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Research on Unmanned and Intelligent Combat Theory and Capability Development

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Abstract: This paper presents a comprehensive analysis of the evolution, foundational concepts, capability development, and operational challenges of unmanned systems. It traces their theoretical progression from post-Cold War origins to systematic maturation in the 21st century, emphasizing the central role of emerging operational concepts and exploratory advances in capability development. Key bottlenecks in unmanned combat operations are examined, particularly limitations in communication bandwidth and the vulnerability of data links in contested environments. The paper further discusses future development trajectories, highlighting both technological and ethical challenges. Overall, unmanned warfare is evolving toward a more intelligent, networked, and resilient operational architecture, with profound implications for the conduct and character of future high-end warfare.

Keywords: Unmanned combat theory; Capability development; Multi-domain collaboration; Artificial intelligence

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1. Introduction

With the rapid advancement of cutting-edge technologies such as artificial intelligence and information technology, modern warfare is progressively shifting towards intelligent and unmanned operations. As a global pioneer in unmanned combat capability development, the world has initially established an unmanned combat system with space-based assets as the core, air-based assets as the lead, and coordinated development of land and sea-based components. Its theoretical evolution and practical exploration not only lead the development direction of intelligent warfare but also profoundly reshape the operational paradigms of the future battlefield. However, the rapid development of theory and technology has also exposed numerous bottlenecks, including the vulnerability of communication links in contested environments, ethical and legal controversies surrounding autonomous decision-making, and insufficient reliability of AI algorithms.

This paper analyzes the unmanned and intelligent combat theory from four dimensions: theoretical evolution, core concepts, system development, and technological bottlenecks. Employing comprehensive literature research and case analysis methods, it aims to systematically outline the developmental logic from technological inception to system formation, analyze the connotative evolution of key operational concepts, and reveal the practical challenges faced in cross-domain integration and intelligent transformation.

2. Evolution of unmanned warfare doctrine

2.1. Theoretical inception in the early post-Cold War era

Following the end of the Cold War, amid profound changes in the international security environment and the concentrated, explosive development of high-tech technologies, some powerful nations began systematically exploring the strategic potential and tactical application paths of unmanned combat systems. During this phase, although unmanned platforms had not yet formed large-scale operational capabilities, their role as a key driving force for transforming future warfare patterns attracted widespread attention from senior leadership. Early theoretical concepts primarily focused on how to embed unmanned systems into existing operational architectures to enhance battlefield awareness accuracy and strike response speed, initially reflecting the basic logic of information dominance theory, achieving real-time battlefield situational reconstruction and dynamic sharing through distributed sensor networks. Simultaneously, the evolution of systems confrontation theory provided structural support for unmanned warfare, emphasizing enhanced resilience and survivability of the overall operational system through coordinated interaction of multi-domain heterogeneous units [1]. Against this backdrop, some countries gradually initiated a series of technology pre-research projects and, relying on top-level design documents like the "Unmanned Systems Integrated Roadmap", explicitly positioned unmanned platforms as key enablers in joint operations.

2.2. Theoretical system maturation in the 21st century

Since entering the 21st century, unmanned combat theory, driven by both the prolonged practice of counterterrorism wars and the anticipation of high-end conflicts, Some countries have gradually achieved systematic and architectural development. The mature application of unmanned aerial vehicles (UAVs) in missions such as intelligence, surveillance, and reconnaissance (ISR), precision strike, and communications relay served as the critical practical foundation for theoretical maturation. Long-endurance, high-precision platforms represented by the RQ-4 Global Hawk and MQ-9 Reaper not only significantly enhanced wide-area battlefield situational awareness but also enabled cross-domain information fusion through real-time data link support, providing technical and tactical validation for multi-domain joint operations. In 2014, the core guiding principle of the "Third Offset Strategy proposed" was proposed, aimed at maintaining the global military superiority through the development of disruptive technologies. It emphasized enhancing the operational effectiveness of unmanned platforms through R&D and integration of emerging technologies like AI, autonomous systems, and directed-energy weapons, with particular focus on building a multi-domain integrated system centered on space-based perception, led by air-based unmanned platforms, and supported by coordinated responses from land and sea unmanned nodes. This laid the strategic foundation for the subsequent deepening of unmanned combat theory. These theoretical explorations and technological practices collectively contribute to the comprehensive maturation of the unmanned combat theoretical system.

3. Analysis of core operational concepts

3.1. Analysis of the "Mosaic Warfare" concept

"Mosaic Warfare," as an emerging operational paradigm, originates from "Decision-Centric Warfare" theory. Within this architecture, the combat system no longer relies on a few high-value platforms but enhances system survivability and resilience through distributed deployment. Even if some nodes are lost, remaining units can reorganize through self-organizing mechanisms and maintain mission execution capability. This decentralized structural characteristic significantly enhances battlefield adaptability, particularly suited for sustained operational requirements in complex contested environments [2]. "Mosaic Warfare" not only changes traditional force composition models but also drives the evolution of command and control systems towards deep human-machine integration, requiring breakthroughs in key technological areas such as situational awareness, communications assurance, and dynamic task allocation. Therefore, the practice of "Mosaic Warfare" is not merely an innovation at the tactical level but a systematic challenge and reshaping of the entire unmanned combat system architecture and its supporting technological capabilities.

3.2. Integration of "Joint All-Domain Command and Control"

"Joint All-Domain Command and Control" (JADC2) is the core architecture through which aims to achieve future intelligentized operations. It seeks to break down traditional information silos between military services via highly integrated communication networks and data link systems, enabling deep integration of multi-domain operational forces. Within this system, unmanned platforms, leveraging their distributed deployment, high mobility, and persistent reconnaissance capabilities, become key nodes for information sensing and tactical execution, supporting the underlying architecture for cross-domain collaborative operations. Notably, the "Mosaic Warfare" concept further drives the evolution of JADC2 towards modularity and reconfigurability. By decomposing the kill chain into flexibly combinable functional units, it achieves rapid response and adaptive reorganization, marking the transition of unmanned combat from single-platform control towards a new stage of system-level intelligent contest [1].

4. Integration of unmanned combat systems

4.1. Integration of unmanned systems into the existing command and control architecture

In advancing its unmanned combat capabilities, the places significant emphasis on the deep integration of unmanned platforms with existing command systems, striving to achieve efficient embedding and process optimization within traditional command chains. This mechanism relies on the synergy between high-bandwidth, low-latency data links and artificial intelligence algorithms, ensuring seamless flow of command information between manned platforms and unmanned units, thereby enhancing overall operational tempo and response speed. Within this command architecture, the manned-unmanned collaborative combat model serves as a bridge connecting traditional command structures with emerging autonomous systems. Human operators act as mission supervisors and strategic decision-makers, responsible for setting rules of engagement and target priorities, while unmanned systems undertake tactical execution tasks such as reconnaissance, strike, and communications relay. This division of labor not only aligns with the requirements for cross-domain coordination under Joint All-Domain Operations (JADO) but also reflects the core value of human-machine teaming (HMT) in modern warfare [3].To further quantify the stability and adaptability of collaborative structures, the complex network theory has been introduced to construct combat network models for manned/unmanned formations. Through static topological analysis, these models reveal the connectivity characteristics and information dissemination efficiency of systems under different autonomy levels [4]. This provides a theoretical tool for assessing the robustness of command links and offers technical support for the future evolution of command and control systems toward distributed and resilient architectures. Thus, through institutional, technological, and theoretical pathways, the unmanned platforms are being promoted for deep integration into existing operational command systems, thereby realizing intelligent and agile decision-making processes.

4.2. Construction of the intelligence-strike closed loop

Within the modern joint operational system, some countries are committed to shortening the decision-making cycle and enhancing strike timeliness. Its core lies in the automation and intelligentization upgrade of the kill chain. In recent years, with the rapid development of the Manned-Unmanned Teaming (MUM-T) concept, a few countries has preliminarily achieved dynamic task allocation and information sharing among heterogeneous operational units, significantly enhancing overall battlefield situational awareness and operational effectiveness [5]. The success of this operation depended on real-time target data provided by external sensor nodes, fully demonstrating the capability for multi-source intelligence fusion and cross-platform coordinated strike within a distributed operational network [6]. To quantitatively assess the effects of such coordinated combat, an extended Lanchester combat model has been proposed within academia, introducing battlefield awareness coefficients and command and control capacity parameters. Simulation results indicate that strengthening the quality of information interaction and system integration level in coordinated combat can reduce operational losses while improving mission success rates.

5. Bottlenecks in system operation

5.1. Communication bandwidth and link security

In long-range unmanned combat missions, limited communication bandwidth and insufficient data link security have become key bottlenecks restricting the effectiveness of unmanned systems. As the operational radius expands, the demand for high-bandwidth, low-latency data transmission by remote unmanned platforms increases sharply, while existing communication architectures struggle to guarantee stable information exchange in complex electromagnetic environments. Particularly in high-intensity conflict scenarios, electronic jamming and spectrum suppression conducted by adversaries significantly degrade link availability. Although traditional frequency-hopping communication possesses certain anti-jamming capabilities, its pre-set hopping patterns are susceptible to detection and prediction, making real-time synchronization of communication parameters difficult and severely impacting the continuity of command and control in MUM-T operations [7]. To address this, researchers are exploring variable-rate non-cooperative frequency-hopping techniques, enhancing parameter stealth by dynamically adjusting hopping sequences to improve communication robustness under contested conditions [7]. Concurrently, artificial noise cooperative jamming technology is being introduced into electromagnetic warfare systems, using directional jamming means to degrade enemy channel quality without affecting friendly signal reception, further strengthening communication superiority [7]. From a network topology perspective, MUM-T combat networks need high resilience to cope with node failure or link interruption. Evaluation models based on connectivity robustness indicate that by constructing a node and edge reconstruction evaluation index system, rapid recovery can be achieved after partial network damage, enhancing the overall system's fault tolerance and mission sustainability [8]. However, even with ongoing technological evolution, cybersecurity threats persist. Network intrusions could lead to command tampering or sensitive intelligence leakage, severely undermining the trustworthiness and stability of the unmanned combat system.

5.2. Ethics and risks of autonomous decision-making

As the autonomy levels of unmanned combat systems continuously increase, the applicability of engagement rules and associated ethical risks during mission execution in complex battlefield environments are becoming increasingly prominent. Highly autonomous unmanned platforms, operating without continuous human intervention, may perform target identification and strike decisions based on pre-set algorithms. When a system causes unintended casualties due to environmental misjudgment or algorithmic bias, it is difficult to clearly define the responsible entity, whether the operational commander, system developer, or the AI itself should bear the consequences, as there is currently no unified international norm for this. This ambiguity not only weakens the legitimacy foundation of military operations but may also undermine public trust in the unmanned combat model. Concurrently, the cognitive limitations of autonomous decision-making systems are further exposed in dynamic conflict scenarios, especially in critical links such as friend-or-foe identification, civilian avoidance, and tactical intent inference. Existing algorithms remain constrained by insufficient situational understanding capability and information fusion accuracy, prone to misjudgment and overreaction. Although multi-agent coordinated strategies are being optimized through reinforcement learning frameworks to enhance system adaptability and behavioral stability. For instance, the application of the PD-MADDPG algorithm in continuous dynamic air combat environments has significantly improved strategy convergence efficiency and execution robustness [9]. Therefore, while advancing high-level autonomous capability development, it is imperative to simultaneously construct a composite governance framework encompassing technology verification, legal review, and ethical assessment, ensuring that unmanned systems achieve a dynamic balance between operational effectiveness and moral acceptability under the premise of adhering to the laws of war.

5.3. Reliability of artificial intelligence algorithms

In the evolution of the unmanned combat system, the reliability of AI algorithms has become a key factor determining the effectiveness of autonomous coordinated operations. Particularly in complex, dynamic, and highly uncertain battlefield environments, the stability of target recognition and behavior prediction by unmanned systems directly relates to mission success and operational safety. Currently, although deep learning models, through multi-layer neural networks, have achieved effective fusion and feature extraction of multi-source sensor information (space, air, sea-based), enhancing situational awareness accuracy, decision bias risks still exist in actual conflict scenarios. Improved algorithms based on the Multi-Agent Deep Deterministic Policy Gradient (MADDPG) with centralized training and decentralized execution have demonstrated stronger strategy convergence and execution stability in simulated air combat tasks [10]. Another example is the introduction of parallel decoupling mechanisms and symmetric attention structures (SAM) to optimize the information screening efficiency of critic networks, enabling unmanned swarms to possess superior coordinated response capabilities in continuous dynamic competition [9]. Their reliability verification requires closed-loop iteration relying on large-scale simulation and live testing. Therefore, constructing intelligent algorithm architectures that combine safety and adaptability is a core research direction for future unmanned combat capability development.

5.4. Autonomous navigation and obstacle avoidance technology

In complex electromagnetic environments and GPS-denied conditions, the autonomous navigation and obstacle avoidance capabilities of unmanned combat platforms face severe challenges, becoming a key technological bottleneck constraining all-domain operational effectiveness. Traditional navigation modes reliant on the Global Positioning System are highly susceptible to jamming and spoofing in contested environments, leading to platform positioning failure, mission interruption, or even tactical exposure. To address this, multi-source fused navigation technology has long been a focus of development, integrating various non-GNSS methods such as inertial navigation, terrain contour matching, visual simultaneous localization and mapping (SLAM), and geomagnetic-aided navigation to enhance the sustained positioning accuracy and robustness of unmanned systems in denied environments [8]. However, existing systems still exhibit significant shortcomings in dynamic environment adaptability, long-term drift suppression, and multi-node coordinated positioning consistency. Particularly in extreme scenarios like underwater or urban canyons, limited communication bandwidth and perception occlusion further exacerbate navigation solution uncertainty. Therefore, the future development of navigation systems for unmanned platforms depends not only on technological breakthroughs at the sensor level but also requires strengthening cross-domain coordination, intelligent reconfiguration, and anti-jam communication capabilities from the perspective of the operational system architecture, achieving a fundamental shift from platform autonomy to system empowerment.

6. Assessment of future development directions

6.1. Evolution towards intelligentization and swarm operations

With the accelerated advancement of global intelligent unmanned combat systems, swarm operation modes represented by small UAV swarms are gradually becoming a key force on the future battlefield. Such swarm systems not only create asymmetric deterrence through numerical superiority but also, under the Mosaic Warfare concept, build flexible and reconfigurable kill webs through modular node combinations, breaking traditional linear operational structures. Simultaneously, the "Combat Cloud" concept in the context of cross-domain coordination further expands the information support dimension for swarm operations. By integrating space-based sensing, airborne early warning, and ground command nodes, it achieves all domain situational sharing and dynamic target guidance. The application of low-cost, attritable platforms like the XQ-58A Valkyrie provides a tactical interface for swarms within high-end manned-unmanned formations, driving the operational system towards intelligent and resilient evolution. Despite facing technical and strategic challenges such as communication latency, coordinated robustness, and ethical regulation, unmanned swarm operations based on autonomous coordination and intelligent emergence are still regarded as a core driving force subvert future warfare patterns [11].

6.2. Deep integration and development of human-machine teaming

With the accelerated evolution of modern warfare towards intelligent and networked forms, major military powers are actively promoting the deep integration of manned platforms and unmanned loyal wingmen at the tactical level, focusing on constructing a new operational system centered on human-machine teaming. This mode relies on advanced command and control architectures and autonomous decision-making algorithms to achieve efficient coupling between human operators and unmanned systems. Distributed control methods based on consensus protocols are introduced into manned-unmanned formation systems, further improving formation coordination efficiency. Information interaction topologies constructed by combining graph theory and leader-follower mechanisms ensure the formation maintains a stable configuration in complex electromagnetic environments. Modeling coordinated combat network structures under different autonomy levels using complex network theory enables quantitative analysis of system robustness and dynamic topological evolution [4,12]. This integrated application of technologies and theories marks a new stage in the evolution of highly intelligent human-machine combat collaboration.

7. Conclusion

The development of unmanned combat theory and capabilities has evolved from its theoretical inception in the immediate post-Cold War era to its systematic development in the 21st century. Driven by the demands of counterterrorism warfare, the widespread operational use of UAVs prompted it to gradually construct an unmanned combat theoretical system spanning land, sea, air, space, and cyberspace domains. Novel operational concepts like "Mosaic Warfare" emphasized distributed architectures and dynamic reorganization capabilities, enhancing the flexibility and survivability of combat systems. The JADC2 concept aimed to break down information barriers between service branches, enabling cross-domain collaboration between unmanned platforms and real-time data sharing. However, challenges persist during this integration process, including delays in command and control response, insufficient automation levels in the intelligence-strike loop, limited communication bandwidth, and ethical risks associated with autonomous decision-making. Regarding key technologies, the stability of artificial intelligence algorithms and autonomous navigation capabilities in GPS-denied environments remain bottlenecks. Future development trends will focus on intelligent swarm operations, deep human-machine collaboration, and enhancing the adaptability of highly autonomous systems in complex battlefield environments, thereby further shaping the character of high-end warfare.

Disclosure statement

The author declares no conflict of interest.

References

[1] Wang J, 2021, Research on Mosaic Cooperative Warfare Theory. Telecommunications Technology Research, 2021(4): 33–39.

[2] Andrews J, 2020, Human Performance Modeling: Analysis of the Effects of Manned-Unmanned Teaming on Pilot Workload and Mission Performance, thesis, Air Force Institute of Technology.

[3] Johnson B, Miller S, Heeter B, et al., 2023, A Human-Machine Teaming Approach for Future Marine Corps Hybrid Operations: Manned Helicopters and Air-Launched Unmanned Aerial Vehicles. Naval Engineers Journal, 135(1): 127–139.

[4] Wang X, Cao Y, Liao W, 2021, Modeling of MAV/UAV Collaborative Combat Network Based on UAV Autonomous Level. Proceedings of 2021 International Conference on Autonomous Unmanned Systems: International Conference on Autonomous Unmanned Systems (ICAUS 2021), 24–26.

[5] Fan J, Li D, Li R, et al., 2017, Analysis for Cooperative Combat System of Manned-Unmanned Aerial Vehicles and Combat Simulation. 2017 IEEE International Conference on Unmanned Systems.

[6] Chabanov V, 2022, Technology of Interaction Between Manned and Unmanned Aerial Vehicles (MUM-T): An

Element of Multi-Domain Combat Operations of the US Ground Forces. Aviation Systems: Scientific and Technical Information, 2022(3): 44–47.
[7] Gao L, Ding J, Lian R, 2019, The Communication Availability of the Cooperative Combat of Manned / Unmanned Aerial Vehicles in Electromagnetic Cyber Confrontation Environment. International Conferences on Ubiquitous Computing Communications; Data Science and Computational Intelligence; Smart Computing, Networking and Services.
[8] Shi G, Zhang L, Zhang J, et al., 2018, Research on Robustness of Manned/Unmanned Aerial Vehicle Collaborative Combat Network. International Conference on Control, Automation, Robotics and Vision.
[9] Wang Z, Guo Y, Li N, et al., 2023, Autonomous Collaborative Combat Strategy of Unmanned System Group in Continuous Dynamic Environment Based on PD-MADDPG. Computer Communications, 200(2): 182–204.
[10] Xu D, Chen G, 2022, The Research on Intelligent Cooperative Combat of UAV Cluster with Multi-Agent Reinforcement Learning. Aerospace Systems, 5(1): 107–121.
[11] Qi D, Zhang J, Liang X, et al., 2021, Autonomous Reconnaissance and Attack Test of UAV Swarm Based on Mosaic Warfare Thought. 2021 6th International Conference on Robotics and Automation Engineering: 6th International Conference on Robotics and Automation Engineering (ICRAE), 19–22.
[12] Ma N, Cao Y, 2024, Consensus-Based Distributed Formation Control for Coordinated Battle System of Manned/ Unmanned Aerial Vehicles. Transactions of the Institute of Measurement and Control, 46(1): 3–14.