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Tactical Research on Military UAVs: Hotspots, Evolution and Frontier Prospects(Visual Analysis Based on CiteSpace for Chinese Core Thematic Literature in CNKI)

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Abstract. As a core element in the evolution of modern warfare patterns, military UAV tactics form a tactical system integrating aerospace engineering, artificial intelligence, reconnaissance and surveillance, and precision strike technologies, covering mission planning, cooperative operations, anti-jamming protection, and effectiveness evaluation. To clarify its development context and laws, this study takes 354 core journal papers (Peking University Core Journals) indexed in CNKI from 1993 to 2025 as samples, using CiteSpace combined with bibliometric and knowledge graph methods to analyze academic ecology, hotspots, evolution paths, and frontiers. The results show that the field focuses on military UAV swarm operation systems and combat modes, forming a "technological breakthrough → tactical verification → actual combat testing" paradigm; hotspots present a "technology → tactics → confrontation" three-dimensional structure; evolution follows "technology-driven → tactical iteration → system reconstruction" logic; frontiers converge on technology empowerment, tactical form, and actual combat confrontation. The research promotes tactical iteration from "laboratory" to "battlefield" and facilitates "new-quality combat forces" innovation.

Keywords: Military UAV Tactics; Knowledge Graph; New-Quality Combat Forces; Swarm Collaboration; Tactical Effectiveness Evaluation.

1. Introduction

Intelligent technology iteration drives military UAVs from single reconnaissance platforms to multi-domain combat nodes, with their tactical application expanding as a global military competition focus. Military UAV tactics integrate multi-field technologies, covering key dimensions that directly affect battlefield situational awareness and combat task success.

Currently, all-domain operation demands accelerate UAV tactics toward "swarm collaboration", "human-machine hybrid formation", and "cross-domain linkage", requiring innovations in theory, technology integration, and effectiveness verification. Meanwhile, complex battlefield challenges (electromagnetic confrontation, anti-UAV threats) drive the field from "passive response" to "active design". However, problems such as fragmented theories and insufficient technology-tactics integration remain; traditional reviews fail to fully present development context, while bibliometric methods can sort patterns and identify frontiers.

Against this background, this study uses 354 CNKI-indexed Peking University Core Journals papers (1993-2025) on military UAV tactics, applying CiteSpace to sort knowledge focus, hotspots, evolution paths, and frontiers, aiming to reveal core context and provide references for tactical theory deepening, technology application, and national defense decision-making.

2. Research Design and Methodology

2.1 Literature Selection and Processing

This study uses Peking University Core Journals in CNKI as the data source,using advanced search with the formula:
SU=("Unmanned Aerial Vehicle" + "UAV") AND SU=("Military" + "Army" + "Navy" + "Air

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Force" + "Combat" + "Battlefield") AND SU=("Tactics" + "Tactical Method" + "Application" + "Operation" + "Concept")

The three keyword groups are positioned as: (1)UAV Chinese-English expressions (platform-related, ensuring all UAV-centered literature inclusion); (2)"Military" as core with "Combat/Battlefield" (domain-related, locking military scenarios); (3)"Tactics/Tactical Method" as core with "Application/Operation/Concept" (theme-related, highlighting tactical focus).

As of October 17, 2025, 379 initial documents were retrieved; 361 target documents were obtained after manual cleaning. Due to CiteSpace 6.4.R1 incompatibility with 7 special-format documents, the final effective sample is 354 (loss rate 1.94%<10%, meeting bibliometric standards).

2.2 Analysis Methods and Parameters

Based on CiteSpace 6.4.R1 Advanced Edition, combining bibliometric analysis and knowledge graph analysis methods, The parameter settings are optimized for as follows: (1)**Cosine Algorithm**: Reduces sparse data interference, enhances co-occurrence network stability, and ensures reliability of literature element relationships. (2)**g-index (k=25)**: Improves cluster quality in cluster analysis, adapting to dynamic time-slice analysis to capture hotspot changes. (3)**Pathfinder Algorithm**: Simplifies complex network structures, filters non-critical paths, and highlights core knowledge network links.

3. Research Results and Analysis

3.1 Knowledge Focus: Analysis of Highly Cited Literature

Since CiteSpace cannot process CNKI literature co-citation maps, this study uses highly cited literature as a substitute. The rationality is supported by existing research: Zhao Jianbao[1] notes that literature co-citation network frameworks consist of highly cited foundational, classic, and key works—these works serve as the network's core nodes and can directly replace the co-citation network for knowledge base analysis; Han Yi et al.[2] propose that the core value of a citation network lies in reflecting the inheritance and development of knowledge. Table 1 lists the top 20 cited literatures:

Table 1. Top 20 Cited Literatures on Tactical Research of Military Unmanned Aerial Vehicles (1993-2025)

No.	Paper Title	Author(s)	Journal Name	Publication Year	Citation Frequency
1	Review and Future Development of Small Fixed-Wing UAV Swarms	Wang Xiangke et al.	Acta Aeronautica et Astronautica Sinica	2019	280
2	Research Prospect of Autonomous UAV Swarm Technology	Duan Haibin et al.	Science & Technology Review	2018	116
3	Technology Application and Development Trend of Intelligent Unmanned Systems	Wang Yaonan et al.	Chinese Journal of Ship Research	2022	102
4	Current Status and Prospect of Multi-UAV Path Planning for Meta-Heuristic Algorithms	Zhao Chang et al.	Control and Decision	2021	101
5	Application of UAVs in the Russia-Ukraine Conflict	Yang Jiahui et al.	Tactical Missile Technology	2022	86
6	Research on Current Status and Development Trend of UAV Swarm Combat	Yang Zhongying et al.	Aerodynamic Missile Journal	2019	72

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7	Current Status and Development Trend of Foreign Military UAV Data Links	Li Guihua	Telecommunication Engineering	2014	70
8	Review of Hot Topics in the UAV Field in 2018	Duan Haibin et al.	Science & Technology Review	2019	68
9	Review of the Development of Foreign Military UAV Swarm Applications in Urban Combat	Lü Zhenhua, Gao Kang	Journal of China Academy of Electronics and Information Technology	2020	67
10	Review of Foreign Military UAV Equipment and Technology Development in 2018	Li Lei et al.	Tactical Missile Technology	2019	66
11	Review of UAV Hot Topics in 2019	Duan Haibin et al.	Science & Technology Review	2020	65
12	Research on the Development of US Military Manned/Unmanned Autonomous Cooperative Combat Capabilities	Shen Chao et al.	Tactical Missile Technology	2018	63
13	Brief Analysis of the Development of Major US Military UAV Swarm Projects	Liu Li et al.	Aerodynamic Missile Journal	2018	61
14	Analysis of US Military UAV Swarm Combat	Yan Qingfeng et al.	Aerodynamic Missile Journal	2017	60
15	Research on the Military Application of Target Positioning in UAV Reconnaissance Images	Yang Shuai et al.	Infrared Technology	2016	59
16	Types and Military Applications of Near-Space Vehicles	Li Yan et al.	Aerospace China	2007	58
17	Key Technologies for Autonomous Collaboration of Unmanned Swarm Systems in Complex Environments	Lin Yuefeng et al.	Acta Aeronautica et Astronautica Sinica	2022	55
18	Technical Characteristics and Application Trends of the Global Hawk Unmanned Reconnaissance Aircraft	Lin Yuefeng et al.	Aerodynamic Missile Journal	2011	53
19	Key Technologies of UAVs in the 21st Century	Song Yuhua et al.	Modern Defense Technology	2004	53
20	Analysis of the Concept and Main Development Trends of Intelligent UAV Swarms	Zou Liyan et al.	Tactical Missile Technology	2019	52

(Note: Citation frequencies are based on CNKI (statistical cutoff: 20:00, October 17, 2025; sorted after cleaning.)

As shown in Table 1, highly cited literatures focus on military UAV swarm operation technical systems and combat modes. With core cases (US OFFSET program: 250 UAV coordination; "Gremlins" aerial recovery: sustained combat; Russia-Ukraine Conflict suicide UAVs: electronic countermeasure shortcomings), they form the "technological breakthrough - tactical verification - actual combat test" paradigm.

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3.1.1 Construction of the Technical System for UAV Swarm Combat

The core of UAV swarm combat is a distributed intelligent collaborative system, achieving swarm intelligence emergence via bionic algorithms (such as pigeon flock collaboration and wolf pack task allocation) to break centralized control limitations[3][4]. The US DARPA-led OFFSET program promotes 250 UAVs /UGVs cooperative combat in complex urban environments[5], while the aerial recovery technology of the "Gremlins" program significantly enhances the sustained combat capability of swarms[6]. Key technological breakthroughs include: enhanced anti-jamming capability via ultraviolet communication[3], dynamic topology reconstruction enabled by self-organizing radio frequency networks[7], and decentralized command of XQ-58A UAV formations by F-35 fighters through the "Loyal Wingman" architecture[8]. However, cross-domain collaboration (UAV-UGV) still faces technical bottlenecks such as communication delay and heterogeneous platform integration[9].

3.1.2 Key Technological Breakthroughs and Operational Effectiveness Verification

The intellectualization of the perception-decision-control closed loop is critical to the operationalization of UAV swarms. Multi-source sensor fusion technology (including LiDAR terrain modeling and infrared/visible light target recognition) significantly enhances adaptability in complex battlefield environments[10], while the CLEAR algorithm optimizes global environmental awareness capabilities[3]. Reinforcement learning is applied to dynamic task allocation, and the U.S. military’s MQ-9 has verified real-time tactical reconfiguration capabilities through air combat decision-making tests[8]. Practical experience from the Russia-Ukraine conflict shows that the significant constraints of electronic jamming on reconnaissance-strike integrated UAVs have exposed shortcomings in their survival capabilities[11]. Breakthroughs in new energy technologies have brought about a endurance revolution: solar-hydrogen hybrid power enables 72 hours of continuous cruising[12], and laser wireless charging technology solves the problem of frontline supply. The VR command and control system allows a single operator to control 50 UAVs[8], yet the real-time response of large-scale swarms is still limited by computing power.

3.1.3 Evolution of Operational Patterns and Prediction of Future Trends

UAV tactics are transitioning from single-platform operations to systematic intelligent swarms. Typical models include: strategic reconnaissance (real-time transmission of 0.3m-resolution images by Global Hawk[13]), saturation attacks (coordinated penetration by 103 UAVs in the "Gray Eagle" program[5]), and manned-unmanned collaboration (joint strikes by X-47B and aircraft carrier battle groups[8]). Future development directions will focus on: (1) **Intelligent upgrading**, such as the Alpha air combat system achieving millisecond-level decision-making[3]; (2) **High survivability design**, such as hypersonic platforms (SR-72) breaking through traditional air defense systems[12]; (3) **Integrated offense and defense**, such as Raytheon’s "Coyote" anti-swarm system realizing "swarm-against-swarm" operations[14]. Urban combat has become a new focus: the OFFSET program has verified swarm collaborative tactics in building-obscured environments[9], yet in-depth adaptation between swarm intelligence and complex battlefield environments still needs to be achieved[15].

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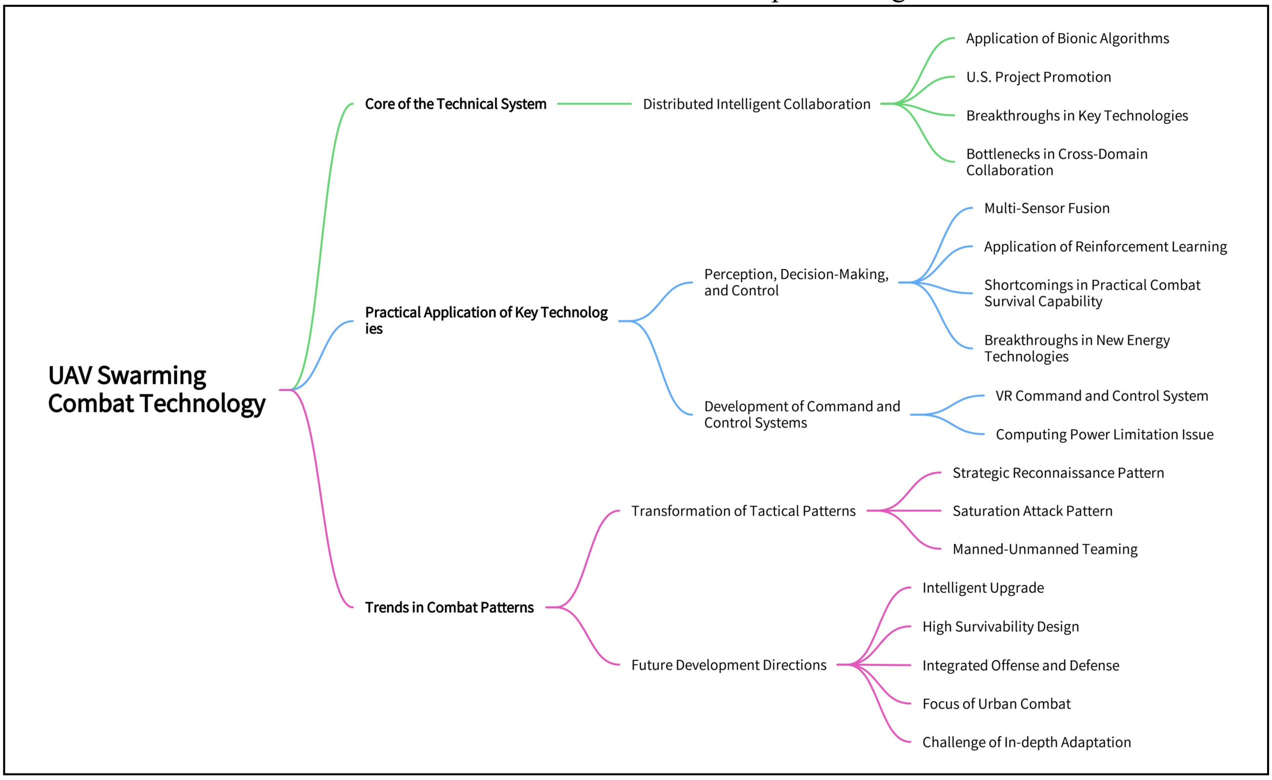

Figure. 1 Knowledge Graph of UAV Swarm Combat Technical System in Military UAV Tactics Research (1993-2025)

3.2 Research Hotspots: Analysis of the Three-Dimensional Structure

3.2.1 Co-Occurrence Network: Analysis of Core Nodes and Connections

As a core indicator for measuring the hub role of keywords, centrality can effectively reveal the core topics and key directions of a research field. It is generally believed that in a network with 100–500 nodes, keywords with a centrality of ≥0.1 are key nodes[16]. Table 2 compiles keyword centrality based on the military UAV tactics keyword co-occurrence network map.

Table 2. Keyword Centrality(C) in Military UAV Tactics Research (1993-2025)

<table>
<tr><th>No.</th><th>C</th><th>F</th><th>year</th><th>Keyword</th><th>Centrality Std. Dev.</th><th>Dispersion Degree</th><th>Frequency Std. Dev.</th><th>Dispersion Degree</th></tr>
<tr><td>1</td><td>1.0</td><td>112</td><td>2004</td><td>UAV</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>0.13</td><td>24</td><td>2017</td><td>Artificial Intelligence</td><td rowspan="10">0.0382</td><td rowspan="10">52.94%</td><td rowspan="10">11.1555</td><td rowspan="10">88.07%</td></tr>
<tr><td>3</td><td>0.09</td><td>26</td><td>2009</td><td>Operational Application</td></tr>
<tr><td>4</td><td>0.08</td><td>24</td><td>2010</td><td>Cooperative Combat</td></tr>
<tr><td>5</td><td>0.06</td><td>9</td><td>2010</td><td>Combat Application</td></tr>
<tr><td>6</td><td>0.06</td><td>7</td><td>2006</td><td>Intelligentization</td></tr>
<tr><td>7</td><td>0.05</td><td>5</td><td>2008</td><td>Multi-UAV</td></tr>
<tr><td>8</td><td>0.05</td><td>3</td><td>2003</td><td>Data Fusion</td></tr>
<tr><td>9</td><td>0.05</td><td>2</td><td>2016</td><td>Unmannedization</td></tr>
<tr><td>10</td><td>0.04</td><td>8</td><td>2008</td><td>Key Technologies</td></tr>
<tr><td>11</td><td>0.04</td><td>6</td><td>2022</td><td>Russia-Ukraine Conflict</td></tr>
</table>

(Note: Analyzed by CiteSpace 6.4.R1; "UAV" excluded from standard deviation calculation; "Operational Application" and "Combat Application" merged.)

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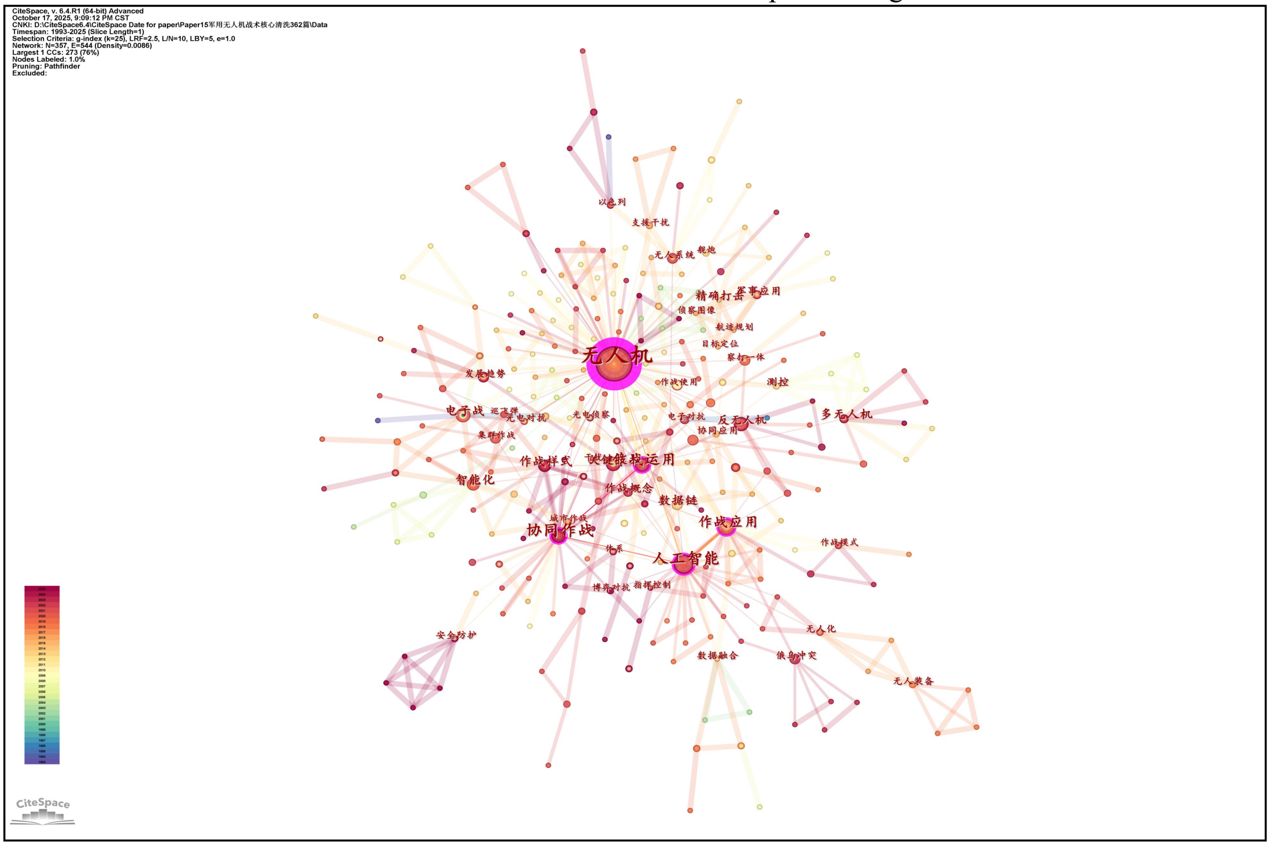

Figure. 2 Keyword Co-Occurrence Network Map of Military UAV Tactics Research (1993-2025)

From the perspective of centrality, "UAV" (centrality 1.0, frequency 112) is the absolute core, connecting technology, tactics, and confrontation. "Operational Application/Combat Application" (0.09+0.06) and "Artificial Intelligence" (0.13) follow, with the former transforming technology to tactical effectiveness and the latter linking intelligent research cores.

From the perspective of network connections, The research shows a "core-sub-core-periphery" modular structure: (1)**Core layer**: "UAV-Technology-Tactics" triangle network (high-density connections form "technology supports tactics, tactics drive technology" closed loop); (2)**Sub-core layer**: "Confrontation-Cooperation" two-way network (offensive-defensive connections, systematic linkage); (3)**Periphery layer**: Scenario-based nodes (Russia-Ukraine Conflict, urban combat) with low density, providing practical verification. Excluding "UAV", other key nodes have low centrality standard deviation and high frequency dispersion, indicating scattered core topics.

Combined with node connotations, the network reveals research leap from "technical tool" to "systematic combat capability": **technical layer** upgrades from "data link" to "artificial intelligence"; **tactical layer** expands from "precision strike" to "swarm combat"; **confrontation layer** evolves from "security protection" to "game confrontation"; force positioning jumps from "auxiliary equipment" to "new-type combat force".

3.2.2 Clustering Characteristics: Cluster Structure and Research Orientation

Figure 3 shows the keyword clustering map of military UAV tactics research. Clustering validity indicators: Q=0.722>0.3 (significant structure); S=0.9472>0.7 (high reliability). Table 3 presents core clusters and research orientations.

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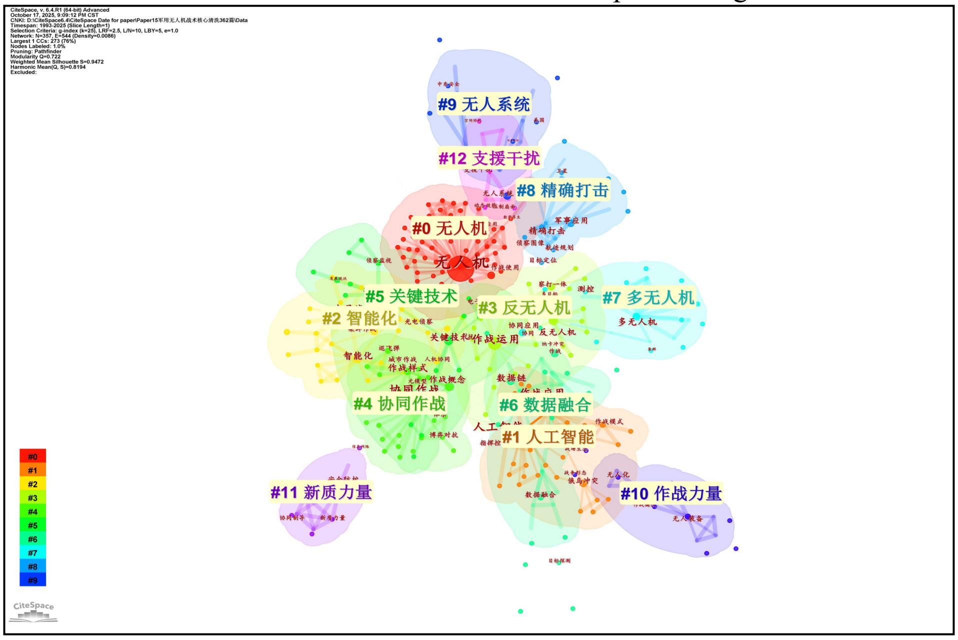

Figure. 3 Keyword Clustering Map of Military UAV Tactics Research (1993-2025)

Table 3. Keyword Clustering and Research Orientation in Military UAV Tactics Research (1993—2025)

Cluster No.	Cluster Name	Research Orientation
#0	UAV	Field "anchor" , covering basic tactical applications such as "operational use", "reconnaissance and surveillance", and "trajectory planning".
#1	Artificial Intelligence	Focuses on "command and control", "data fusion", and "unmannedization", empowering UAV tactical decision-making and intelligence processing.
#2	Intelligentiza-tion	Connects "electro-optical reconnaissance", "urban combat", and "human-machine collaboration", exploring tactical scenario expansion .
#3	Anti-UAV	Centers on "collaborative application", "electronic countermeasures", and "combat", studying UAV threats and "offense-defense" system.
#4	Cooperative Combat	Involves "combat concepts", "cooperative guidance", and "game confrontation", focusing on multi-UAV and manned-unmanned cooperative logic.
#5	Key Technologies	Covers "operational application", "data link", and "mission planning", serving as the technical cornerstone for the implementation of UAV tactics. For example, data links ensure multi-node information interaction, and mission planning optimizes combat effectiveness.
#6	Data Fusion	Links "artificial intelligence", "combat mode", and "target detection", enhancing battlefield situational awareness via multi-source intelligence fusion.
#7	Multi-UAV	Focuses on "measurement and control", "reconnaissance-strike integration", and "multi-UAV collaboration", researching tactical coordination, task allocation, and long-range measurement and control technologies for UAV swarms.
#8	Precision Strike	Centers on "military application", "reconnaissance images", and "target positioning", exploring "reconnaissance-strike" closed loop precision tactics.
#9	Unmanned System	Expands to "air-space collaboration" and "system integration", studying the all-domain unmanned combat systems (UAVs, satellites, and manned equipment).
#10	Combat Force	Connects "unmanned equipment" and "new-type combat capability", focusing on UAVs new-type combat force formation, application, and capability generation.
#11	New-Type Combat Force	Reflects the innovation of UAVs on traditional combat forces, studying their new-type combat capability in "cooperative guidance" and "cross-domain combat".
#12	Support Jamming	Centers on "electronic jamming" and "support and guarantee", exploring the tactical value of UAVs in electronic warfare and battlefield support.

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3.2.3 Three-Dimensional Structure: Technology – Tactics – Confrontation Collaboration

Based on co-occurrence network and clustering analysis, research hotspots form a "Technology-Tactics-Confrontation" three-dimensional structure: (1)**Technology Dimension**: "Artificial intelligence" (drives intelligent upgrading) and "data link" (ensures multi-domain data interaction) are dual engines for tactical innovation. (2)**Tactics Dimension**: "Cooperative combat", "precision strike", "combat patterns" evolve from single-equipment reconnaissance-strike to multi-UAV swarm systematic combat. (3)**Confrontation Dimension**: "Anti-UAV", "electronic warfare", "Russia-Ukraine Conflict" drive tactics toward "intelligent penetration and asymmetric confrontation", with practical cases verifying innovation.

With "UAV" as the core hub, the three dimensions interconnect: technological breakthroughs support tactical innovation, tactical demands drive technology development, and confrontation/practical combat iterates both, forming a "Technology-Tactics-Confrontation" closed-loop driven hotspot pattern.

3.3 Evolutionary Path: Logical Context and Cutting-Edge Exploration

3.3.1 Phased Evolution Logic: Basic Exploration → Systematic Development → Capability Leap

Integrating time into keyword analysis, the "Keyword Core Clustering Evolution Map" (Figure 4) divides 1993-2025 hotspots into three phases:

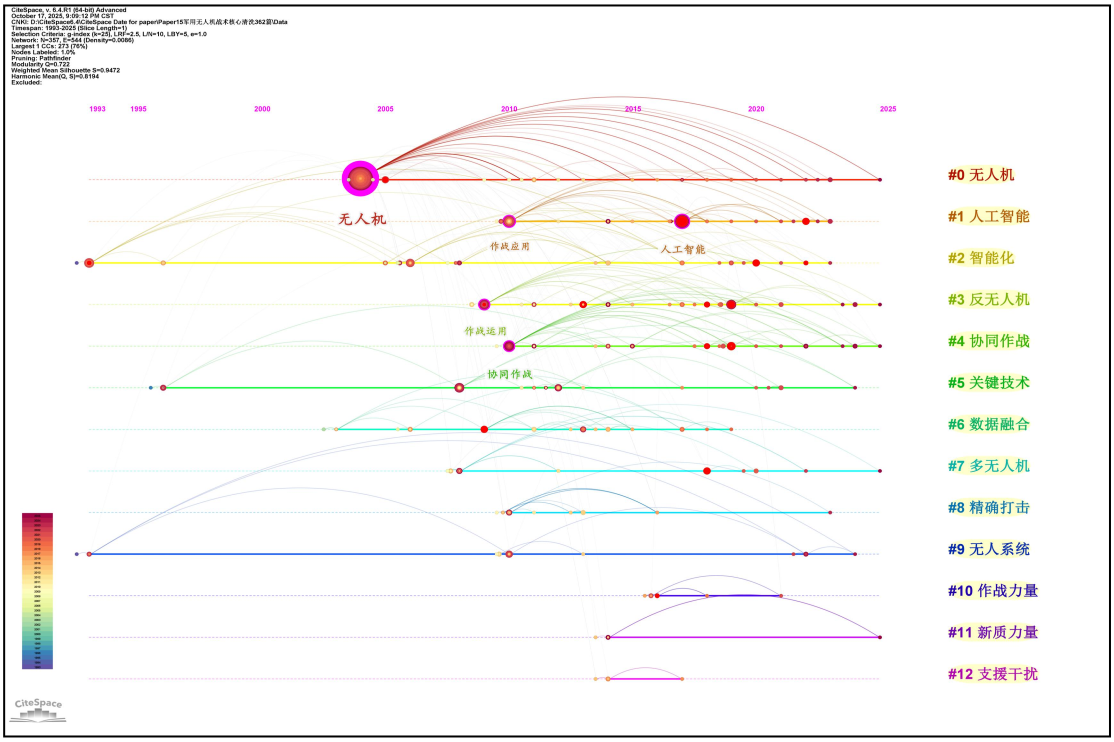

Figure. 4 Core Clustering Evolution Map of Keywords in Military UAV Tactics Research (1993-2025)

(1) **Basic Exploration Phase (1993–2009)**: This phase focused on "whether to have UAVs", core clusters: #0 UAV, #8 Precision Strike, #9 Unmanned System. Research centers on UAV conceptualization to practical application, prioritizing technical feasibility and precision strike function, laying "existence-level" foundation.

(2) **Systematic Development Phase (2010–2017)**: This phase focused on "system capability", core clusters: #1 Artificial Intelligence, #3 Anti-UAV, #4 Cooperative Combat. Research shifts from single-UAV to "systematization-intelligentization"; artificial intelligence/data fusion breaks single-UAV bottlenecks; anti-UAV cluster promotes "offensive-defensive confrontation" thinking.

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(3) **Capability Leap Phase (2018–2025)**: This phase focused on "qualitative change", core clusters: #10 Combat Force, #11 New-Type Combat Force, #12 Support Jamming. Research elevates from "technology-tactics application" to "warfare form impact"; UAVs transform from "auxiliary equipment" to "core variable" for combat system reconstruction, realizing "tactical single-point breakthrough to full-domain system reshaping".

The evolutionary logic follows the sequence of "technology-driven → tactical iteration → system reconstruction" logic, reflecting a three-stage leap from single-point application to system empowerment..

3.3.2 Cutting-Edge Topics: Technology Empowerment, Tactical Form, and Confrontation in Practical Combat

Setting λ=0.4, the "Keyword Burst Map" (Figure 5) reveals cutting-edge topics. Combined with burst intensity and time, three categories emerge:

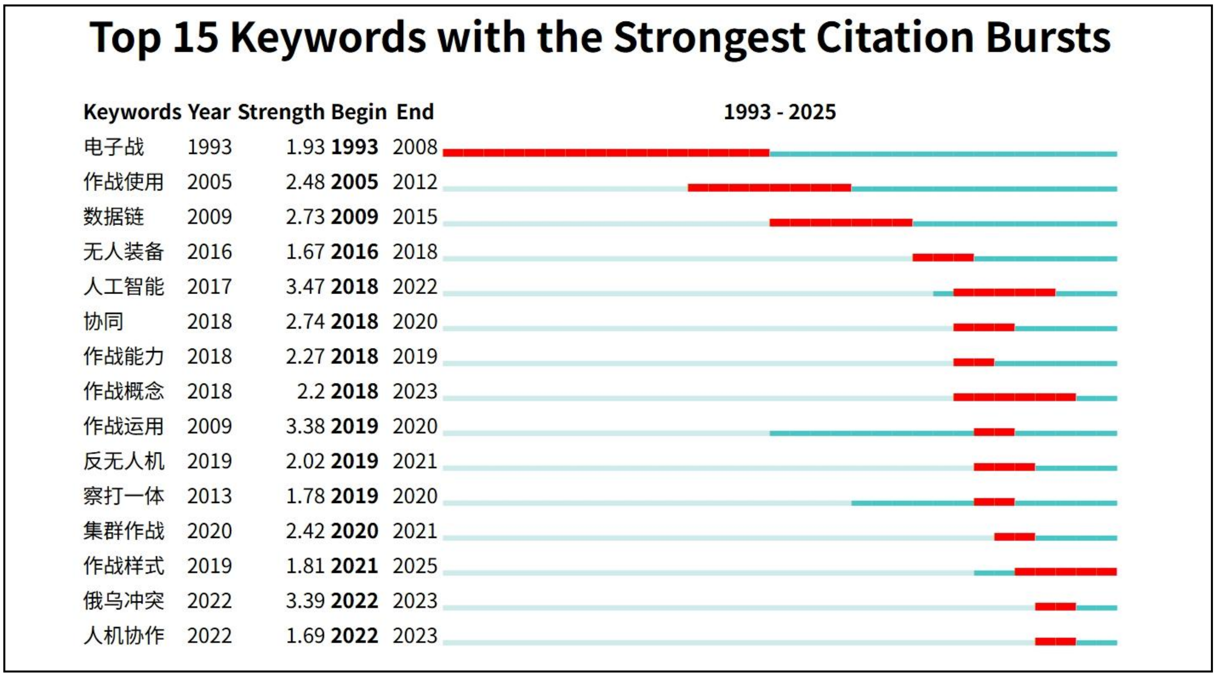

Figure. 5 Keyword Burst Map of Military UAV Tactics Research (1993-2025)

(1) **Technology Empowerment Category**: "Artificial Intelligence" (2018-2022, intensity 3.47) drives "intelligent decision-making-autonomous combat"; "Data Link" (2009-2015, intensity 2.73) provides multi-UAV collaboration support.

(2) **Tactical Form Category**:"Collaboration" (2018-2020, intensity 2.74) and "Swarm Combat" (2020-2021, intensity 2.42) realize "single-UAV to multi-UAV swarm" leap; "Combat Concept" (2018-2023, intensity 2.2) and "Combat Pattern" (2021-2025, intensity 1.81) promote "technology application to combat theory innovation".

(3) **Confrontation in Practical Combat Category**: "Anti-UAV" (2019-2021, intensity 2.02) shifts to "offensive-defensive confrontation"; "Russia-Ukraine Conflict" (2022-2023, intensity 3.39) drives tactical practical verification.

Cutting-edge topics form a "technology-tactics-practical combat" closed loop: technology empowerment continues "technology-driven" logic, tactical form upgrades "tactical iteration" logic, and confrontation/practical combat verifies "system reconstruction" logic.

3.3.3 Future Path: Intelligentization, Systematization, and Practical Combat Orientation

Based on cutting-edge continuity and evolutionary logic, the future development of military UAV tactics will follow the following paths: **First, in-depth penetration of intelligentization**. Leap from "AI-assisted decision-making" to "autonomous combat", combining "human-machine

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collaboration" for "manned-unmanned hybrid formation" adaptive tactics in complex scenarios. **Second, upgrading of systematic collaboration**. Expand "cross-domain multi-domain collaboration", integrate "data link iteration" to build "air-space-cyber-electronic" integrated UAV combat system. **Third, innovation driven by practical combat.** Use Russia-Ukraine Conflict as samples, establish "tactical application-practical feedback-technical optimization" iteration mechanism to solve anti-UAV and electronic warfare pain points. At the same time, it will spur theoretical and practical innovations in "new-type combat forces".

4. Discussion and Outlook

4.1 Research Conclusions and Theoretical Contributions

First, at the knowledge focus level, Highly cited literatures center on "UAV swarm combat technical system construction" and "practical combat pattern innovation", forming a "technological breakthrough-tactical verification-actual combat testing" paradigm with US projects and Russia-Ukraine Conflict cases.

Second, research hotspots present a three-dimensional focus pattern of "Technology – Tactics – Confrontation". "artificial intelligence-data link" are dual technology engines; "cooperative combat-swarm combat" are tactical cores; "anti-UAV-Russia-Ukraine Conflict" drive confrontation innovation.

Third, the evolutionary path follows the logical context of "technology-driven → tactical iteration → system reconstruction" logic, experiencing three phases from "existence solution" to "qualitative change", completing "single equipment to systematic new-type combat force" leap.

Fourth, cutting-edge topics are highly consistent with the evolutionary logic. technology empowerment, tactical form, and confrontation/practical combat categories jointly form core development directions .

4.2 Future Outlook and Practical Recommendations

Based on the research conclusions and the continuity of cutting-edge topics, the research and practice of military UAV tactics can be deepened in the following four aspects:

Promote in-depth intelligent empowerment: Break through the limitations of "AI-assisted decision-making", explore "autonomous combat closed-loop" technology, and combine the innovation of "human-machine collaboration" models to realize adaptive tactical adjustments of "manned-unmanned hybrid formations" in scenarios such as complex electromagnetic environments and urban street battles.

Strengthen systematic cross-domain collaboration: Take "data link iteration" and "heterogeneous platform integration" as breakthroughs, expand the "air-space-cyber-electronic" multi-domain UAV cooperative combat system, and solve technical bottlenecks such as cross-domain communication delay and multi-platform task allocation.

Build practical combat closed-loop iteration mechanism: Use practical combat cases such as the Russia-Ukraine Conflict and regional security conflicts as samples to establish an iterative mechanism of "tactical application – practical combat feedback – technical optimization", focusing on solving practical pain points such as "anti-UAV interception" and "response to electronic warfare jamming".

Accelerate the theoretical construction of new-type combat capabilities: Focus on topics such as "formation of UAV new-type combat forces", "full-domain combat effectiveness evaluation", and "cross-service tactical collaboration standards" to improve the theoretical system, and provide systematic theoretical support for national defense strategic decision-making, equipment research and development, and tactical training.

Ultimately, this promotes military UAV tactics transformation from "laboratory theory" to "battlefield capability", reshaping modern warfare tactical forms.

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