the constant increase of the innovative potential of all participants. That is, the integration of science, education and business in the field of UAV development and production will contribute to the constant generation of new knowledge and the continuous flow of innovations at the request of consumers, driven by the synergistic efforts of all ecosystem participants.

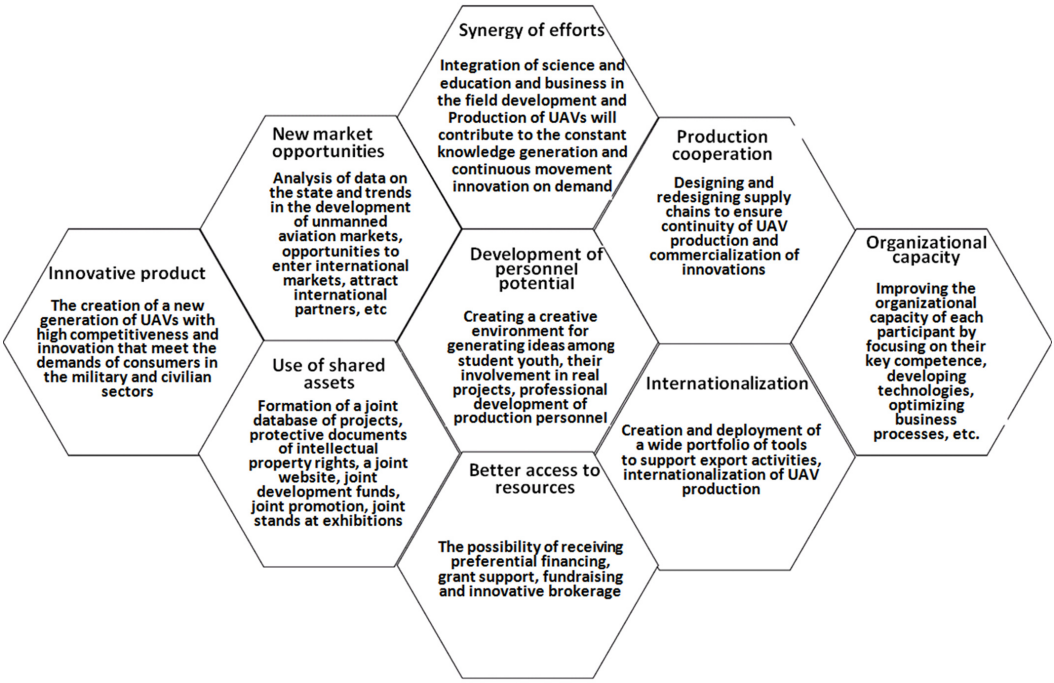
The value proposition (focus innovation) of the UAV innovation ecosystem

In the scheme presented, the participants of the UAV innovation ecosystem pool their resources on mutually beneficial terms, exchange common knowledge and work collectively with the aim of jointly achieving innovative results. They create value that none of them would be able to generate on their own. Therefore, the innovative UAV ecosystem should, on the one hand, create consumer value, since it is the consumer's receptivity and willingness to pay for scientific advancements for further use that determines the consumer value of UAVs. On the other hand, the ecosystem must have value for its participants, i.e. create benefits for all stakeholders involved in generating ideas, designing products or manufacturing UAVs.

As we have adopted the structural approach – which involves the formation of an ecosystem based on a value proposition (focal innovation) – we first define a value proposition, then the types of activities necessary for its creation, and then finish with the stakeholders whose participation depends on whether the focal innovation will be produced (Fig. 2).

This scheme shows that the basis for cooperation among various organizations and enterprises in a single innovative ecosystem is the focus on the final outcome of that cooperation – the creation of the next generation of UAVs with high competitiveness and innovation that meet the requirements of the military and civilian sectors of the economy. The approach underscores the consumer's perception of UAV value, which encompasses the structural, technological, ecological, and ergonomic characteristics of the new product.

Figure 2. The value proposition (focus innovation) of the UAV innovation ecosystem



Source: original compilation.

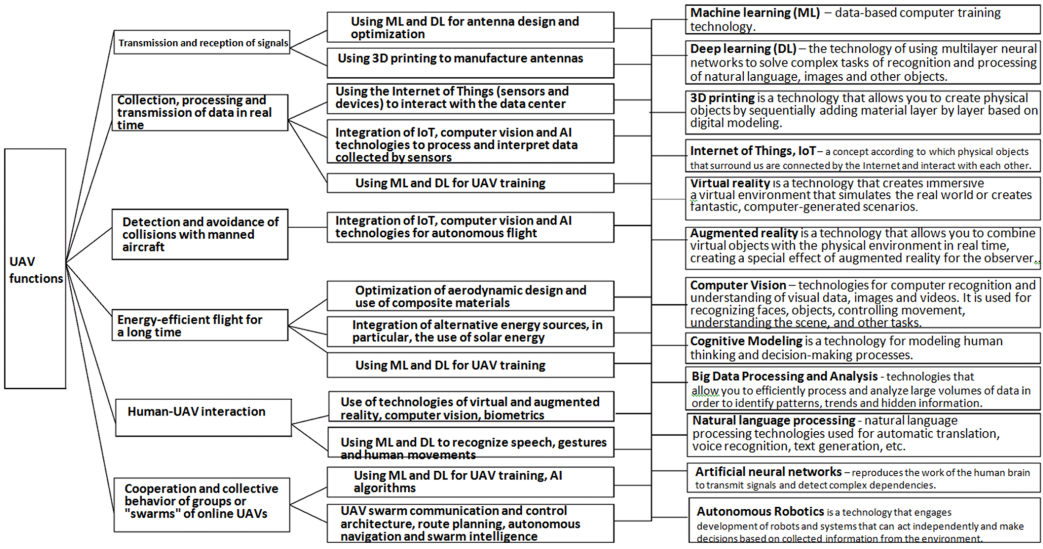
The value proposition of the UAV innovation ecosystem, in turn, should be based on the following: the creation of new market opportunities and the promotion of innovative products to domestic and international markets, production cooperation in supply chains to ensure the continuity of production and commercialization of innovations, the development of personnel potential and the creation of a creative environment for the generation of ideas among university students, their involvement in real projects, improving the qualifications of company personnel, boosting the organizational capacity of ecosystem participants, improving their business processes, as well as joint use of assets and better access to resources.

Current directions of scientific research for UAV innovation ecosystem stakeholders

A great deal of research is currently underway on the design of both whole UAV systems and their individual components (airframes, engines,

control systems, etc.), as well as in related areas (use of new energy sources, sensors, communication interfaces, etc.). In particular, Telli et al. (2023), in their extensive review of the worldwide literature, identified unresolved challenges in augmenting UAV efficiency, enhancing security, and countering cyber threats. They see potential solutions to these problems as lying in the use of modern information technologies, in particular, the Internet of Things, blockchain and artificial intelligence. Core AI technologies include machine learning and deep learning, natural language processing, image processing, object recognition and video analytics. Figure 3 summarizes the main directions of current and future scientific research related to the development of drones and the expansion of their functionality.

Figure 3. Current directions of scientific research for UAV innovation ecosystem stakeholders



Source: original compilation.

As can be seen from the figure, the most promising areas of research are related to the use of state-of-the-art information technologies. The use of wireless sensors (IoT) is crucial for creating intelligent traffic control systems and improving the performance of UAVs. Sensor-equipped drones can collect data on crop health, soil moisture and temperature that can be analyzed in real time to inform irrigation and fertilizer decisions. Similarly,

UAVs can be used to monitor natural disasters and assess damage, enabling a faster and more accurate response. The integration of various sensors, cameras, and radars allows information about the environment to be collected quickly, which can be processed and interpreted by computer vision algorithms. Modern big-data technologies create opportunities for fast transfer and processing of large arrays of information in real time. Artificial intelligence, in particular machine learning and deep learning algorithms, can be used to optimize flight modes, automatically adjust flight paths, and make autonomous decisions in collision avoidance scenarios. Detecting and avoiding collisions with manned aircraft is a key task in the operation of UAVs, especially in shared airspace.

Ukraine is currently engaged in a lot of research on the use of artificial intelligence technologies to track moving objects and automatically identify various types of targets. In particular, reconnaissance drones can not only scout for information, but also recognize hardware and transmit information in real time. For instance, the aforementioned Ukrainian company "DroneUA" has been successful in the field of artificial intelligence for agriculture.

Another crucial aspect of research focuses on enhancing the energy efficiency of UAVs, which is pivotal for improving UAV performance and capabilities, including flight time, payload, and range. In this context, the use of composite materials, the integration of electric and hybrid power systems, the use of light solar panels and energy storage systems are important. Researchers from Yunnan University and the Chinese Academy of Sciences recently presented a new object-detection system based on boundary computing – potentially enabling UAVs to detect objects with minimal power consumption, thanks to edge computing's faster and more efficient data processing capabilities.

A separate area of research relates to the safety of UAVs and combating cyber threats through the implementation of reliable encryption, authentication mechanisms and effective countermeasures against cyber attacks. A very important challenge restraining the development of UAVs is ensuring the transmission of information via communication channels between the UAV and the ground control point, in the required amount, at the necessary speed and without distortion. This task can be solved by enhancing the bandwidth and immunity of information transmission channels, as well as by concentrating onboard the UAV a maximal set of

component devices that work in autonomous (software) mode without the need for constant information exchange with the control point.

Another promising direction of research is swarm behavior, involving groups of UAVs able to cooperate and continually exchange information with one other. One of the challenges of swarm behavior is how to ensure effective cooperation between UAVs while adapting to changing conditions and environments. To address this problem, researchers are developing new algorithms for cooperation and coordination, as well as new approaches to task allocation and resource management. In addition, the development of algorithms that allow UAVs to operate autonomously and make decisions based on their environment, including the integration of AI techniques such as ML and DL, is an important aspect of swarm behavior. Last July, Ukraine's Ministry of Digital Transformation, Ministry of Defense, General Staff and State Special Communications launched the "Army of Drones" project, which focuses on the state's long-term needs and priorities in terms of drones and robotic platforms. The strategic plans of the Ministry of Defense for saturation with such weapons over the next decades will stimulate manufacturers and investors to invest in the creation of new production facilities and the development of new platforms.

On the other hand, after its victory in the current war, the Ukrainian drone market will require deregulation of the permit system and increased civilian oversight of the circulation and use of UAVs, especially given the emergence of a large number of qualified pilot operators among the military. Drones will find applications outside of military use, including in the field of infrastructure monitoring, expedited delivery services, and agriculture. The existing legislation needs to be revised in accordance with the needs of the market and the further development of the industry.

The International Civil Aviation Organization (ICAO) defines the main requirements for the organization and implementation of the use of remotely piloted aircraft systems (RPAS). The aim is to develop an international regulatory framework based on Standards and Recommended Practices (SARPS), complemented by Air Navigation Services Rules (PANS) and guidance material, which will enable safe, coordinated and effectively integrated flights of UAVs similar to flights of manned aircraft. The most important task is ensuring that the integration of UAVs in non-segregated airspace does not lead to an increase in the level of risk to the safety of manned aviation flights. According to the recommendations within the

framework of the civil aviation system, UAVs will play the role of an equal partner, able to interact with air traffic control authorities and with other aircraft in real time (Kharchenko, 2017).

The structure of UAV innovation ecosystem participants

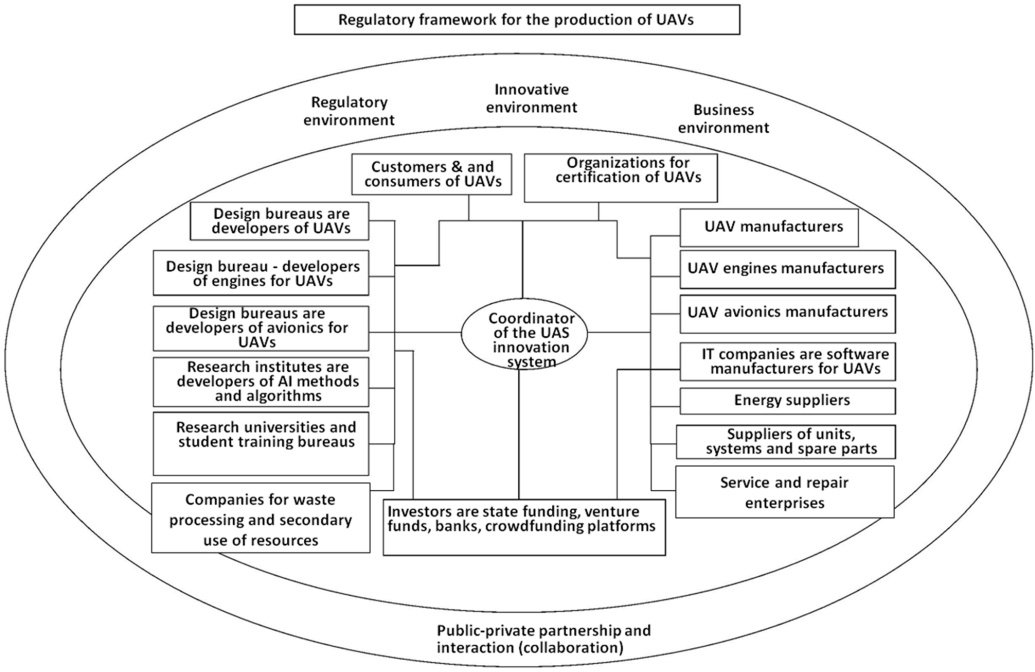
So far, we have outlined a wide range of current scientific problems in the field of UAV design and production that can be solved more efficiently and effectively within the framework of the innovative ecosystem. The next important aspect is forming a set of partners interested in mutually beneficial cooperation, who have a common vision and understanding of how to achieve goals in the course of implementing the innovation ecosystem strategy. All innovative ecosystems, regardless of their level of creation, are formed at the initiative of participants, have a high degree of self-organization, an internal self-regulation mechanism and sufficient potential for self-development. Self-development arises as a result of continuous updates, and is also characterized by a decentralized way of decision-making. In our case, in order to develop an innovative ecosystem of UAVs, we must identify potential participants who have enough resources, capabilities, competence and capital to implement the general idea in a hierarchically structured manner (Fig. 4).

This structure of the participants of the UAVs innovation ecosystem entails a transition from a linear model of creating innovations to a nonlinear one, where dynamic horizontal connections between the participants of the innovation process based on a complementary combination of resources, opportunities and competencies. At the same time, in our ecosystem model, an important role is played by the coordinator, who should facilitate the joint work of various participants. The coordinator ensures the resolution of conflicts, the creation of an conducive environment and the pursuit of common interests, and it actively engages external developers, startups, research institutions and other third-party organizations to participate in the open ecosystem.

The main hubs of the UAV innovation ecosystem are enterprises and organizations that engage in the ecosystem's main activity of producing UAVs – namely design bureaus, developers and serial manufacturers of UAVs, aircraft engines and avionics. The activities of these hubs need to be integrated into the system, as a guarantee of coherent action towards achieving the

common goal. However, the UAV production ecosystem is an open-type system that requires the development of interfaces with other groups, with which it cooperates and/or on whose activities it depends.

Figure 4. The structure of UAV innovation ecosystem participants



Source: original compilation.

The first is the group of customers, which in Ukraine's UAV production ecosystem consists of civil aviation enterprises, state aviation, aviation and multimodal logistics enterprises, organizations and individual customers of aviation and transport services. The civil aviation enterprises of Ukraine (as in other countries of the world) include airlines (state, non-state, mixed-capital, etc.) and aviation companies that provide services for various sectors of the national economy: agriculture, environmental monitoring of pipelines, forest areas, reservoirs, aerial photography, etc. The State Aviation of Ukraine, in turn, includes the Air Force, Army Aviation, Naval Aviation, National Guard Aviation, Police Aviation, Aviation of the State Emergency Service, Aviation of the State Border Guard Service, other State Aviation. Aviation and multimodal logistics enterprises play an increasingly powerful

role in the air transportation market and are of particular importance in supporting the national economy in wartime conditions. Also, with the ecosystem approach, it is customary to take into account not only the needs and requests of direct operators of UAVs, but also those of the potential customers of UAVs services: organizations and individual customers of aviation and transport services.

The second group consists of entities supporting the production of UAVs, which includes: suppliers of units, systems and spare parts, organizations responsible for the certification of UAVs, organizations responsible for energy supply, nature protection organizations, organizations of fuel and lubricant support, the system of airports and airfields, and the air traffic control system. Looking forward, it is imperative to integrate service enterprises supporting the life cycle of unmanned aerial vehicles; their primary functions will include development and implementation of activities for the operation, modernization, repair and maintenance of UAVs. Special attention should be paid to the end of the life cycle of innovative products and the organization of recycling and disposal processes. Recycling should be aimed at the maximum possible secondary use of UAV materials and components or their use for the production of new goods or components, effectively creating a closed-loop drone supply chain infrastructure. In this cycle, manufacturers not only produce and distribute UAVs to customers but also encourage the return of these products for repair, resale, or component reuse – thereby adhering to the "Zero Waste" principles of minimizing waste and loss and fostering a new attitude towards the management of production and consumption waste.

The third group consists of entities providing innovative support and training of personnel of the aviation industry of Ukraine, which includes: scientific research institutes of the National Academy of Sciences of Ukraine and institutions of other ministries and departments, research universities, experts and scientists of the aviation industry.

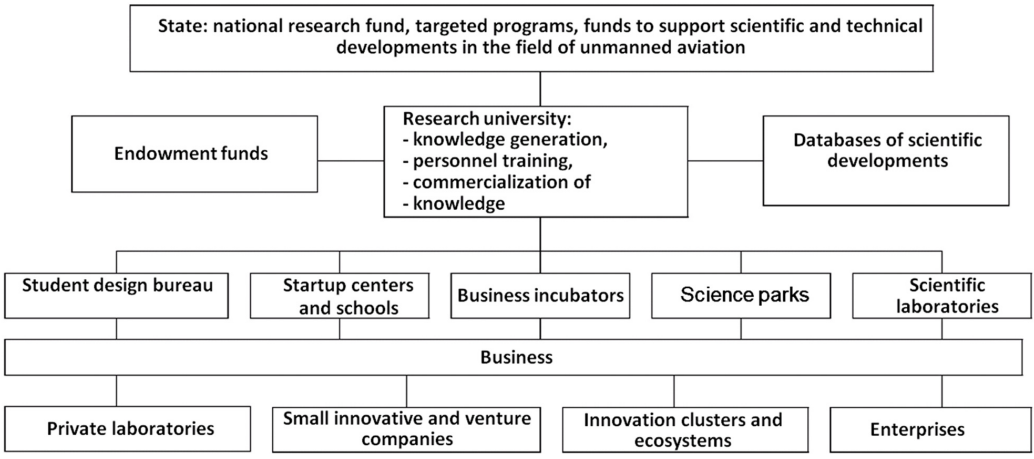
The role of research universities in the innovation ecosystem

Let's consider in more detail the role of research universities, which should become centers of innovation generation. Universities provide interdisciplinary and fundamental education while also supporting the research efforts of teachers, graduate students and undergraduates. In

the context of the ecosystem approach, it is important to determine the avenues through which universities interact with scientific institutions and the business environment. The general scheme of such interaction is presented in Fig. 5.

The innovation process at universities is built around the activities of entities that generate new knowledge (such as individual researchers, groups of researchers, undergraduate and graduate students, academic departments, laboratories, and divisions) and those focused on commercializing those innovations (departments dedicated to R&D, technology transfer centers, etc.). Key strategies for involving students in research and innovation include establishing start-up centers, organizing startup schools, holding startup competitions, organizing startup festivals and exhibitions of scientific works, supporting business incubator activities, etc.

Figure 5. The role of research universities in the innovation ecosystem



Source: original compilation.

For universities to effectively manage their scientific and educational endeavors, several foundational conditions must be met:

1) Leadership within the universities should facilitate the generation and dissemination of new knowledge and technologies, going beyond the organizational structures, creating conditions conducive to the development of the necessary competencies and supporting continuous learning at higher education institutions.

2) The establishment of integrated structures is essential; these should the encompass technologies and competences needed to advance specific target areas, based on the coordination of interests and providing incentives to all participants.

Moreover, these units should formulate guidelines governing the relations between generators of new knowledge and technologies and the entities responsible for commercializing them, ensuring effective cooperation with other participants of the innovation ecosystem.

The organizational and economic mechanism for integrating education, science and business within the innovation ecosystem proposed here is a general outline, which requires further detailing, refinement, and customization in accordance with the specific needs of universities and the specifics of their functioning, as well as with the set purpose and goals of creating an innovative ecosystem.

UAVs scientific technical direction at the National Aviation University (Kyiv, Ukraine)

At the National Aviation University (NAU) in Kyiv, Ukraine, the incorporation of cutting-edge technologies into the educational curriculum is deemed essential for equipping future aviation specialists with practical skills. Recognizing the importance of unmanned aerial vehicles (UAVs) in the global civil aviation industry, NAU has dedicated significant efforts to researching and developing experimental remotely piloted aircraft systems. The university's research and production center, "Virage," has developed a series of UAVs, including the single-engine M-3 "Border" and M-6 "Skylark," as well as the twin-engine M-7, M-7D, M-7V5 "Sky Patrol," and the electric motor-powered "Eye" UAVs. These UAVs serve as practical training tools for aviation specialists (see Fig. 6) (Isaienko et al., 2018).

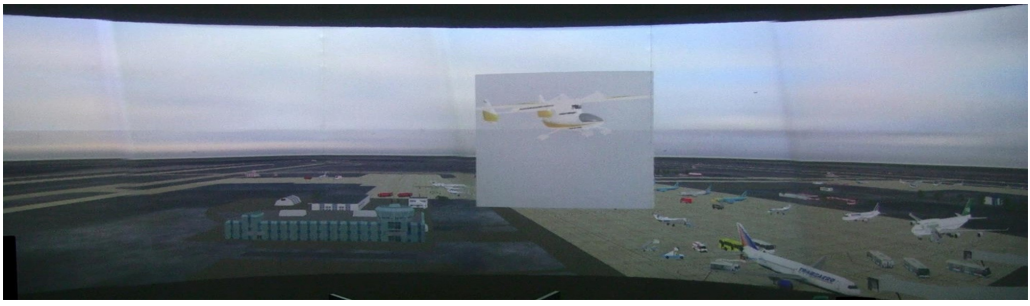
A significant component of NAU's training program involves the use of simulators, including a complex of Air Traffic Control and Flight Simulators designed and operated at NAU (see Fig. 7). Simulator software with elements of artificial intelligence was jointly developed by NAU scientists and students. These simulators are designed for:

- air traffic management (ATM) training for students and staff, simulating the real-world scenarios,
- training and qualification testing for both manned aircraft pilots and UAV ground control operators.

Figure 6. UAVs of the National Aviation University

Source: Isaienko et al. (2018).

Figure 7. UAVs of the National Aviation University



Source: Isaienko, Pawęska, Kharchenko et al. (2018).

The ATM simulator includes an air traffic control (ATC) tower simulator, a UAV flight simulator, and a Yak-18T airplane flight simulator.

NAU also boasts an Aerodynamic Research Center for conducting scientific and practical training in UAV aerodynamics, alongside a UAV Components Durability Complex Test System, which enables researchers and students to explore new UAV designs (Kharchenko et al., 2014). Collaborative efforts with the International University of Logistics and

Transport in Wroclaw have focused on assessing the capacity and effectiveness of Remotely Piloted Aircraft Systems (RPAS) in addressing logistical challenges within territorial infrastructure (Kharchenko et al., 2014). Furthermore, NAU develops methods for integrating, searching, recognizing, and processing data from satellite systems, navigation, and UAV onboard avionics (Isaienko et al., 2018).

Noise generation due to civil use of UAVs has been identified as an important issue, particularly over densely populated areas and especially given the potential for a rapid increase in UAV applications. NAU conducts intensive research on UAV noise prediction for commercial operations and community exposure (Makarenko et al., 2020; Tokarev & Makarenko, 2021), based on UAV acoustic characteristics in operational modes. The concept of acoustic noticeability of UAVs is introduced in order to mitigate the influence of noise and for urban noise management, making it possible to evaluate the extent of population exposure to UAV noise – especially important in low-altitude urban airspace. Traffic distribution of UAV flights based on the entropy approach (maximum entropy method) for air traffic system optimization with various operational scenarios is proposed to minimize noise exposure (Tokarev & Kazhan, 2014; Zaporozhets et al., 2011). NAU's research extends to environmental impact considerations, including air pollution (Synylo et al., 2020), electromagnetic fields (Glyva et al., 2023), third-party risk (Zaporozhets et al. 2019) and visual pollution, highlighting the comprehensive scope of NAU's commitment to advancing UAV technology and its responsible integration into civil aviation.

UAVs scientific and technical direction at the National Technical University of Ukraine "Ihor Sikorsky Kyiv Polytechnic Institute" (KPI) (Kyiv, Ukraine)

At the National Technical University of Ukraine "Ihor Sikorsky Kyiv Polytechnic Institute" (KPI), the development and research in UAV technologies have been significant, underpinned by the "Sikorsky Challenge Ukraine" (SCU) innovation ecosystem. This ecosystem integrates various structural divisions of the university, including the Department of Innovation and Technology Transfer, the scientific research sector, the Center of Intellectual Property, TechnoHab, the Sikorsky School Startup, KPI Challenge, and the Institute of Advanced Defense Technologies.

Moreover, the SCU encompasses 15 regional and city innovation clusters, numerous enterprises, business associations, foundations, and maintains 10 representative offices across five countries: the United States, Israel, Poland, China, Azerbaijan.

KPI's student design bureau for unmanned aerial vehicles and onboard equipment is a hub of innovation, where graduate and undergraduate students and faculty collaborate on modernizing existing aerial vehicles and devising new hardware models. This collaboration leverages advanced design methodologies, contemporary and emerging technologies for manufacturing airframe elements and onboard UAV equipment, and draws on the expertise of industry professionals from Yuavia and the Zlit Design Bureau. A notable achievement includes the development of a miniature integrated navigation system by the student design bureau. This system makes it possible to determine the parameters of UAV movement with high accuracy under difficult traffic conditions.

KPI's connection with UAV development for the Ukrainian army is multifaceted:

- KPI offers educational programs and courses in robotics, autonomous systems and robots, which allow students to acquire the necessary knowledge and skills in these areas.
- The university is actively engaged in research in the field of unmanned systems. This includes the development of new technologies for the creation of drones and robots, the development of algorithms for their autonomous navigation and control.
- KPI supports student projects and startups related to the development and production of unmanned systems. The university provides access to resources and expert support for the development of such initiatives.
- KPI cooperates with other universities and research organizations in Ukraine and abroad for joint projects in the field of unmanned systems.

One of the promising startups is the UAV "Spectator," developed by graduate student Roman Karnaushenka together with undergraduates Ihor Bogachuk and Yevhen Sedochenko. In order to achieve the ideal shape and good aerodynamics of the plane, they consulted with experienced scientists and engineers from KPI and Antonov State Enterprise. The "Spectator," a UAV primarily intended for reconnaissance, features compact size that helps it remain inconspicuous and opaque to electromagnetic detection.

Currently, KPI scientists are working with engineers from the Meridian company to create civilian versions of unmanned aerial vehicles, with a focus on their use in agriculture, forestry and water management in Ukraine and other countries. Special drones are also being developed for monitoring oil pipelines, gas pipelines and power lines, as well as for cartography. Several so-called "civilian" drones have already been purchased by farmers, as they have proven to be very useful for agricultural monitoring. These UAVs allow multispectral surveying of a large area of agricultural fields in real time and analyzing crop condition. In one flight, such devices can cover an area of up to 500 hectares.

This work illustrates KPI's significant contributions to both military and civilian UAV applications, fostering innovation and practical solutions in various sectors.

Conclusions

In conclusion, this paper has illustrated the vital need for Ukraine to cultivate an "innovative ecosystem" specifically tailored for the advancement of unmanned aerial vehicle (UAV) technology. Embracing an ecosystem approach, we argue, is not merely beneficial but essential for navigating the complexities inherent in the development and production of UAVs. This approach emphasizes the importance of creating a dynamic, open, and non-linear networking environment, thriving on the horizontal connections among diverse participants. These connections, characterized not by simple cooperation but by deep, collaborative engagement, underpin the ecosystem's capacity to foster the creation and diffusion of knowledge flows, their transformation into innovations, and their ultimate commercialization.

Central to our argument is the conviction that such an ecosystem must leverage the intellectual and infrastructural capabilities of Ukraine's premier research institutions, such as the National Aviation University (NAU) and the National Technical University "KPI." The collaboration between these institutions – as well as with their international counterparts, notably the Łukasiewicz Research Network – Institute of Aviation in Warsaw, Poland – is pivotal. Such collaboration accelerates the development of innovation "factories" that support the training, incubation, and growth of startups, encouraging the formation of micro- and small high-tech enterprises and facilitating their entry into global and regional markets. Furthermore, this collaboration enhances the mechanisms of interaction between startup teams

and financial backers, including venture capital funds and investment companies, fostering a culture of trust and establishing common norms to navigate complex challenges collectively.

The business ecosystem approach, with its focus on co-specialization and the joint creation of new value, underscores the collaborative nature of innovation. Participants engage in distinct yet complementary activities, each contributing resources to the innovation process. This interactive exchange of knowledge and resources, characterized by dialogue, agreement, and feedback, shares risks and obligations among independent stakeholders. Such a process not only cultivates a collaborative culture but also creates structures to address the growing complexity of technology and the vast amounts of information and knowledge required for innovations in UAV design and operation. The UAV technologies that are rapidly developing in wartime are also widely used in non-military realms as well, and so will be of particular importance in the post-war reconstruction of the independent nation's economy.

Our findings lay the groundwork for further theoretical and methodological research within the ecosystem framework, offering a strategic foundation for developing an ecosystem strategy and refining practical tools for ecosystem management across various administrative levels. This approach not only fosters innovation but also ensures that the development and production of UAVs contribute to broader objectives of economic sustainability and technological advancement.

In this endeavor, the role of modern universities cannot be overstated. Acting as generators of new ideas and inclusive educational spaces, they create a synergy of science, education, innovation, and business. This paper underscores the pivotal role of research universities in catalyzing UAV innovations within such an ecosystem, highlighting their indispensable contribution to creating a sustainable, technologically advanced future for UAV development in Ukraine.

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