Research on development status and technology trend of intelligent autonomous ammunition

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Abstract. Research on the new tasks and capabilities are required for ammunition in the future intelligent air combat, the concept of smart munitions is put forward, and the intelligent development approaches of single equipment intelligence, system intelligence, swarm intelligence and system of system intelligence are put forward. This paper classifies and analyzes the relevant projects currently carried out by the US military, and on this basis summarizes the development trend of airborne smart munitions. Finally, some suggestions for the development of airborne smart munitions in China are given. The above research results will provide reference for the construction of intelligent equipment system of airborne intelligent ammunition and the direction of technology research.

1. Introduction

With the acceleration of the pace of military intelligence, especially the equipment-based application of artificial intelligence technology, the future air-space battlefield will be an intelligent and winning game confrontation situation under the condition of systematic confrontation. Intelligent air combat will make full use of artificial intelligence technology to replace people to implement autonomous aerial battlefield situation judgment, and then autonomous decision-making and weapon control and execution. In 2016, the "Alpha" intelligent software developed by the University of Cincinnati controlled the F-15 fighter aircraft to defeat the human-driven F-22 fighter aircraft, which opened the curtain of intelligent air combat, and also proposed the development of airborne ammunition for intelligent air combat New tasks and capacity requirements. How to adapt to the new game rules and winning mechanism of "winning experience with data, winning brainpower with computing power, and winning rules with learning" in the era of intelligent air combat is a major subject for urgent research on airborne ammunition.

The use of artificial intelligence technology in traditional precision-guided weapons can enhance combat effectiveness and expand equipment functions [1]. Applying artificial intelligence technology, especially machine learning technology to weapons and equipment, can not only achieve efficient information collection and processing, but also provide auxiliary decision-making. The main features of intelligent equipment are equipment autonomy, resource layer cloudization, integrated situation, intelligent decision-making, precise action, human-machine integration, ability systemization, and power integration [2].
As the most active field of artificial intelligence applications, airborne precision-guided weapons are highly valued and developed rapidly by major military powers, which are mainly reflected in the high integration of intelligent technology and combat systems, combat styles, weapons, equipment and algorithms to form intelligent perception and intelligent decision-making. Intelligent strike, intelligent defense, and other multi-element, cross-domain, and comprehensive application of the entire process [3].

2. Overview
Airborne intelligent air ammunition is based on the future intelligent air combat as the mission scenario. Based on the existing airborne guided missile equipment system and technical system support, it makes full use of intelligent technologies such as artificial intelligence, big data, and network information. Research and other diversified research and development models, to enhance or achieve airborne ammunition in the key links of O (Observe), O (Orient), D (Decide) and A (Action), single installation, system, cluster and The system has new levels of autonomous or cooperative capabilities, including new types of airborne intelligent weapons with capabilities such as reconnaissance, target recognition, mission decision-making, coordinated attack (including interference, deception, strike, etc.) and online assessment.

3. Classification
According to the different application levels of intelligent technology in the airborne ammunition equipment system, referring to the basis of the autonomous control level division of the UAV [4], it can be divided into four types: intelligent single equipment, intelligent system, intelligent cluster, and intelligent system.

Figure 1. Intelligent classification of ammunition.

Figure 1 Intelligent level division of airborne ammunition Single-package intelligence refers to the application of technologies such as intelligent navigation, intelligent perception and intelligent recognition to airborne weapons such as missiles, missiles and missiles. The focus is on the relationship between weapons and targets, tapping the potential of guided weapons, and further deepening single-package guidance. It is the US LRASM long-range anti-ship missile and a three-mode compound small-diameter bomb SDB-II.

System intelligence refers to the application of technologies such as situational awareness, threat avoidance, and online planning to multiple airborne weapons. The focus is on the relationship between weapon systems and situational confrontation, and research on the capability of cooperative autonomous operations. Weapon CODE and Joint Air Defense Destruction System (MALD-JSOW-HARM Anti-Advanced SAM Missile Combo).

Swarm intelligence refers to the application of technologies such as centerless networking, cluster awareness, and cooperative formation to a single-function, low-cost airborne weapon cluster, and to study the relationship between the weapon group and the task. Typical representatives are American clusters, wingman, and coyote system.
System of system intelligence refers to the application of technologies such as intelligent navigation communication, reconnaissance, and cooperative decision-making to the OODA ring of an intelligent airborne weapon system. Researching intelligent airborne weapon equipment systems around the system's adversarial relationship, typically represented by the United States' distributed coordination Combat system.

4. Status of development

The United States has adopted artificial intelligence technology as the key to the intelligentization of weapons and equipment, and systematically promoted the development of related technologies at the national level. It has successively released "Preparing for the Future of Artificial Intelligence", "National Artificial Intelligence Research and Development Strategic Planning", "Intelligence, Automation, and Economy" white paper details the development status, planning, impact and specific measures of artificial intelligence, and clarifies the government's responsibilities for artificial intelligence technology. The U.S. Department of Defense has supported autonomous "deep learning" machines and systems, human-robot collaboration, human combat operations assistance systems, advanced manned / unmanned combat formations, and cyber-enhanced network-enhanced autonomous weapons for the third time. The key technology of the "offset strategy" was invested 2 to 3 billion US dollars for this in 2017. Trump plans to increase investment in the development and application of artificial intelligence-related emerging technologies in the defense budget in 2018, and further promote the development of artificial intelligence technologies that are closely related to military defense. The US Office of Strategic Competence is committed to short-term operational concept innovation and system integration, focusing on advancing the application development of unmanned clusters and intelligent systems. The United States Defense Advanced Research Projects Agency pays attention to medium and long-term disruptive technology research, and has listed artificial intelligence technology as the focus of research in the next 30 years [5].

From the development of numerous artificial intelligence-related projects by the US Department of Defense and the United States Defense Advanced Research Projects Agency (DARPA), we can sort out the typical representatives and development ideas in the following four aspects, that is, using long-range air-surface missiles as the breakthrough point to lead the smart order The equipment is equipped with combat power, the core technology of intelligent system is focused on patrol ammunition, the cluster drone is used as a breakthrough point to test and verify the intelligent cluster combat style, and the distributed cooperative combat is used as the traction to build a test intelligent airborne weapon system architecture.

4.1. Taking long-range air-to-surface missiles as a breakthrough point to lead intelligent single equipment to form combat effectiveness

The US LRASM long-range anti-ship missile is the most representative representative of airborne intelligent single equipment. LRASM is regarded by the US military as an "artificial intelligence" missile with a range of 600 ~ 1000 kilometers, equipped with an infrared / radar composite guidance head, an anti-jamming global positioning system terminal developed by British Aerospace, and a high-performance two-way based on data link CEC technology The data link communication system can relay missile guidance from different platforms, with a built-in processing system capable of coping with the more varied naval environment, and other specifications maintain the level of JASSM-ER. At present, LRASM has successfully carried out multiple air-launch and ship-launch tests. The air-launched version of the LRASM has first listed the 28th US Air Force Bomber Wing in 2018. It is planned to enter the US Navy (first F / A-18E) in 2019. / F) into service [6].

The LRASM missile can perform different strike missions and represents the direction of the United States' next-generation anti-ship missile. It is an intelligent missile. It has a high level of intelligence in terms of autonomous perception of threats, autonomous online trajectory planning, multi-bomb collaboration, target value classification, and target recognition. The LRASM missile can rely on advanced missile-borne sensor technology and data processing capabilities for target detection
and identification. It can perform fully autonomous navigation and terminal guidance without any support of relay guidance information, and intelligently complete strike tasks. Its intelligence is mainly reflected in reducing the reliance on relay guidance, and has the ability of intelligent target recognition. The core technology of the LRASM missile is to sense the electromagnetic signals of the enemy air police radar when it is turned on through equipment similar to passive radio frequency devices, and use the target recognition algorithm to classify the detected signals, so as to determine the threat location and coverage in a timely manner under the background of the island and shore Area, avoiding the influence of the island shore, maneuvering to the enemy target. At the same time, it can rely on advanced inertial navigation devices, missile sensors, radar altimeters and data processing technologies to realize autonomous navigation guidance in the case ofensor and information network interruptions, reducing dependence on intelligence, reconnaissance systems, and GPS and ISR information sources.

![Images of drones and maps]

**Figure 2.** Combat operation of LRASM.

4.2. **Focusing on the core technology of intelligent systems with cruise ammunition as the starting point**

The US Defense Advanced Research Projects Agency (DARPA) has developed "Collaborative Operations in the Denial of Environment" to enhance the capabilities of existing unmanned systems (unmanned aerial vehicles, missiles, etc.) and make them better suited to denial of environmental operations in Denied Environments (CODE) project. The rejection of environmental cooperative operations is both a new concept and a new technology proposed by the US military. DARPA gradually advances the concept by first mentioning the concept, and then conducting virtual experiments, technology verification, and installation demonstrations. The key technologies involved in the CODE project include single-vehicle autonomy, coordinated autonomy of weapon formations, monitoring interfaces, open architecture, technologies for verifying full mission capabilities, and technologies used in transitioning to military aircraft. Key technology developments focus on sensing, strike, communication and navigation. And other aspects of autonomous collaborative operations to reduce the required communication bandwidth and artificial system interfaces.

![Images of maps and diagrams]

**Figure 3.** Collaborative navigation, communication and control of CODE.

In a series of tests conducted by DARPA at the Yuma Proving Grounds in Arizona in November 2018, the CODE project demonstrated the adaptation and response of CODE-equipped unmanned aerial systems (UAS) in an "anti-access area rejection" (A2AD) environment. Unexpected threat capability. While the drone system minimizes communication traffic, it efficiently shares information, collaborates in planning and assigning mission objectives, formulates coordinated tactical decisions, and collaborates to cope with high-threat dynamic environments [7].

In February 2019, six RQ-23 Tiger Sharks with sensor arrays took off in sequence. Inside a small combat center next to the runway at the U.S. Army Yuma Proving Ground, the task force tracked the drones and up to 14 virtual aircraft on an aerial map. The apex demonstration pairing project executives-Raytheon's software and autonomous algorithm team and the Johns Hopkins University...
Applied Physics Lab's "White Army Network" team, created a constructive testing environment for realistic virtual reality. During the four demonstration runs, the team activated various virtual targets, threats, and countermeasures to understand how the Tiger Shark drone accomplishes its goals under suboptimal conditions.

Figure 4. Multi-aircraft cooperative formation of CODE.

4.3. Verifying the intelligent cluster operational model with the cluster uav as a breakthrough test

The U.S. Air Force is also developing micro drone swarm technology based on the bee colony biological concept. It has developed algorithms that allow small unmanned air fleets to fly without collisions. The drone has carried out more than 500 tests and accumulated more than 670 test flights. This type of drone fleet will be designed to resist and interfere with enemy radar systems, or to cover multiple areas with multiple sensors at the same time. Even if one or several drones are lost, the technology will not have a significant impact. This technology can be used for Achieve strategic margins in high-threat areas.

In a test conducted by the U.S. Air Force in June 2015, an F-16 fighter jet flew at a speed of 690 km/h. During the flight, a large number of "Perdix" small unmanned were thrown through the tracer launcher machine. The "quail" UAV is about 16.5 cm long, 30 cm wingspan, weighs about 0.3 kg, cruise time is about 20 minutes, and the flight speed is about 75 km/h to 110 km/h. The drone was launched in a small metal container with a parachute. A few seconds after the launch, the parachute was separated from the drone, and the propeller began to work, propelling the drone to fly. Prior to throwing, the drone was wrapped in a protective cover and placed inside the aircraft's bait launcher. The protective cover helps the drone withstand the thrust of a throw. A drag-reducing streamer or parachute is installed on the rear side of the protective cover, which can reduce the resistance when the drone descends, and ensure that the nose of the drone is downward when the drone descends. After descending to a certain height, the protective cover is opened, the drone is released, the fuselage is stabilized by the passive stabilization system, and then the drone autonomously controls the flight control system. When the battery power is low, the drone will enter taxi mode and can collect data during taxiing. The drone is equipped with a short-range communication system that can transmit data to fighters, other drones, and the ground. The "quail" unmanned aerial vehicle has an endurance of 45 minutes and a gliding endurance from 9,000 meters above sea level is also 45 minutes.

After the first launch test in Alaska, during the "Northern Blade" military exercise in June, the fighter jets launched a total of 72 UAVs of this type. On October 25, 2016, three F / A-18F aircraft were used to launch 103 "quail" unmanned aerial vehicles. Under the control of the ground command station, through the inter-machine communication and coordination, 4 orders were completed in different formations task [8].

The demonstration of this project provided hundreds of unmanned bee swarm systems to replace the more expensive miniature air-launched decoys, become low-cost, more efficient air defense system decoys, or use their own loads to perform intelligence, surveillance and reconnaissance tasks One possibility.
4.4. Building a test intelligent airborne weapon system architecture with distributed cooperative operations as the traction

The US Defense Advanced Research Projects Agency (DARPA) proposed a System Integration Technology and Test (SoSITE) project in 2015. The purpose is to get out of the stealth fighter, command the "mission truck" (large transport aircraft / bomber) to launch multiple drones / cruise missiles for detection and target identification at the forefront, and command the "mission truck" based on the target information returned from the front. Launch a large number of cruise missiles and launch a "bee colony" attack on the target. This capability will increase the complexity of the main opponent's precise strike weapon planning, forcing it to spend a lot of time and ISR resources to find and combat the goal of distributed deployment of the US military one by one, in order to improve its own survival and combat capabilities and consume opponents' combat resources [9].

The research on the SoSITE project carried out by the U.S. military on the top-level architecture aims to explore the concept of distributed operations and system architecture. At the same time, it focuses on the three basic elements of "command control / management", "weapon platform" and "communication network" that constitute the combat system. The United States DARPA, Air Force and Navy also supported related research projects [10].

In terms of "command control / management", the US military studies distributed warfare planning through the "DBM" project, and through the "OFFSET", "CODE", and "ALIAS" projects from three levels of group autonomy, human-machine collaboration, and weapon autonomy Research on distributed operational coordination; in terms of weapon platforms, research on high-speed aircraft, small aircraft, and micro-aircraft platforms were carried out with the support of items such as "elves", "wingman" and "pigeon", forming complementary functions and adaptations Distributed combat weapon pedigrees of different combat styles, synchronized with the "LOCUST" and other projects to complete the rapid launch demonstration of the weapon, and gradually explored the research of aerial recovery technology; in the "communication network", in the "TTNT" weapon collaborative data link In terms of application results, in order to meet the requirements of different platforms for reliable communication in an adversarial environment, the US military successively carried out research on "C2E" and "DyNAMO" projects.
Figure 7. Distributed operation of Airborne Intelligent Ammunition.

5. Development trend analysis

5.1. The level of individual intelligence continues to improve
With the development of electronic information technology, high-precision autonomous navigation and advanced seeker technology have been further developed, and a data link has been introduced to connect with the C4ISR system to obtain target change information and battlefield environment information. At the same time, new technologies such as battlefield situational awareness, mission planning, coordinated operations, damage assessment, and intelligent target strikes have gradually developed and started to be applied to missile models, improving the intelligence of ammunition from all aspects. In order to further enhance the penetration and strike capabilities of precision guided missiles in complex battlefield environments, the US military has continuously increased the intelligent research and development of new guided missiles [11]. The first is to enhance self-recognition capabilities. The intelligent missile under study in the United States uses "image understanding" artificial intelligence technology, which can distinguish targets and fake targets such as enemy and friendly military trucks, surface-to-air and surface-to-surface missiles with the same shape and size. In addition, autonomous navigation is improved. Using chip-level high-precision inertial navigation technology and other multi-mode composite guidance technology, to achieve autonomous navigation that does not rely on GPS and remote long-range networks, can sense opponents' electronic countermeasures against interference, independently plan paths, change ballistic flight trajectories, and achieve ballistic maneuver at the end of the missile Autonomous search and autonomous attack.

5.2. The platform's autonomy is continuously strengthened
The Integrated Roadmap for Unmanned Systems (2017-2042) issued by the U.S. Department of Defense is the 8th version of the UAV / Unmanned System Integrated Roadmap released by the United States since 2001. Further enhance the military capability of the U.S. military to use unmanned systems [12]. "Integrated Roadmap for Unmanned Systems (2017-2042)" states that in the future, unmanned systems should focus on all combat domains and meet joint operational needs. Related technologies should support cross-domain command and control, cross-domain communications, and integration with joint forces. The roadmap also identified four key technical themes and driving forces for the future development of unmanned systems, namely interoperability, autonomy, network security, and human-machine collaboration. The U.S. military unmanned platform autonomy has a core role in building a global surveillance and strike network.

5.3. Networked Cooperative Operations Achieved
In order to use battlefield information more effectively, intelligent ammunition will have the ability to autonomously detect, track, identify, and confirm targets, the ability to transmit real-time information, and the ability to coordinate operations, as well as the ability to selectively and accurately attack highly mobile targets. It gives intelligent munitions an irreplaceable role and status in the future information battlefield. Networked collaborative operations, regional collaborative containment and control: Multiple cruise missiles form a combat network, and information is exchanged between the missiles and the bombs to reasonably assign combat missions to avoid multiple bombs attacking the
same target. This is an important use of the cruise missile battlefield Development direction [9]. The way to achieve the networked cooperative combat capability of intelligent ammunition: install data links to improve real-time and flexible strike capabilities; strengthen network technology research and improve the interoperability between ammunition and ammunition and between ammunition and the battlefield. Two-way data link technology, animal behavior and robotics technology, ad hoc network fuze technology, fast information processing technology, etc. have become the focus of the future development of intelligent ammunition network technology.

5.4. Artificial intelligence will be integrated into the entire battle
Captain Michael Burns of the United States Air Force wrote in "Air Force" describing: "Unmanned combat aircraft with tactical autonomy, using OODA ring, high maneuverability configuration and nanosecond-level ultra-fast computing capabilities and The ability to learn autonomously on mission experience will form an unparalleled lethality, which will have a disruptive effect on future air-to-air combat. "Among them, OODA refers to observation (observe) and judgment (orient) during the combat process of air combat weapon systems., Decide, Action and other key links. In the future air combat, intelligence will run through the whole process of air combat OODA [3].

6. Conclusion
The informatization development of airborne ammunition is continually incorporating intelligent elements, and the importance of intellectual power will also be highlighted in the future intelligent air combat. The military application of intelligent technology is also evolving from a tactical level to a strategic level, extending from weapons and equipment to combat methods, accelerating penetration and expansion. The world's military science and technology powers are all strategically deployed around military intelligence, strengthen military intelligence construction, develop artificial intelligence systems for various purposes, and strive to seize the initiative of future military competition strategies.

The development of China's airborne intelligent air surface ammunition should grasp this development trend, give full play to the military-civilian integration policy and technological advantages, and build an airborne intelligent air surface ammunition equipment system that matches the mission of our air force. From single-package intelligence, system intelligence, Starting from the four levels of cluster intelligence and system intelligence, the artificial intelligence technology group is integrated into the OODA link of the combat process to promote the transformation of artificial intelligence technology to the improvement of equipment capabilities.

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