Research on the Development and Application of Unmanned Aerial Vehicles

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Abstract. The new military revolution in the new era is spurring the development of combat means and combat forces to unmanned, intelligent, and clustered direction and gradually forming new methods of warfare and winning mechanisms. Unmanned combat platforms represented by unmanned aerial vehicle (UAV), unmanned combat vehicle, unmanned surface vessel, and unmanned underwater vehicle have gradually become new research areas in which various military powers are committing to. Among the various unmanned combat platforms, UAVs achieve the fastest development and have the most operational applications. This paper gives a brief overview of UAVs and their applications and focuses on the advantages and problems of UAV and UAV cluster.

Keywords: Unmanned combat · Unmanned aerial vehicle · UAV · Drone

1 Introduction

Unmanned aerial vehicle (UAV) is a non-manned aircraft operated by radio remote control equipment and self-contained program control devices or operated autonomously by the onboard computer completely or intermittently. In the Vietnam War of the 1960s, UAVs were first used in wars. The American "Fire Bee" unmanned aircraft carried out reconnaissance missions over Vietnam and obtained accounted for 80% of the total intelligence, which made people realize UAV's value. In 1991, during the Gulf War, more than 200 drones from the USA, Britain, France, Canada, and Israel all appeared on the battlefield, which provided an important basis for the multinational forces to control the battlefield situation in real time and evaluate the effects of air strikes. In 2003, the US military mobilized more than 10 kinds of drones to participate in the Iraqi battlefield. The Global Hawk carried out several combat missions over Baghdad and collected more than 3700 images [1].

With the rapid development of military revolution, unmanned combat platforms represented by drone, unmanned combat vehicle, unmanned surface vessel, and unmanned underwater vehicle have gradually emerged in military applications, emitting enormous development potential and broad application prospects. The main functions of unmanned equipment have evolved from past target drones, reconnaissance, etc., to the current functions of reconnaissance, surveillance, communication, and attack. With the development of artificial intelligence, network, coordination, and

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control technology, all kinds of unmanned cluster like "wolves", "fish groups", and "bee colonies" may appear in various combat spaces such as land, sea, air, and sky. The operational cluster implements a global unmanned cluster attack and defensive operation against the enemy. The National Science Council has predicted: "The core weapon of the twenty-first century is the unmanned combat system" [2].

Due to the diversity of drones, there are different classification methods for different considerations: According to the structure of flight platform, it can be divided into fixed-wing UAVs, rotary-wing UAVs, unmanned airships, wing drones, etc.; classified by purpose, it can be divided into military drones and civilian drones, of which military drones are divided into reconnaissance drones, electronic countermeasure drones, communication relay drones, unmanned fighters, target drones, etc., and civil drones are divided into inspection/monitoring drones, agricultural drones, meteorological drones, exploration drones, mapping drones, etc.; according to scale, it can be divided into micro drones, light drones, small drones, and large drones; classified by activity radius, it can be divided into super short-range drone, short-range drone, medium-range drone, and remote drones; according to mission height, it can be divided into super low-altitude drones, low-altitude drones, medium-altitude drones, high-altitude drones, and super high-altitude drones.

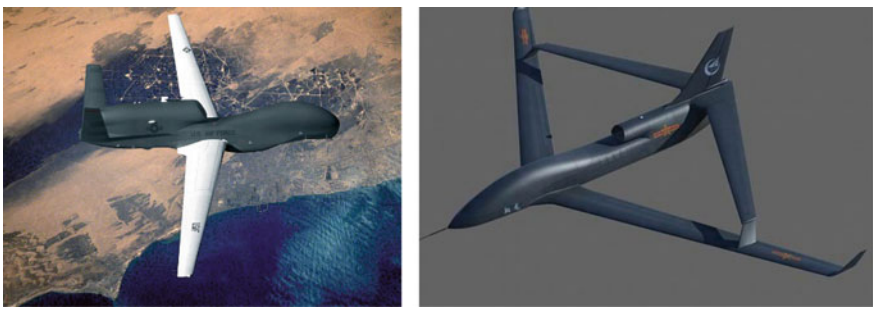
2 Development of UAVs

As early as the beginning of the twentieth century, the US military considered converting a manned aircraft into a specialized unmanned torpedo attack aircraft. During World War II, the US military envisioned converting the B-17 and B-29 bombers into unmanned bombers, but subject to the technical conditions at the time, both programs ended in failure. It was not until the 1950s that the US military successfully used the BQM-147 "Fire Bee" unmanned high-altitude reconnaissance aircraft in the Vietnam War. Afterward, many countries competed to follow suit and developed their own drones, whose functions were mainly based on reconnaissance and surveillance.

Since the beginning of the twenty-first century, the rapid development of electronic information technology has provided an opportunity for the breakthrough of many key technologies of drones. In addition to the traditional reconnaissance and surveillance functions, drones have added new features such as communication and navigation, electronic countermeasures, and firepower. These combat support functions enable military experts from all over the world to see the trend of drones transitioning from performing support tasks to direct participation in the war. According to its operational requirements and operational effectiveness assessment, the foreign military has made a number of UAV development plans that are suitable for different regions and deployment phases. The US military has an unmanned system integrated road map, Russia has formulated the "National Arms Plan 2018–2025", the British army has a development plan of "watchman" drone, and Europe has a development plan of "neuron" UAV. Among them, the USA has the most complete range of drones, the highest level of technology, the largest number of services, and the most experienced use [3, 4].

The development of US military drones is at the world's leading level. There are unmanned reconnaissance aircrafts at all levels of strategy, campaign, and tactics, as well as reconnaissance/attack UAVs and transport drones. At present, US military drones are deployed in large areas such as the air force, army aviation, and naval air force, including RQ-4 "Global Hawk", RQ-7 "Shadow", MQ-1B "Predator", MQ-9A "Reaper", and BQM-147 "Fire Bee" drones. From low altitude to high altitude, short range to long range, micro to heavy, the US military covers almost all types of military drones, even vertical takeoff drones and transport drones. Compared with foreign troops, the development of China's UAVs started relatively late. However, after entering the twenty-first century, explosive growth began, especially the successful development of "Wing Loong", "Soar Dragon", and "CH" series UAVs, marking that China's level of R&D and design of military drones has entered the international advanced level.

The RQ-4 "Global Hawk" is a high-altitude unmanned reconnaissance aircraft, shown in Fig. 1a. Its total length is 13.5 m, with the wingspan of 35.4 m and the height of 4.6 m. The maximum takeoff weight is 11,610 kg, and the ceiling is 20,000 m. Its maximum flight speed is 740 km/h, and the cruising time is 42 h. With a range of more than 26,000 km, it can fly from the United States to anywhere in the world. Equipped with high-resolution synthetic aperture radar and photoelectric/infrared modules, it can provide long-range and long-time dynamic monitoring. It can also perform espionage work on spectrum analysis, discovering crises, and conflicts around the world in advance and can also help guide the air force's missile bombing to reduce the number of missed attacks.



(a) RQ-4 "Global Hawk" **(b) Soar Dragon**

Fig. 1. Unmanned reconnaissance aircrafts

The "Soar Dragon" drone is also a high-altitude unmanned reconnaissance aircraft, shown in Fig. 1b. The total length is 14.3 m, the wingspan is 24.9 m, and the height is 5.4 m. Its maximum takeoff weight is 6800 kg, the mission load is 600 kg, and the ceiling is 20,000 m. The maximum flight speed is 700 km/h, the battery life is 10 h, and the combat radius is 2500 km. The UAV's electronic equipment is similar to the RQ-4 "Global Hawk," with high-definition digital cameras, digital TVs, and equipped with synthetic aperture radar, inverse synthetic aperture radar, and several parallel

communication systems. In addition, the digital communication relay task can be performed by replacing the modular head electronic task compartment, and it plays a very high signal-forwarding tower.

The MQ-9A "Reaper" UAV is a reconnaissance/attack drone developed on the basis of the MQ-1B "Predator", with the flight speed and the amount of bomb load greatly improved, shown in Fig. 2a. Its total length is 11 m, the wingspan is 20 m, and the height is 3.8 m. The maximum takeoff weight is 4760 kg, and the ceiling is 15,000 m. Its maximum flight speed is 460 km/h, and the combat radius is about 5900 km. It can fly continuously for more than 15 h under the status preparing for war. The main airborne weapons include two GBU-12 laser-guided bombs and four AGM-114 "Hellfire" air-to-ground missiles. They can also carry 227 kg of combined direct attack ammunition and 113.5 kg of small-diameter bombs, which can accurately hit the target in inclement weather.

(a) MQ-9A "Reaper" **(b) WingLoong-I**

Fig. 2. Reconnaissance/attack drones

The "Wing Loong-I" drone is a multi-purpose UAV with medium-altitude, long-range and long-haul, as well as full autonomous takeoff and landing and flight capabilities, shown in Fig. 2b. It looks like the MQ-9A "Reaper", and the size of the fuselage is similar to the MQ-1B "Predator". Its total length is 9 m, with the wingspan of 14 m and the height of 2.7 m. The maximum takeoff weight is 1200 kg, and the ceiling is 5300 m. Its maximum flight speed is 280 km/h, the battery life is 20 h, and the maximum range is 4000 km. The total payload capacity is 200 kg, and the front-view infrared sensor is about 100 kg. Therefore, each wing can also carry 50 kg of ammunition to accurately strike the ground targets.

Since 2001, the USA has released eight versions of the unmanned system integrated road map to assist decision makers in the Department of Defense to plan long-term strategies for research and development and procurement of drones and to guide the industry to carry out research work of drones. In 2009, the "United States Air Force Unmanned Aerial System Flight Plan 2009-2047" was released, which is an actionable plan characterized by Doctrine, Organization, Training, Materiel, Leadership and

Education, Personnel, Facilities, and Policy (DOTMLPF-P) recommendations. It consists of four ideas, five main steps, and several key objectives, whose vision is to harness increasingly automated, modular, globally connected, and sustainable multi-mission unmanned systems resulting in a leaner, more adaptable, and efficient air force.

3 The Advantages of UAVs

Due to its strong adaptability, maneuverability, and no risk of life, drones have received extensive attention in the civil and military fields. Especially in the military field, UAVs have great advantages in performing reconnaissance and surveillance, ground attack, communication relay, setting false targets, and electronic interference. As a substitute for humans to complete the "dull, boring, harsh, dangerous" missions, the military UAVs have strong adaptability, long battery life, and large load capacity, which can provide strong support for military operations. On the one hand, it can realize high-definition coverage reconnaissance and surveillance in the entire airspace for a long time. On the other hand, it can also perform non-lethal attacks or precise destruction on target objects according to operational intentions and provide reliable communication relay and delivery guarantee for combat command [5, 6].

- Low using cost

UAVs do not need to install airborne equipment for pilots such as the cockpit, life support systems, lifesaving systems, human–computer interaction systems, and so on. At the same time, since there is no need to carry pilots, drones do not have a limitation on the size of the body. Therefore, drones can do cheaper than man-machines to achieve the same performance indicators in theory. In addition, drone operators do not need to operate on the aircraft in the sky, because the training on the simulator is not much different from the actual training environment, which can save a lot of training costs.

- Good stealth performance

Currently, the radar scattering cross-sectional area on the side of manned stealth aircraft is usually not ideal. One of the largest short plates is the size limitation of the pilot cockpit, resulting in that the height of the fuselage cannot be lowered too low. However, UAVs are not bothered by this problem. They can be designed with a flatter body and a thinner wing as needed and can also form a wing-body fusion design that is more concealed, thereby greatly reducing the radar scattering cross-sectional area on the side of the fuselage and improving stealth performance.

- Less casualties

For a manned aircraft, its casualties mainly come from two aspects: the usual training accident caused by unskilled operation or aircraft failure and the casualties caused by the aircraft being hit by the enemy in wartime. However, for UAVs, whether in peacetime or in wartime, drone operators can operate the machine remotely from the ground control station, thus avoiding the military personnel directly in danger. There are no pilot casualties even if the plane is shot down. In addition, the long-haul

characteristics usually allow the drone to have sufficient time to accurately identify and lock targets in the theater, thereby reducing accidental injuries and collateral damage.

- Strong maneuverability

At present, for a fighter aircraft based on metal material structure, the turning overload that the body structure can withstand is usually within 15G. However, due to the physiological limitations of the pilot, the turning overload will generally not exceed 9G. For a drone, in theory, as long as the engine and maneuverability allow, the drone can make the most overloaded turning maneuver that the body can withstand. In the future, with the improvement of autonomy, drones can greatly shorten the OODA ring. As a result, the agility of the drones will be higher, which can respond to the battlefield situation more quickly.

- Long endurance

For a manned aircraft, its endurance is mainly limited by the pilot's physiology. If the flight time is too long, the pilot will have fatigue and negative emotions, and it is prone to safety accidents. However, the drone operators can operate the aircraft in the ground control station by turns. Meanwhile, automatic flight can be set during the cruise phase, and nearly no human intervention is required. As long as the power and structure of the drone are sustainable, it can be active in the theater for a long time without interruption, so the endurance is far stronger than that of the manned aircraft.

4 UAV Formation

With the continuous development of artificial intelligence technology, the combat style of UAVs has gradually evolved from "single-handedly fighting" to "clustering intelligence", shown in Fig. 3. At present, the world's military powers are all actively developing the UAV cluster combat technology, because the UAV formation can improve the efficiency of task that a single drone cannot complete in reconnaissance

Fig. 3. Schematic diagram of cluster formation

and surveillance, target strike, communication relay, electronic interference, battlefield evaluation, and so on [7, 8].

UAV cluster combat usually refers to hundreds of thousands of small, fast, and powerful UAVs in the battlefield airspace, simulating cluster behaviors such as bee colonies, fish schools, and ant colonies to construct bionics formations. Interactive communication is carried out through various channels such as combat data link systems, tactical radio systems, and communication relay networks. They rely on advanced technologies such as cloud computing, big data, and artificial intelligence to conduct operational coordination and carry out strategic deterrence, campaign confrontation, and tactics action in military operations [9, 10].

UAV cluster combat has multiple advantages [11]. (a) Diversity functions: With different equipment for different drones, a UAV formation can possess multiple functions such as reconnaissance, surveillance, electronic interference, strike, and evaluation; (b) the effectiveness of combat: a UAV formation can attack one target simultaneously from different directions, or strike against multiple targets at the same time; (c) group's invulnerability: When a certain drone in the formation fails or is destroyed by the enemy, the formation can adjust the task division and use another drone to replace it to ensure that the entire formation can continue to perform the task.

There are also some problems in UAV cluster combat that need to be solved [12]: (a) formation flight control technology: When performing certain tasks, the UAV formation needs to change the structure of the formation in real time according to the mission requirements during the flight, which poses a great challenge to the controller; (b) anti-collision and obstacle avoidance technology: When a drone in a formation is disturbed, or in the process of turning maneuver or at high speed, there is the possibility of collision; (c) track planning problem: The UAV formation not only needs offline route planning to avoid known threats and obstacles, but also needs to renew the track in real time during the flight to avoid emerging threats and obstacles.

5 Conclusions

Same as drones, unmanned combat vehicles, unmanned surface vessels, and unmanned underwater vehicles have also achieved great development. With the further breakthrough of key technologies such as modularity, interoperability, intelligence, and autonomy, in the future, unmanned systems can do almost anything that a manned system can do, and they can do it better. There is no doubt that the future battlefield will be dominated by unmanned combat systems and will present cluster, three-dimensional, intelligent, and synergistic features. Therefore, in order to effectively cope with the future intelligent warfare, we need to plan well in advance, rationally arrange, and vigorously develop unmanned combat systems such as drones that are suitable for China's national conditions, and ensure that our army can catch up with Western powers in this new field, and further, walk in the forefront of the world.

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