AERONAUTICAL DRONES, PART 2: CURRENT APPLICATIONS AND TRENDS

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DOI: 10.19062/2247-3173.2026.27.22

Abstract: *This paper examines the current applications and emerging development trends of unmanned aerial vehicles (UAVs), with emphasis on the technological and operational evolution of contemporary drone systems across civil and military domains. The study reviews the expanding use of UAVs in precision agriculture, infrastructure inspection, logistics, emergency response, urban air mobility, intelligence, surveillance and reconnaissance (ISR), electronic warfare and tactical operations, highlighting the operational advantages offered by unmanned platforms in diverse mission environments.*

The principal challenges affecting future UAV deployment are also analyzed, including battery endurance, cybersecurity, communication reliability, regulatory compliance, airspace integration and environmental constraints. Attention is given also to the increasing role of artificial intelligence, autonomous mission execution, swarm coordination, advanced propulsion technologies and digital airspace management in shaping the next generation of unmanned aircraft systems.

Current research directions indicate a transition from individually operated drones toward interconnected, intelligent and highly autonomous aerial systems capable of cooperative decision-making and large-scale deployment. The analysis shows that future progress in unmanned aviation will depend not only on improvements in aircraft performance but also on advances in systems integration, secure communications, resilient autonomy and regulatory frameworks that enable the safe and efficient operation of increasingly complex UAV ecosystems.

Keywords: *Unmanned Aerial Vehicles (UAVs), Artificial Intelligence (AI), Autonomous Systems, Military Drone, Civil Drone*

1. INTRODUCTION

The technological foundations, classification and structural development of modern unmanned aerial vehicles (UAVs) have enabled their rapid transition from specialized aerospace platforms to operational systems employed across an increasingly diverse range of civil and military missions. As discussed in Part 1 of this review, continuous progress in lightweight structures, propulsion technologies, avionics, sensors and manufacturing methods has significantly expanded the capabilities of contemporary UAVs while improving their accessibility and cost effectiveness [8], [9], [29]–[34].

Building upon these technological developments, attention is increasingly shifting from aircraft design toward the operational integration of UAVs into complex civil and defense environments. Rather than functioning solely as remotely piloted platforms, modern drones are becoming interconnected systems capable of supporting autonomous decision-making, distributed sensing, real-time data processing and collaborative mission execution.

Their role has consequently expanded from aerial observation to applications including precision agriculture, infrastructure inspection, logistics, disaster response, environmental monitoring, intelligence, surveillance and reconnaissance (ISR), electronic warfare and tactical support [10], [11], [16].

At the same time, the rapid growth of UAV operations has introduced new engineering and operational challenges. The safe integration of unmanned aircraft into controlled airspace, increasing levels of autonomy, cybersecurity, resilient communications, energy storage and regulatory compliance have become central research topics influencing the future development of both civil and military drone systems [1], [16], [17], [25], [21].

The objective of this paper is to examine the principal operational applications, current limitations and emerging technological directions of contemporary UAV systems. Particular emphasis is placed on the evolution of civil and military applications, the challenges associated with large-scale deployment, and the research trends that are expected to define the next generation of unmanned aviation. Together with the technological overview presented in Part 1, this paper provides a complementary perspective on the operational maturity and future evolution of unmanned aerial systems.

The increasing adoption of UAVs reflects a broader transformation occurring throughout the aerospace sector. Advances in onboard computing, satellite navigation, wireless communications and artificial intelligence have enabled drones to perform missions that previously required conventional crewed aircraft or extensive ground-based operations. Improvements in sensing technologies and data processing have further expanded their value, allowing UAVs not only to collect information but also to support rapid decision-making through near real-time analysis [20], [13], [23].

In civil applications, UAVs are progressively integrated into digital infrastructures supporting precision agriculture, industrial inspection, transportation, emergency management and environmental monitoring. Simultaneously, defense organizations continue to broaden the operational use of unmanned systems for persistent surveillance, precision engagement, electronic warfare, logistics and cooperative combat operations. Recent operational experience has demonstrated the effectiveness of distributed drone employment while emphasizing the growing importance of autonomous functions, secure communications and rapid adaptation to dynamic mission environments [3], [5], [11].

These developments indicate that the future competitiveness of UAV systems will increasingly depend on the integration of autonomous capabilities, resilient system architectures and advanced mission management rather than on improvements to individual aircraft performance alone.

Following the technological overview presented in “Aeronautical drones, part 1: current status and trends”, this Part 2 of the paper focuses on the operational dimension of contemporary UAV systems. Chapter 2 reviews the principal civil applications of drones, including agriculture, infrastructure inspection, logistics, emergency response and urban air mobility. Chapter 3 examines current military applications, addressing ISR missions, strike capabilities, electronic warfare, maritime operations and emerging concepts.

Chapter 4 analyzes the principal engineering, operational and regulatory challenges affecting widespread UAV deployment, including energy limitations, cybersecurity, communication resilience, certification and public acceptance. Chapter 5 discusses future research directions, with emphasis on artificial intelligence, autonomous mission execution, swarm systems, sustainable propulsion, integrated airspace management and human-machine teaming. Finally, the concluding chapter summarizes the principal findings and outlines the technological trends expected to influence the continued evolution of unmanned aerial systems during the coming decade.

2. CIVIL APPLICATIONS AND FUTURE URBAN INTEGRATION

Civil applications of unmanned aerial vehicles (UAVs) represent one of the fastest-growing segments of the global drone ecosystem. Unlike military systems, which prioritize survivability and mission persistence in contested environments, civil drones are optimized for cost efficiency, safety, regulatory compliance, ease of use and data acquisition quality. Their deployment spans a wide spectrum of industries, including agriculture, construction, energy, transportation, public safety and environmental monitoring [10], [31].

The civil UAV market has evolved from simple remote-controlled aerial photography platforms into automated data acquisition systems integrated with cloud computing, artificial intelligence and digital twin technologies. This transformation enables drones not only to collect data but also to process and transmit insights in near real time.

2.1 Agriculture.

Precision agriculture is one of the most impactful civil applications of drones. UAVs are used for crop monitoring, soil analysis, irrigation optimization, fertilizer distribution and pesticide spraying. Multispectral and hyperspectral imaging systems allow detection of crop stress, disease and nutrient deficiencies before they become visible to the human eye [19].

Drone-based agricultural operations improve efficiency by reducing chemical usage, minimizing water consumption and optimizing yield prediction. In large-scale farming, drones complement satellite imagery by providing higher spatial resolution and flexible temporal coverage.

Typical applications include: vegetation health indexing (NDVI mapping), pest detection and localization, variable-rate spraying, livestock monitoring, field boundary and terrain mapping.

2.2 Inspection and surveying.

Infrastructure inspection is a major driver of civil UAV adoption. Drones are widely used to inspect bridges, power lines, wind turbines, pipelines, railways and industrial facilities. Compared to traditional inspection methods involving scaffolding, cranes or helicopters, UAVs offer significant reductions in cost, time and operational risk.

Advantages are related to access to hazardous or inaccessible areas, high-resolution imaging and thermal sensing, reduced downtime of critical infrastructure, repeatable automated inspection routes.

Surveying and mapping applications rely heavily on photogrammetry and LiDAR-based data acquisition. The generation of 3D models and digital terrain maps is widely used in construction planning, mining operations and urban development.

2.3 Logistics and delivery.

Drone-based logistics is emerging as a disruptive technology in last-mile and middle-mile delivery systems. UAVs offer the ability to bypass road congestion, reduce delivery times and access remote or difficult terrain locations such as islands, mountains and rural areas.

Applications may include medical supply delivery (blood, vaccines, pharmaceuticals), e-commerce parcel delivery, industrial spare parts transport, emergency response logistics.

Companies such as Amazon, Wing (Alphabet) and Zipline have demonstrated operational drone delivery systems in controlled environments and selected commercial regions [32].

However, widespread adoption is constrained by factors such as: airspace regulation and BVLOS approval, safety requirements for populated areas, noise limitations, payload and range constraints or public acceptance.

2.4 Emergency response and public safety.

Drones have become essential tools in emergency management and disaster response. Their ability to rapidly deploy and provide aerial situational awareness makes them particularly valuable in time-critical scenarios such as earthquakes, floods, wildfires and industrial accidents.

Typical applications could include: search and rescue operations, victim localization using thermal imaging, fire monitoring and prediction, hazard mapping in contaminated areas or real-time coordination of emergency teams.

In wildfire scenarios, drones equipped with infrared sensors can detect heat signatures and assist in predicting fire propagation. In flood situations, UAVs provide rapid terrain assessment when satellite data is obstructed by cloud cover.

2.5 Urban air mobility and smart cities.

Urban Air Mobility (UAM) represents the long-term integration of drones into urban transportation systems. Although often associated with passenger-carrying air taxis, UAM also includes cargo drones, emergency medical UAVs and automated aerial infrastructure inspection systems.

Smart city integration involves real-time traffic monitoring, environmental data collection (air quality, noise levels), infrastructure diagnostics, autonomous delivery corridors and emergency response coordination.

A key requirement for UAM systems is seamless integration into digital airspace management systems. This includes Unmanned Traffic Management (UTM) platforms that coordinate flight paths, prevent collisions and ensure regulatory compliance.

Table 1. Civil UAV Application Domains

Sector	Primary Use	UAV Type
Agriculture	Crop monitoring, spraying	Multirotor / Fixed-wing
Construction	Mapping, inspection	Fixed-wing / VTOL
Energy	Wind/solar inspection	Multirotor
Logistics	Delivery services	VTOL / Hybrid
Public Safety	Surveillance, rescue	Multirotor
Urban Mobility	Transport systems	Advanced VTOL

Table 1 presents the principal civil application domains of UAV systems and the drone configurations most suitable for each mission profile. Multirotor platforms are widely preferred for inspection, public safety and precision tasks requiring hovering capability, while fixed-wing and VTOL systems are more effective for large-area mapping and longer-range operations. The table illustrates that drone selection is dependent on operational requirements such as endurance, payload, maneuverability and deployment environment. It also confirms the growing diversification of UAV technology as civil industries increasingly adopt specialized aerial solutions.

2.6 economic and operational efficiency. Challenges in civil integration.

The economic advantage of UAV systems in civil applications is largely driven by reduced operational cost per task. Compared with conventional manned aviation or manual inspection, drones significantly reduce labor, fuel consumption and risk exposure.

Usually, the cost for a UAV mission is lower than that of a manned aircraft mission. Economic benefits include: lower operational overhead, reduced insurance and safety costs, faster data acquisition cycles, improved decision-making speed, scalability through fleet operations.

Despite rapid adoption, several barriers remain. Some of them are: regulatory fragmentation across countries, privacy concerns in urban environments, limited battery endurance, weather sensitivity, cybersecurity risks, airspace congestion management.

The integration of drones into civilian airspace requires robust UTM systems, reliable communication infrastructure and standardized certification frameworks.

2.7 Future trends.

Future civil UAV development is expected to focus on:

- Fully autonomous BVLOS operations;
- AI-based real-time data interpretation;
- Hydrogen and hybrid-electric logistics drones;
- Integration with 5G/6G communication networks;
- Swarm-based infrastructure inspection;
- Digital twin integration for cities and industries.

Civil drones are gradually evolving from standalone tools into interconnected aerial data networks forming part of global digital infrastructure.

3. MILITARY APPLICATIONS AND BATTLEFIELD EVOLUTION

Military drones have transformed modern warfare by extending surveillance reach, reducing pilot exposure, increasing operational persistence and enabling precision engagement at lower cost than many conventional manned systems. What began as reconnaissance assets has evolved into a wide spectrum of unmanned platforms ranging from nano tactical drones to strategic HALE systems and loitering munitions [5], [11].

Recent conflicts have demonstrated that drones are no longer auxiliary assets, but central elements of battlefield. Their influence now extends across intelligence gathering, artillery correction, electronic warfare, maritime operations, logistics and strike missions.

3.1 ISR missions (Intelligence, Surveillance And Reconnaissance).

ISR remains the foundational military application of UAVs. Persistent airborne observation provides commanders with real-time situational awareness and shortens the sensor-to-decision cycle. Typical ISR payloads include: electro-optical / infrared cameras, Synthetic Aperture Radar (SAR), signals intelligence sensors, laser designators, communication relays. MALE [14], [15] systems such as the MQ-9 Reaper and tactical systems such as TB2-class aircraft have demonstrated the operational value of long-endurance surveillance over wide operational areas [5], [20]. Nano and micro drones are increasingly used by infantry units for local reconnaissance in urban combat, trench warfare, forested terrain and indoor environments.

Table 2. ISR Drone Classes

Class	Typical Range	Endurance	Main Use
Nano / Micro	<10 km	15–45 min	Squad reconnaissance
Tactical	10–150 km	2–12 h	Brigade / battalion ISR
MALE	500+ km	20–40 h	Theater surveillance
HALE	Strategic	24–40+ h	Strategic intelligence

Table 2 classifies military ISR UAV systems according to operational scale, range, endurance and mission role. Smaller nano and micro drones are optimized for short-range tactical reconnaissance at unit level, while tactical UAVs support battlefield surveillance over wider areas and longer durations. MALE and HALE platforms provide persistent theater and strategic intelligence with greatly extended endurance and coverage. UAV size and capability increase progressively with command level and mission complexity.

3.2 Strike and loitering munitions.

Armed drones have become one of the most visible military UAV categories. These systems combine surveillance sensors with guided weapons, allowing detection and engagement within a single mission chain.

Typical weaponized UAV roles: precision strike against vehicles or infrastructure, counter-insurgency operations, battlefield interdiction, persistent armed overwatch.

Loitering munitions [26] represent a hybrid class between missile and drone. They can patrol an area, identify targets and impact directly upon engagement. Examples include Harop-type systems and numerous newer tactical expendable drones [22].

Table 3. Armed UAV vs Loitering Munition

Parameter	Armed UAV	Loitering Munition
Reusable	Yes	Usually No
Endurance	Medium / High	Medium
Payload	Missiles/Bombs	Integral warhead
Mission Flexibility	High	Target-specific
Cost per Sortie	Lower after reuse	Single-use

Table 3 compares reusable armed UAVs with loitering munitions, highlighting their different operational roles and cost structures. Armed drones offer greater mission flexibility, longer service life and the ability to carry multiple weapons or sensors across repeated sorties.

In contrast, loitering munitions are generally single-use systems optimized for rapid target engagement with an integrated warhead. The table shows that future military operations are likely to employ both categories in complementary roles, balancing persistence, precision and affordability. These systems have changed force structure economics by enabling lower-cost precision effects.

3.3 Electronic warfare and counter-UAS operations.

As drone usage expands, electronic warfare (EW) has become a decisive battlefield factor. UAVs rely heavily on navigation, datalinks and sensors, all of which may be disrupted.

Common threats include GNSS jamming, GNSS spoofing, command-link interference, cyber intrusion and radar detection and interception.

As a result, military UAV development increasingly emphasizes on anti-jam antennas, inertial backup navigation, autonomous return-to-base logic, mesh networking, frequency agility and low-probability-of-intercept communications.

Counter-UAS (C-UAS) systems have also become a major defense sector including radar detection, RF sensing, kinetic interceptors, directed energy systems and electronic neutralization [33].

3.4 Maritime and naval drone operations.

Naval forces increasingly employ UAVs for maritime patrol, over-the-horizon sensing, mine countermeasures support, convoy protection and shipborne reconnaissance. Rotary-wing UAVs are particularly suitable because they can operate from frigates, destroyers and patrol vessels without runways.

Benefits include: expanded sensor horizon, reduced helicopter operating cost, persistent maritime surveillance, faster threat detection.

Future naval doctrine is expected to combine aerial, surface and underwater unmanned systems in integrated autonomous fleets.

3.5 Logistics and resupply.

Battlefield logistics is another growing military drone application. UAVs can transport ammunition, medicine, batteries, communications equipment and spare parts to forward positions where roads are dangerous or inaccessible.

This capability reduces exposure of personnel and vehicles to artillery, ambushes or mined routes, therefore is relevant for military operations [38].

3.6 Lessons from recent conflicts.

Recent wars have highlighted several operational realities:

- Low-cost FPV drones can threaten expensive armored systems;
- Mass production may matter more than unit sophistication;
- Electronic warfare can degrade high-end systems;
- ISR ubiquity reduces battlefield concealment;
- Rapid adaptation cycles are critical;
- Civil technology supply chains increasingly influence combat capability.

These lessons are reshaping procurement strategies globally.

3.7 Future military trends.

Likely developments include [27]:

- Loyal wingman combat drones;
- Fully autonomous reconnaissance swarms;
- AI target recognition with human oversight;
- Attritable mass-produced strike UAVs;
- Stealth unmanned combat aircraft;
- Multi-domain integration with land/sea systems.

Military aviation is moving toward mixed manned-unmanned force structures rather than purely crewed fleets.

4. CHALLENGES AND LIMITATIONS

Despite rapid technological progress, drones continue to face significant engineering, operational, regulatory and societal limitations. Many current constraints are not related to aerodynamic feasibility, but rather to energy storage, airspace integration, cybersecurity, weather resilience and public acceptance.

Understanding these limitations is essential for realistic forecasting of future UAV deployment.

4.1 Battery endurance and energy density.

For most civil multirotor drones, endurance remains one of the principal constraints. Hovering flight demands continuous power, causing relatively short mission durations compared with fuel-powered aircraft.

Table 4. Typical Endurance by UAV Type

UAV Type	**Typical Endurance**
Small Consumer Multirotor	20–40 min
Industrial Multirotor	25–60 min
Fixed-Wing Electric UAV	1–3 h
Hybrid UAV	4–12 h
MALE Fuel UAV	20–40 h

Table 4 presents the typical endurance ranges of major UAV categories and emphasizes the influence of propulsion type and aircraft configuration on mission duration.

Small multirotor drones offer high maneuverability but limited flight time due to continuous hovering power demand. Fixed-wing and hybrid systems achieve longer endurance through improved aerodynamic efficiency and higher energy availability, while MALE fuel-powered UAVs provide persistent long-duration operations. The table highlights that endurance remains a key design parameter shaping present and future drone applications.

Battery improvement is gradual, meaning airframe efficiency and mission optimization remain equally important [36], [37].

4.2 Cybersecurity risks.

Modern UAVs depend on software, communications links, GNSS signals, cloud systems and data networks. This creates vulnerabilities uncommon in traditional aviation.

Main cybersecurity threats: unauthorized command takeover, data interception, malware insertion, GNSS spoofing, denial-of-service attacks.

Table 5. Cyber Risk Severity

Threat	Operational Impact
Link Loss	Mission abort
GNSS Spoofing	Navigation deviation
Camera Data Theft	Intelligence compromise
Firmware Attack	Total platform loss

Table 5 summarizes the main cybersecurity threats affecting UAV systems and their potential operational impact. Communication link loss may interrupt missions, while GNSS spoofing can cause navigation errors or route deviation. Unauthorized access to sensor data may compromise sensitive information and firmware attacks can lead to complete loss of the platform. The table highlights that cybersecurity has become a critical requirement for both present and future drone operations, especially as autonomy and network connectivity continue to expand.

Cybersecurity certification is becoming a critical procurement requirement [21].

4.3 Spectrum congestion and communications.

As drone fleets expand, radio frequency spectrum becomes increasingly congested. Command links, telemetry, video transmission, remote ID and traffic management systems all compete for bandwidth.

Challenges include:

- Urban interference;
- Multipath signal degradation;
- Simultaneous fleet operation;
- Military jamming environments;
- Rural long-range connectivity gaps.

Future solutions are expected through 5G/6G integration, satellite backup links, adaptive spectrum allocation and mesh networking.

4.4 Certification and regulation.

Aviation regulators require high safety standards, especially in populated environments. Certification becomes increasingly difficult when UAVs are autonomous, heavy-lift, operating BVLOS, carrying hazardous payloads, sharing controlled airspace with crewed aircraft.

The regulatory challenge lies in balancing technological innovation with public safety while ensuring that UAV operations satisfy appropriate safety objectives, certification requirements and airspace integration standards [2], [6], [16], [17].

Figure 1 illustrates the relationship between increasing operational capability and growing regulatory complexity in the drone sector. At the lower end of the spectrum, consumer recreational drones require relatively simple rules because they operate with limited range, payload and risk exposure.

FIG. 1 Regulatory Complexity vs Operational Capability

As platforms evolve toward standard commercial drones and industrial BVLOS inspection systems, regulations become more demanding due to expanded airspace use, autonomy and safety requirements. Heavy cargo BVLOS operations represent a further step in complexity, requiring advanced certification, detect-and-avoid systems and integration with conventional aviation traffic management. At the highest level, passenger and Urban Air Mobility platforms demand the most comprehensive regulatory frameworks, reflecting the critical need to protect human life, public safety and urban airspace efficiency.

4.5 Weather and environmental sensitivity.

Small and medium drones remain sensitive to weather conditions.

Major operational limitations:

- Strong wind gusts;
- Rain;
- Icing;
- Dust contamination;
- Temperature extremes;
- Reduced GNSS visibility in urban canyons.

Compared with larger aircraft, low mass and small control surfaces increase disturbance sensitivity.

4.6 Privacy and public acceptance.

Public acceptance is essential for widespread civil UAV integration. Common concerns include:

- Surveillance and data privacy;
- Noise annoyance;
- Safety over crowds;
- Visual clutter in cities;
- Misuse by criminals.

Transparent regulation, geofencing, remote identification and clear data governance are required to maintain trust.

4.7 Supply chain and industrial constraints.

Drone manufacturing depends on batteries, semiconductors, sensors, cameras, composites, rare earth magnets and communication modules. Geopolitical disruptions or export restrictions may affect production capacity.

This has become especially relevant in defense procurement and critical infrastructure applications.

4.8 Future mitigation strategies.

Higher-density batteries and hydrogen systems;
- Secure encrypted datalinks;
- AI fault detection;
- Certified autonomy frameworks;
- All-weather airframes;
- Low-noise propellers;
- Localized supply chains.

4.9 Conclusion.

The principal barriers to drone expansion are increasingly systemic rather than aerodynamic. Success in the next decade will depend on solving energy, trust, cybersecurity, regulation and fleet-management challenges as much as improving aircraft hardware.

5. FUTURE TRENDS AND RESEARCH DIRECTIONS

The drone sector is entering a new technological phase in which future competitive advantage will depend less on basic flight capability and more on autonomy, scalable manufacturing, secure connectivity, energy efficiency and integration into broader digital ecosystems. Over the last decade, drones evolved from specialized remote-controlled tools into intelligent aerospace systems. Over the next decade, they are expected to become distributed robotic infrastructure supporting civil, industrial and defense operations [13], [31].

Current research directions are influenced by five major drivers:
- Artificial intelligence and autonomous decision-making;
- Beyond Visual Line of Sight (BVLOS) regulatory expansion;
- Advanced propulsion and energy storage;
- Swarm coordination and multi-agent systems;
- Full integration with smart cities, defense networks and digital industry.

5.1 Fully autonomous operations.

One of the most significant future developments is the transition from supervised automation to truly autonomous mission execution. Modern drones already perform waypoint navigation and automated landing, but next-generation systems are expected to:
- Detect and avoid dynamic obstacles independently;
- Replan missions in real time;
- Continue operation after communication loss;
- Select safe emergency landing areas;
- Coordinate with other drones without direct operator input.

Recent research in embodied AI and onboard reasoning shows progress toward adaptive decision-making in uncertain environments, including emergency landing behavior and context-based mission responses

Table 6 presents the evolution of UAV operational autonomy from fully manual control systems to fully autonomous mission execution.

Table 6. Evolution of UAV Operational Autonomy

Generation	Main Capability	Human Role
Gen 1	Remote piloting	Continuous control
Gen 2	Automated routes	Supervision
Gen 3	Adaptive autonomy	Mission oversight
Gen 4	Cooperative fleets	Intent command
Gen 5	Full autonomy	Human-on-the-loop

Early generations rely heavily on direct human piloting, while intermediate levels introduce waypoint navigation and supervised decision-making. Advanced autonomy enables cooperative fleet behavior, where drones operate with minimal human intervention and execute complex missions based on high-level intent. The table highlights a clear progression toward reduced human workload and increased system intelligence, reflecting the ongoing transition in UAV development from remotely piloted aircraft to autonomous robotic systems. The long-term objective is not necessarily human removal, but human scaling—where one operator supervises many intelligent platforms.

5.2 AI-driven fleets and swarm systems.

Swarm intelligence is increasingly viewed as one of the most disruptive future directions. Rather than relying on a single expensive platform, fleets of lower-cost drones can cooperate to perform surveillance, mapping, logistics or strike functions.

Modern swarm research focuses on:

- Decentralized decision-making;
- Shared sensing and collaborative mapping;
- Dynamic task allocation;
- Autonomous formation changes;
- Self-healing communication networks.

Recent 2026 research on agentic AI combined with edge computing indicates that onboard cooperative reasoning can significantly improve mission speed and coverage in wildfire and search-and-rescue scenarios

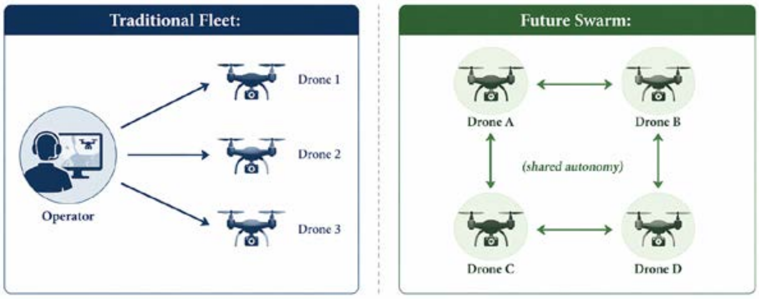

FIG. 2. Centralized vs Distributed Drone Swarms

Figure 2 presents the differences between centralized and distributed drone swarms. The left side shows a traditional centralized model, where a single operator manages each drone individually. In this approach, the operator workload increases with the number of drones, with limited scalability. The right side of Fig. 2 shows a distributed swarm, where drones communicate and coordinate directly with each other. Shared autonomy enables collaborative decision making, adaptive mission execution and exclude from the start a single point of failure. This distributed architecture improves scalability, efficiency and robustness, enabling complex missions with minimal operator load. The benefits and the challenges of drone swarm are listed also in Table 7.

Table 7. Swarm Benefits vs Challenges

Benefits	**Challenges**
High redundancy	Communication latency
Scalable coverage	Deconfliction
Lower unit cost	Cybersecurity
Fast area search	Regulatory approval
Survivability	Ethical governance

Military demand is accelerating this field, but civil applications such as wildfire monitoring, agriculture and infrastructure inspection may become equally important.

5.3 Sustainable UAV design.

Environmental sustainability is becoming a key research priority. As fleets grow globally, energy consumption, battery waste, noise pollution and lifecycle emissions become increasingly relevant.

Future sustainable trends include hydrogen fuel-cell, recyclable thermoplastic composite airframes, low-noise propeller optimization, solar-assisted platforms, battery-swapping ecosystems, lightweight additive-manufactured structures [39], [4], [12].

Table 8 below shows de expected benefit of the drone technologies. The trend is to increase air time (reduce energy consumption, increase efficiency, increase autonomy and range. Additionally, environmental factors should be considered (chemical and noise pollution. Sustainability is likely to become especially important in urban logistics and public-service fleets.

Table 8. Sustainability Pathways

Technology	Expected Benefit
Hydrogen fuel cells	Longer endurance, low emissions
Solar UAVs	Persistent low-energy flight
Recyclable composites	Lower lifecycle waste
AI energy management	Reduced power demand
Quiet propulsion	Better urban acceptance

5.4 Integrated airspace ecosystems.

Future drones will not operate as isolated aircraft, but as nodes inside digitally managed airspace ecosystems. This requires integration with Unmanned Traffic Management (UTM), manned air traffic control interfaces, remote identification systems, dynamic geofencing, weather data services, real-time risk assessment platforms.

The expected expansion of BVLOS operations depends heavily on this transition. Industry reporting in 2025 highlighted increasing regulatory focus on moving from waiver-based approvals toward scalable BVLOS frameworks.

As autonomy improves, the effective value of m increases significantly.

5.5 Human-machine teaming.

Instead of replacing people, drones are expected to amplify human productivity.

Examples include:

- One technician supervising inspection fleets;
- One firefighter directing thermal mapping swarms;
- One soldier managing reconnaissance drones [27], [35];
- One logistics controller dispatching cargo UAV networks.

This shift from one-human/one-machine toward one-human/many-systems is one of the most important structural trends in robotics.

5.6 Security and resilience research.

As dependence on drones grows, resilience becomes critical. Future systems must permit GNSS denial and spoofing, cyber intrusion, communication outages, adverse weather, sensor degradation, autonomous system faults.

Research priorities therefore include: vision-based navigation, multi-sensor fusion, edge AI fault recovery, secure mesh networking, explainable AI for certification.

5.7 Industrialization and mass production.

A major future shift is the industrialization of drone manufacturing. Modern conflicts and expanding commercial demand demonstrate that low-volume premium aerospace production may be insufficient.

The emerging model proposes modular open architectures, rapid software updates, commercial component adaptation, large-volume scalable assembly, short iteration design cycles.

This resembles consumer electronics and automotive innovation cycles more than traditional aviation timelines.

5.8 Outlook to next decade.

By 2035, drones are likely to be common infrastructure in many sectors. High-growth use cases in the near future are expected in almost every field: Agriculture - autonomous crop fleets, Energy - continuous inspection networks, Logistics - regional drone delivery, Cities - emergency response, Defense – Loyal wingman systems, Environment - monitoring fleets.

The most valuable future drone companies may be software, autonomy and systems-integration firms rather than pure airframe manufacturers.

The future of drones will be shaped by intelligent autonomy, swarm coordination, sustainable propulsion and integration into regulated digital airspace systems. Hardware improvements will remain important, but the dominant differentiator is shifting toward software-defined capability. In practical terms, the next generation of UAVs will function less as individual aircraft and more as connected robotic ecosystems.

6. CONCLUSIONS AND REMARKS

The analysis presented in this paper demonstrates that unmanned aerial vehicles have evolved beyond specialized aerospace platforms into versatile operational systems supporting an expanding range of civil, commercial and military missions. Building upon the technological foundations discussed in Part 1, current developments indicate that the principal advances in the UAV sector are increasingly driven by operational integration, intelligent system management and the ability to execute complex missions in dynamic environments [8], [9], [30].

Civil applications continue to diversify as drones become established tools in precision agriculture, infrastructure inspection, logistics, environmental monitoring, emergency response and urban air mobility. Their capability to acquire, process and transmit high-quality data rapidly has transformed UAVs into essential components of modern digital infrastructure, while ongoing developments in Beyond Visual Line of Sight (BVLOS) operations and Unmanned Traffic Management (UTM) are expected to further expand their operational role [10], [16], [17], [31].

In the military domain, recent operational experience confirms that unmanned systems have become integral elements of contemporary battlefield doctrine. Persistent intelligence, surveillance and reconnaissance (ISR), precision engagement, electronic warfare support, loitering munitions and distributed unmanned operations are reshaping force structures and operational concepts.

At the same time, advances in autonomous mission management and collaborative drone operations are accelerating the transition toward increasingly networked and coordinated unmanned capabilities [3], [5], [11], [33].

The review also highlights that future UAV development is influenced by challenges extending beyond aircraft design. Energy storage limitations, cybersecurity, resilient communications, spectrum management, certification requirements and public acceptance remain key factors governing large-scale deployment. Addressing these issues will require coordinated progress in engineering, regulatory policy and operational procedures to ensure the safe and reliable integration of increasingly autonomous systems into shared airspace [16], [17], [36], [37], [21].

Current research trends indicate a gradual transition from individually operated platforms toward intelligent, interconnected UAV ecosystems. Artificial intelligence, distributed swarm coordination, secure communications, sustainable propulsion technologies and human-machine teaming are expected to become defining characteristics of next-generation unmanned aviation. Future competitiveness will therefore depend not only on advances in individual aircraft performance but also on the successful integration of autonomous decision-making, digital connectivity and scalable system architectures [7], [39], [4], [13], [18], [24], [28].

Overall, the continued evolution of unmanned aerial systems reflects a broader transformation within aerospace engineering, where software, autonomy and systems integration are becoming as significant as traditional airframe and propulsion technologies. Together, Parts 1 and 2 provide a comprehensive overview of the technological foundations, operational applications and future development trends that are expected to shape the next generation of UAV systems across both civil and military domains.

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