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PRC Concepts for UAV Swarms in Future Warfare

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Abstract

This report examines the People's Republic of China's (PRC's) writings on the growing use of uncrewed aerial vehicles (UAVs)—commonly called drones—in warfare. The PRC has been developing and testing uncrewed platforms since the 1960s but has largely lagged behind the world's leading military powers technologically in uncrewed systems, particularly in autonomous and semi-autonomous drone swarm research. An examination and analysis of PRC writings from 2019 through 2024 indicates an intent to accelerate and advance the People's Liberation Army's (PLA's) development, testing, and use of uncrewed systems, especially for drone swarm technology, in part because of the perceived threat from advancements in US drone capabilities. PRC writings suggest that the widespread use of drones in recent conflicts is drawing further PRC attention to drone warfare. PRC writings from the past four years demonstrate that the PLA is exploring the use of uncrewed systems and testing drone swarm technology for use in a possible invasion of Taiwan. In addition, the PRC is examining militaries' use of drones and drone swarms to develop its own counter–drone swarm methods and technologies.

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Executive Summary

This paper examines writings from 2020 to 2024 produced by subject matter experts (SMEs) in the People's Liberation Army (PLA) and others in the People's Republic of China (PRC) defense community discussing the growing use of uncrewed aerial vehicles (UAVs)—commonly called drones—in warfare. It also provides preliminary insights into this community's views on the use of uncrewed systems (UxS) and drone swarms as the next generation of warfare able to supplement, and even replace, many crewed platforms for combat missions, as well as on the potential employment of drones in an amphibious assault or blockade of Taiwan.

Key findings

A central finding of this paper is that the PLA is researching and developing autonomous drone swarm technology to solve one of the PRC's most difficult challenges—a potential military invasion of Taiwan—and developing the capability to employ drone swarms in either an amphibious assault or blockade scenario.

- An examination of PRC writings suggests that the PRC is learning from both sides in the Russia-Ukraine war on the use of drones and drone countermeasures and applying these lessons to a PLA-Taiwan military scenario.
- Articles from PLA-produced and technical journals indicate that the PLA is researching, testing, and exercising with drones and drone swarms for a potential Taiwan invasion.

PRC SMEs observe that the world's militaries are successfully using UxS for combat operations, including drone swarms, which they describe as providing the following advantages:

- Lower casualty rates because fewer soldiers need to deploy to the most dangerous combat operations.
- Lower cost to produce medium and small drones, particularly for intelligence, surveillance, and reconnaissance (ISR) and tactical strike missions.
- Easier training for drone operators.
- Asymmetric advantage to less powerful militaries.

PRC SMEs state that the PRC's naval forces are faced with the threat of drone swarm technology from the world's leading militaries and describe a growing need to develop countermeasures to protect against offensive drone swarms and threats to maritime forces. This challenge would be especially acute during a Taiwan invasion.

- The PLA and PRC military research institutes are tracking the progress of the US and other countries' research on countering UAV swarm warfare, particularly research on directed energy and high-power microwave weapons.
- PRC writings categorize counter–drone swarm warfare into four functions—detection, soft kill, hard destruction, and camouflage—and describe the technologies and tactics needed for each function.

As the PLA develops and advances its own autonomous drone swarm capabilities, the US joint force could be faced with a PLA force keenly aware of both the value and the advantage of drone swarm warfare. Some of the implications for the joint force include the following:

- PLA researchers are closely watching the development of US drone technology and examining US defense publications for identified weaknesses in drone development.
- If the joint force acted to protect Taiwan in an attempted military takeover by the PRC, US and allied forces could face several advanced PLA UxS, including ISR, strike, and autonomous drone swarm platforms, in the Taiwan Strait.
- In a conflict scenario, the PLA could deploy drone swarms from land-, sea-, or air-based platforms for antiship and other naval combat missions, potentially diversifying and extending its current capabilities.

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1. Introduction

The People's Republic of China's (PRC) People's Liberation Army (PLA) is constantly reassessing the nature of modern warfare and how it must adjust organizationally, doctrinally, and materially to prevail in future contingencies. The war in Ukraine, the conflict in Gaza, and recent military and technological developments abroad—especially those in the United States—are affecting how the PLA thinks it should fight in the future.

This paper is narrowly focused on how subject matter experts (SMEs) in the PLA and others in the PRC defense community think about the use of uncrewed aerial vehicles (UAVs)—commonly called drones—in warfare. It also provides preliminary insights into this community's views on the employment of drones in an amphibious assault or blockade of Taiwan.

The paper draws on data from public domain PLA professional military journals, technical journals from the PRC defense industrial complex, and PLA- and Chinese Communist Party–controlled media. It also benefits from recent discussions with PLA analysts who focus on the changing nature of warfare.

PLA analysts have already determined that the evolution of warfare has moved beyond the era of "informatization" as the dominant "form of war" into the era of "intelligent warfare" that is driven in part by the potential battlefield applications of artificial intelligence (AI).[1]

PLA and other PRC SMEs are still debating and studying how future wars will be fought (i.e., with what systems, weapons, and doctrine) in the age of intelligent warfare. There seems to be consensus on the importance of uncrewed systems (UxS)—particularly drones—in multiple battlespace domains.

> Form of war (战争形态; zhànzhēng xíngtài) *is a term that the PLA uses to identify the main technical attributes of the weapons or systems used in warfare in any given era—for example, the age of mechanized warfare and the age of information-centric warfare.*
>
> —Adapted from the *PLA Dictionary of Military Terminology*

PLA thinking about the employment of drones is not new. The PRC has been developing uncrewed military platforms for decades.[2] What is new is how the PLA is thinking about the use of drones in the age of AI and intelligent warfare.

The PRC writings surveyed for this paper describe a growing trend of drone use among militaries across the world and provide observations on recent combat operations in which drones have been deployed. PRC authors describe drone use in combat operations as evolving from large single platforms into smaller networked intelligent drone swarms with autonomous or semi-autonomous capabilities. Recent PRC writings describe how the PLA is developing and testing its own concepts for drone swarms in a military scenario involving Taiwan. In addition, PRC defense thinkers recognize the growing threat of offensive drones and drone swarms to the PLA's maritime forces and are researching methods for counter–drone warfare.

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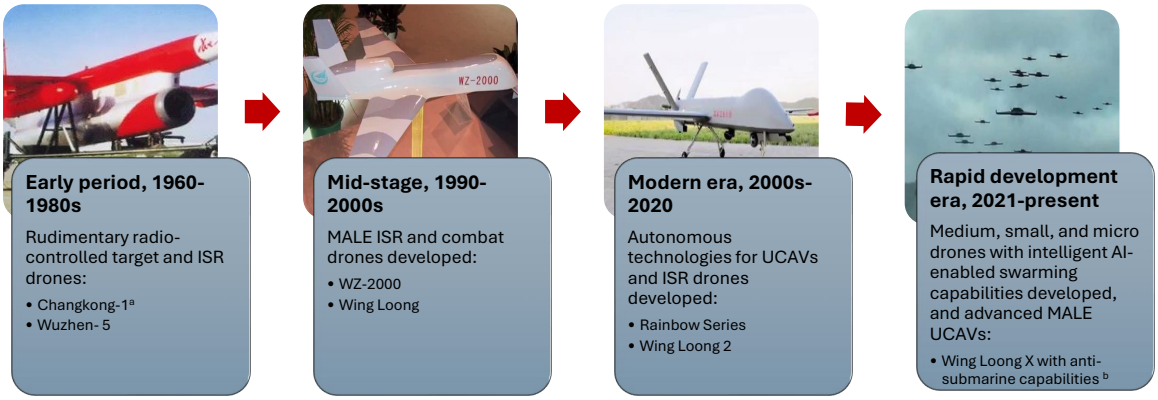
2. PRC Drone Development: A Persistent Area of Research

The PRC has a long history of exploration into military-use uncrewed aircraft. PRC research on drones dates to the early 1960s, when the Beijing Institute of Aeronautics and Astronautics began to develop high-altitude uncrewed aircraft such as the Changkong-1 remotely controlled target aircraft and the Wuzhen-5 high-altitude photo reconnaissance UAV.[3] Although the PRC's research on remotely piloted drones began relatively early, the PRC was a relative latecomer to the development of autonomous drone technology, particularly for drone swarms. The PRC's development of drones can be roughly divided into four eras:

1. **Early period (1960s to 1980s)**, characterized by basic reproductions of Soviet models of radio-controlled target and reconnaissance drones.
2. **Mid-stage (1990s to early 2000s)**, in which the PRC began developing medium-altitude long-endurance (MALE) intelligence, surveillance, and reconnaissance (ISR) and combat drone platforms.[4]
3. **Recent era (mid-2000s to circa 2020)**, when the PRC began designing uncrewed combat aerial vehicles (UCAVs), similar in appearance to the US MQ-9 Reaper (also known as the Predator-B), with autonomous capability.[5]
4. **Period of rapid development (beginning in 2021)**, in which PRC state-led initiatives appear to have given greater importance and resources to the development of drone technology, including autonomous drone swarms with AI capability.

See Figure 1 for a timeline of the PRC's drone development.

Figure 1. Timeline of PRC military drone development



Source: CNA. Data from Yunnan Junying Aviation Technology Co.,"Research on the Development of UAV in China;" Elsa Kania, *The PLA's Unmanned Aerial Systems: New Capabilities for a "New Era" of Chinese Military Power*, CASI, 2018.

[a] "90 Firsts: The First Military Drone, Changkong-1," China Military Online, July 20, 2017, http://www.81.cn/2017jj90/2017-07/20/content_7684475.htm.

[b] "China's Wing Loong-X Drone on Display with Antisubmarine Capabilities," *Global Times*, Nov. 13, 2024, https://www.globaltimes.cn/page/202411/1322979.shtml.

PRC defense thinkers have long recognized the potential of uncrewed systems for changing the modern battlefield. Yet PRC research efforts on drones lagged behind US efforts. Back in 2013, an article written in *Modern Navy*, the official magazine of the PLA Navy (PLAN), highlighted the PLA's intent and resolve to study the growing field of drones. In the article, PLA Air Force (PLAAF) Major General Wang Tianlin recognized the emerging field of drone warfare and discussed the rise of drones in modern combat. Major General Wang stated that "it is [the PLA's] mission and responsibility to study the occurrence, formation, and development of drone combat forms, master their characteristics and laws, and actively innovate combat methods."[6]

According to PLA experts, however, the PRC's early drone research effort was scattered across the PRC's military and defense industrial base, causing the PRC to "lag behind" the world's military powers, especially the US.[7] Current PRC writings indicate that the PRC intends to rectify this research gap, catching up on drone swarm technology and even surpassing the most advanced military powers through top-down initiatives, military research, and implementation of a military-civil fusion development strategy.

2.1 PRC national-level efforts for drone research and development

PRC statements on research and development of drone technology and military drone acquisition indicate the PRC's intent to be a global leader in the military UAV domain. PRC state-owned enterprises, military research institutes, and private-sector civilian research organizations are furthering the PRC's drone research and development. In 2018 state-owned aerospace and defense conglomerate Aviation Industry Corporation of China (AVIC), the PRC's largest developer and producer of military drones, released a paper on the development of UAVs. *White Paper on the Development of Unmanned Aerial Vehicle Systems (2018)* stated two primary goals for AVIC's UAV research:

> 1. By 2025, [AVIC] will establish a high-end breakthrough in UAV systems and build a UAV industry system that is internationally competitive.
> 2. By 2035, [AVIC's] UAV key technology will reach world-class levels [and] have the independent innovation capability to lead the development of the UAV industry.[8]

In March 2021, the PRC National People's Congress released its 14th Five-Year Plan (FYP), covering the years 2021 to 2025. The 14th FYP details the PRC's near-term priorities for development of economic, trade, science and technology, defense, political, social, cultural, environmental, and other policy. Regarding national defense and military issues, Chapter 56 of the 14th FYP emphasizes the need for "development of intelligentized weapons and equipment."[9] According to an explanation in a press release by the China Communist Party News Network, the modernization of PLA forces discussed in the 14th FYP focuses heavily on uncrewed platforms, drone swarms, and their control systems.[10] The report states that "future wars will be uncrewed and intelligent" and that the PRC must "steadily advance national defense and military construction" to meet this need.[11]

Data suggest that the national-level effort initiated by the 14th FYP has been successful at getting PRC industry to focus on drone production. An analysis of PRC UAV industry market reports following the release of the 14th FYP indicates that the procurement budget for military UAVs may have increased significantly. A financial report on PRC's Aerospace Rainbow UAV Co., Ltd., described as a "primary developer of medium and large UAVs and airborne weapons," states that "increased domestic demand for military drones is driven by policy." The report anticipates a 67 percent increase in PRC military spending on UAVs following the 14th FYP, stating the following:

> Assuming that [the PRC's] military UAV procurement expenditure is comparable to that of the United States, the proportion of defense budget is about 0.4 percent. It is estimated that the market demand for military drones in [the PRC] will be about 6 billion yuan [US$840 million] in 2023; by the end

> of the fifth quarter of the 14th Five-Year Plan, the annual scale of [the PRC's] military UAV market is expected to exceed 10 billion yuan [US$1.4 billion].[12]

Analysis from the Massachusetts Institute of Technology indicates that the PRC has a well-established industrial base and highly advanced manufacturing centers capable of meeting the growing demand for drones.[13] According to the Association for Uncrewed Vehicle Systems International, a multinational UxS market research and advocacy organization, "companies based in China and subsidized by the Chinese government control 90 percent of the [international] consumer drone market."[14]

Although the number of drones being manufactured by PRC private-sector and state-owned factories demonstrates the PRC's industrial capacity, the data do not describe the capabilities that the PLA can field with this hardware. Understanding the capabilities is especially important with intelligentized platforms such as drones, in which one piece of hardware can be programmed to perform a variety of tasks and missions. To understand some of the battlefield effects that the PLA is building using drones, we next examine the PLA's exploration of drone operational concepts. One concept getting attention in PRC military drone warfare research circles is drone swarms.

2.2 PRC testing of drone swarm technology

Various PRC journals surveyed for this paper make clear that the PLA and the PRC defense industrial complex are working on drone swarms and associated technologies. Dozens of research institutes affiliated with the aviation and shipbuilding industries are likely working on the issue. A 2022 article appearing in the *Journal of Ordnance Equipment Engineering*, a defense industry journal focusing on scientific research on weapons and technology, provides insight into the high level of research among organizations tasked with conducting drone swarm research. The article identifies some of the primary research organizations involved, stating that "in recent years, the units and organizations involved with drone swarm research are the Academy of Military Science, National Defense University, Air Force Engineering University, and military and civilian research institutions from the aviation and shipbuilding industry."[15]

PRC writings and media reports indicate that the PRC institutions and state-affiliated organizations are developing and testing new types of drone swarms. A 2020 report from the Uncrewed Aerial Vehicles Research Institute of Nanjing University of Aeronautics and Astronautics details tests conducted for ground- and air-launched drone swarms. The tests were conducted by China Electronic Technology Group Corporation (CETC) and reportedly were the "first practical test for fixed-wing drone swarms used for ground surveillance and precision strike."[16] The ground-based launch vehicle could deploy 48 fixed-wing drones at a

time to form a swarm, whereas the air-launched drones were deployed from a helicopter. See Figure 2 for images of the launch vehicle and fixed-wing drones making up the swarm.

Figure 2. Fixed-wing drone swarm test of land- and air-launched platforms

Source: Nanjing University of Aeronautics and Astronautics.

According to the report, the test demonstrated multiple combat mission capabilities for drone swarms, including "rapid vehicle-mounted deployment, mid-air hover delivery, maneuverable delivery, and formations, formation changes, ground surveillance, and precision strikes."[17]

In May 2021, PRC media outlet China Central Television (CCTV) reported that CETC had again conducted a test of a new UAV launcher capable of launching up to 200 fixed-wing drones to form a swarm.[18] During an interview on the CCTV broadcast, PLAAF Senior Colonel Wang Mingliang, a professor in the Strategy and Campaigns Department of the Air Force Command College, said that this test represented a very important step toward the PLA having a "true swarm."[19]

PRC writings assess that after a late start to drone swarm development, the PRC is catching up to—or even surpassing—the US in drone swarm technology. An article from the PRC journal *Ship Electronic Engineering*, a research publication of the state-owned shipbuilding conglomerate China Shipbuilding Industry Corporation, describes the state of the PRC's UAV swarm research in 2021. The authors state that before 2021, the PRC lagged behind other military powers in swarm research because the PRC's research efforts on swarm warfare had been aimed mainly at "large-scale formations and control, while the US had transitioned to swarm warfare research directly for combat missions."[20] The PLA authors state that

although "China started late in the research on UAV swarms," PRC researchers have "made achievements in UAV swarm warfare through continuous research."[21]

An article from 2021 published in *National Defense Technology*—the journal of the National University of Defense Technology (NUDT), the PLA's premier institution for scientific research and education—calls for an "acceleration in progress on military drone swarm research" based on the "realistic threat" from US advances in drone swarm technology.[22] Another article from 2021, featured on the PRC drone industry platform Global Drone Network, a subsidiary of the PLA's China National Defense Science and Technology Network, states that the "United States and PRC are the only two countries in the world that have the advanced technology to control hundreds or thousands of drones in a swarm."[23]

A 2023 article in the journal *Weapon,* a popular national defense and military science journal sponsored by China North Industries Group Corporation Limited (NORINCO), the PRC's largest state-owned defense conglomerate, describes the PRC's growing technological development of drones as catching up with, or even surpassing, the US's ability, especially in drone swarm technology. [24] The authors describe the US Naval Research Laboratory's research and development of ship-based drone swarms as stalling while the PRC's own research has advanced. The authors state that the US Navy (USN) had begun research in 2014 for a "20,000–30,000-ton straight-deck ship equipped with a small electromagnetic rail catapult and electromagnetic arresting cables to support the takeoff and landing of large and medium-size drones." The authors state that this "drone swarm mothership" concept failed for two reasons—USN institutional bureaucracy and difficulty managing shipborne command and control (C2).[25] The article asserts that the PRC has advanced its development of UAV and counter-UAV technologies, such as electronic warfare (EW) technology, electromagnetic environment detection systems, over-the-horizon strikes, and breakthroughs in phased array radar technology, concluding that "compared with the United States, China's drone swarm progress is quite encouraging."[26]

3. PRC Observations and Lessons from the Growing Use of Military Drones

In the past few decades, warfighting has profoundly changed with the emergence of remotely piloted and autonomous drone technology. Rudimentary military drones have been used for nearly a century, such as the British Royal Navy's "Queen Bee," a radio-controlled aircraft used for target practice developed in 1935.[27] However, drone use entered a new era beginning with the US military's use of drones for tactical strikes in the Gulf War in the early 1990s and in Afghanistan in the early 2000s. As the PLA continues its widespread modernization efforts, PRC researchers, SMEs, and PLA planners are examining how the PLA can adapt its force to the latest technologies, including using drones across battlespace domains.

3.1 PRC defense thinkers describe rising value in drones and drone swarms

PRC media reports and articles from technical journals describe a rise in drone use over the last two decades by the world's leading militaries. This rise in drone use is described as driven in part by the technological developments of US military platforms after the Gulf War.[28] An article in the PRC journal *Weapon* describes the US as an "early adopter" of drone technology. The article identifies specific US military research institutions such as the Naval Research Laboratory, the Naval Postgraduate School (NPS), and the Defense Advanced Research Projects Agency as pioneers in research on drones and drone swarms.[29]

A 2020 report from China Military Online noted that great military powers such as the United States, Russia, Japan, South Korea, and the North Atlantic Treaty Organization alliance are advancing their research on drones and have already adopted new strategic plans for military construction of drones and drone swarms using AI. Adoption of uncrewed technologies combined with AI is described as "the strategic commanding height of military intelligence."[30]

PRC authors observe that drones will "perform more types and higher intensity tasks on the future battlefield than manned aircraft," "completely change the battlefield" of the future, and follow the trajectory of military development from mechanization to informatization and "intelligentization."[31] PRC writings reviewed for this paper discuss the growing role of drones in recent conflicts and identify the following trends:

- The United States and other leading military powers are rapidly advancing drone technology; however, the PRC is catching up.

- Drones have demonstrated real-world combat superiority and asymmetric capabilities against more advanced opponents in the past decade.
- Small, inexpensive drone platforms offer capabilities that are difficult to counter.
- Drone swarms are the next revolution in uncrewed warfare.

An article from 2023 authored by PLA Senior Colonel Wu Minwen, a professor at the PLA's NUDT, states that UAV combat systems have the potential to be highly disruptive to future battlefields. However, UxS will not make crewed systems obsolete. Wu details that uncrewed combat forces will "coordinate with manned systems to perform battlefield situational awareness, integrated strike, joint support, and intelligent support during operations."[32]

In 2024 PLA specialists from the Academy of Military Sciences published an article in *The Paper*, a popular online newspaper based in Shanghai, discussing the growing role of uncrewed equipment, describing it as the "evolution of battlefield equipment."[33] The authors state that as warfare has evolved from mechanized to informatized to intelligent warfare, autonomous uncrewed platforms have become the preferred type of battlefield equipment. The authors caution, however, that even though the "pace of uncrewed equipment is accelerating," these platforms are still not ready to replace most soldiers on a battlefield.[34]

3.2 Recent combat operations reinforce the value and evolution of drone technology

Many PRC writings outline the asymmetric capabilities that drones offer, pointing to examples from recent or ongoing conflicts in which drones provided significant advantage to the user. The 2020 Nagorno-Karabakh conflict between Armenia and Azerbaijan is a frequently cited example, as is the ongoing Russia-Ukraine war.

3.2.1 Nagorno-Karabakh conflict

The Nagorno-Karabakh conflict is part of an ethnoterritorial dispute between Armenia and Azerbaijan over the long-contested region of Nagorno-Karabakh. Azerbaijan's widespread use of drones in 2020 was seen by PRC military analysts as crucial in determining the conflict's outcome.[35]

An article from *PLA Daily* published in 2022 described Azerbaijan's An-2 drone as a cheap platform modified from an old An-2 transport aircraft to serve as an aerial decoy in combat. The article stated that Azerbaijan flew its drones into firing range of the Armenian forces, luring the Armenian air defense system radar to turn on or fire on the drones, thereby exposing Armenian firing positions and leaving them vulnerable to counterfire by Azerbaijan.[36]

According to authors writing in the PRC journal *Tank and Armored Vehicles*, a military journal sponsored by major PRC defense industrial conglomerate NORINCO, Azerbaijan's use of drone swarm assault tactics "reversed the entire situation of the war," allowing Azeri forces to "hit Armenian land targets with 'zero casualties.'"[37] Researchers from the PLAN's Naval Research Institute stated that "from the conflict between Armenia and Azerbaijan, it can be seen that drone swam technology has the advantages of asymmetric strikes and is a technology that can subvert the rules of future warfare."[38]

3.2.2 The Russia-Ukraine war

Since Russia's invasion of Ukraine in February 2022, PRC civilian and military authors have assessed that air- and sea-based drones have been employed to great offensive and defensive effect by both the Russian and the Ukrainian militaries. These writings state that Ukraine's use of both high-end and cheap, expendable commercial off-the-shelf UAVs to penetrate Russian airspace, conduct ISR, and destroy high-value targets has demonstrated an emerging prominence for drones as an asymmetric tactic in contemporary warfighting. Since 2022, PRC technical journals have published on the tactics used by both forces, examining the offensive capabilities of drones as well as measures that each country has taken to defend against tactical drones and drone swarm attacks.

The war in Ukraine is providing PRC civilian and military analysts the opportunity to assess the efficacy of various types of drones as well as drone countermeasures. PRC authors writing in authoritative publications have noted both the strengths and the weaknesses of deployed drones in the war. For example, an article from 2023 in *Defense Science and Technology Industry*, the publication of the PRC's State Administration of Science, Technology and Industry for National Defense, states that drones have played an "indispensable role" for both Russia and Ukraine on the battlefield.[39] According to the author, because of "international pressure and public opinion, military costs, and political purposes," the Russia-Ukraine war has been limited in scope, with neither Russia nor Ukraine deploying fighter jets on a large scale, thereby making drones the most viable option for combat. The article argues that drones have been used heavily by both sides for ISR, tactical strikes, and targeting designation and have significant advantages in expendability, cost, and use, with little to no training of operators. However, the author maintains that the Russia-Ukraine war has also exposed four weaknesses of drones:[40]

1. Without electronic jamming and passive countermeasures, drones from both sides have limited defense capabilities, making larger tactical drones vulnerable to attack.
2. Integrating new drone platforms into current combat systems can be difficult, particularly for small and medium drone platforms using EW methods.

3. Russia's drone capabilities lag behind those of other countries, such as the US. Russia lacks high-altitude long-endurance UAV reconnaissance aircraft, the altitude is too low for ISR and attack drones, and the load capacity for attack drones is too small, making Russian drones vulnerable.
4. Russian air defense systems were not prepared for or capable of dealing with Ukraine's escalating drone attacks.

The author uses these weaknesses as lessons for the PRC, stating that the PRC should do the following to improve its capabilities:[41]

- Execute drills for drone attack and defense regularly.
- Innovate crewed-uncrewed combined tactical training methods.
- Conduct in-depth research on UAV applications, including swarm operations and UAV electronic countermeasures.
- Analyze insufficient communication and intelligence fusion processing capabilities.
- Expand the integration of drones into joint multidomain operations.

A 2023 article from the PRC journal *Small Arms*, a NORINCO publication, notes that the war in Ukraine is "the perfect testing ground for new weapons."[42] The article argues that Ukraine's successes in fighting Russia's infantry forces have been primarily in its use of large numbers of small ISR drones and modified drone loitering munitions. The authors explain that in the Russia-Ukraine war, the extensive use of drones has led to continuous development of anti-drone weapons, the most successful of which is the electromagnetic gun (also known as a counter–uncrewed aircraft system or C-UAS) developed by Russia. The authors state that Russia's REX-1 C-UAS can "suppress the signals of GPS, GLONASS, China's Beidou and Europe's Galileo, but also interferes with mobile communications, 3G and LTE signals," thereby slowing Ukraine's ability to attack Russia with small drones by disrupting and jamming its communication signals.[43]

An article in PRC aerospace journal *Tactical Missile Technology*, sponsored by China Aerospace Science and Industry Corporation, describes how studying the war in Ukraine can help the PRC prepare for future combat operations using uncrewed platforms.[44] The authors state that the use of drones by both Russia and Ukraine demonstrates the following:[45]

- Drones breaking the traditional air combat pattern dominated by crewed aircraft.
- Air-space integration through use of space-based satellite imagery to provide target data to attack drones and crewed-uncrewed coordination.
- Improvements in long-range strategic strike, mid- and low-altitude target interception, stealth penetration, and other combat capabilities.

3.2.3 Lessons learned from conflicts: drone swarms are superior to single drones

Following the conflicts that have occurred in the last four years in which drones were deployed, PRC authors, SMEs, and military analysts have observed the type of drones used and tactics employed.

Before the war in Ukraine, PRC writings reviewed for this study focused mainly on the theoretical attributes of drone swarms. For example, a 2019 article from *People's Daily* examined the use of drone swarms on future battlefields. The article argues that there are three main advantages for drone swarms over single uncrewed platforms:[46]

1. Individual drones in a swarm are small, making targeting of individual units difficult.
2. The networked effect of drone swarms increases ISR capabilities significantly for battlefield commanders.
3. Drone swarms are difficult to detect.

The article describes drone swarms as having asymmetric capabilities able to take on the world's most advanced ship-based weapons system, specifically mentioning the USN's Aegis Combat System. The authors explain that USN ships equipped with Aegis are vulnerable to drone swarm attacks, stating that "the US military has discovered through a large number of simulation experiments that even if it [Aegis] is equipped with such an advanced detection and anti-missile system, it is unable to deal with drone swarm attacks."[47] A 2022 article appearing in the *Journal of Ordnance Equipment Engineering* provides more detail on the vulnerabilities of the Aegis system. The authors quote early research from the US NPS in which "hundreds of simulation results showed that when eight drones participated in an attack [on an Aegis-class destroyer], an average of 2.8 drones were still able to break through the defenses."[48] The PRC authors conclude that, based on the NPS analysis, "aerial drone swarms have the power to attack surface ships."[49]

According to PLA Army Senior Colonel Wu Minwen, a professor at the PLA's National University for Defense who has published in multiple core PRC journals of military science on emerging military technology issues, drone swarms have distinct advantages over single drone platforms. Senior Colonel Wu states that swarms are based on "artificial intelligence, big data, and network technology, with larger land, sea, and air combat platforms acting as carrying and launching platforms."[50] Wu states that there are three primary areas in which drone swarms excel over single drone platforms:

1. Quantity and scale
2. Diversity of composition for varying missions
3. "Algorithmization"

First, regarding the quantity and scale of drone swarms, Wu states that whereas a single uncrewed platform has a "small load, simple functions, and limited destructive power," once multiple drones are used in a swarm, the "functional complexity and destructive power can be greatly increased." Wu cites the "Cicada" micro-UAV (the USN's concept for a low-cost GPS-guided micro disposable air vehicle[51]), which can "carry weather, temperature, humidity, air pressure sensors, or micro-electronic equipment such as acoustic detection and biochemical detection," as an example of the benefit of drone swarms. According to Wu, by scaling up to thousands or even tens of thousands of drones in a swarm, the loss of hundreds of individual drones will be insignificant and will "not affect combat ability."[52]

Second, drone swarms composed of sizes varying from as small as insects to larger types can be formed based on mission need. For example, Wu states that swarms can be tailored to "early warning detection, ISR, and network warfare" missions, giving them an advantage over individual drones with one mission ability.

The third advantage of swarms is what Wu calls their "algorithmization," which he describes as "handing over the processing of large amounts of information to algorithms and microprocessors," thus giving drone swarms abilities greater than those of a human operator. Wu cites the US Naval Research Laboratory's work in developing algorithms to help long-endurance UAVs maneuver and extend their flight time as a successful example of algorithmization.[53] Wu warns, however, that the disadvantage of algorithms controlling drone swarms is the "danger of being deciphered by our opponents" and that the PRC must "strengthen communication confidentiality and algorithm encryption." Wu suggests the following specific methods:[54]

- Using diversified communication and control encryption for different subgroups of large-scale swarms
- Customizing and solidifying control software and algorithm encryption
- Providing multiple layers of high-tech encryption and rotating encryption technology constantly

PRC SMEs describe the trend in drone use as evolving from large, expensive attack drones to smaller, cheaper platforms. According to a 2022 article by Xinhua, the PRC's official news agency, until recent years, larger model tactical strike drones such as the US military's MQ-1 Predator and MQ-9 Reaper were the primary platforms used in combat operations. The authors note that remotely piloted drones were used by the US in counterterrorism and counterinsurgency operations in Afghanistan and Iraq, mostly in uncontested airspace to locate and hit targets. However, the article states that recent conflicts in Nagorno-Karabakh and Ukraine demonstrate shifting trends in drone use for combat operations, with smaller drone platforms being used for a variety of combat missions.[55]

PRC technical journal articles assert that as drones have gotten smaller and cheaper, they have taken on an expanded role in ISR. For example, a 2022 article in PRC aerospace industry publication *Space Exploration* describes the use of 13 small drones by the terrorist organization ISIS against the Russian military base in Syria in 2018, stating that this attack "set a practical precedent" for the use of small drones to find and fix targets in contemporary warfare.[56] Another 2022 article, from the PRC technical journal *Command, Control, and Simulation*—listed the PRC's Chinese Science Citation Database as a "core Chinese academic journal" in 2024—discusses the growing use of uncrewed combat systems in naval warfare.[57] The authors, including two from the PLA, state that small uncrewed platforms can be used to perform a variety of maritime combat tasks and have distinct advantages over crewed systems in terms of ISR and counter-ISR capabilities and operability length.[58]

PRC writings describe drone swarms as the next evolution in uncrewed intelligent warfare technology and as having multiple advantages over single drones. Across many writings, PRC authors and PLA articles describe drone swarms as a low-cost, more effective asymmetric capability compared to larger, more expensive attack drone platforms. According to Wang Yingxun, director of the Chinese Society of Aeronautics and Astronautics, the intelligent algorithms technology needed for swarm coordination and control is much more advanced and complex than the "fixed script programs that single drone platforms use," making control of drone swarms much more difficult but once mastered, swarms then become superior to simpler groups of drones.[59]

Based on observations of the war in Ukraine, PRC technical journal articles from the past two years describe the growing role of drone swarms for combat. Given the advantages described above that drone swarms have demonstrated in battle, multiple PRC articles discuss the role that drone swarms can fill in future operations. For example, a 2022 article in *Command, Control, and Simulation* states that drone swarms can be used for a variety of naval warfare tasks, including support of amphibious landings, and are optimal for the following missions:[60]

- Forward deploying to conduct long-term reconnaissance and monitoring of key sea areas and routes
- Conducting close reconnaissance of enemy shores and islands to seek and detect targets
- Conducting electronic jamming and tactical deception
- Guiding attacks with long-range firepower

4. Swords and Shields: PRC Research on How to Apply Drones in Combat

PLA SMEs and others in the PRC defense community have written much about how the world's militaries are thinking about—and using—drones in warfare. PRC writings are also beginning to describe how the PLA could apply the lessons learned from the past decade of research to the adoption of drones for its own warfighting concepts, including solving one of the PRC's most difficult military challenges: an amphibious assault on Taiwan. PRC writings beginning in 2020 indicate that the PLA is exploring the use of drones, particularly drone swarms, for a Taiwan military scenario, either as the vanguard of an amphibious island seizure operation or to blockade the island.

4.1 Research and testing of swarms for a takeover of Taiwan

PRC writings from technical journals and media reports indicate that the PLA aspires to use uncrewed platforms and drone swarms in a Taiwan military contingency. In 2020, PLA authors from the NUDT wrote an article in the journal *National Defense Technology* focused on the use of drone swarms for an island-seizure operation.[61] The authors argue that contested amphibious operations are the most complex joint military operation to implement and thus "in future joint sea crossing and island landing operations, drone swarms will play a pivotal role."[62] The authors state that in 2020, research on drone swarms in China is still "in the theoretical research stage;" however, "the progress and development trend of artificial intelligence and drone platform–related technologies have made drone swarms highly feasible."[63] According to the article, island-landing operations are divided into three phases, and drone swarms could be used during each phase, as outlined in Table 2.

Table 1. Three phases of landing operations and the role of drone swarms in each phase

Phase	Objective	Role of Drone Swarms
Crossing	Open sea transportation lines to carry out transportation of materials and combat forces	*Early warning and ISR* Distribute swarms around the crossing forces to conduct long-term real-time monitoring of enemy positions and operations as well as changes in the sea conditions *Precise delivery of materials and equipment* Deliver medicine, food, and special equipment

Phase	Objective	Role of Drone Swarms
Landing	Control the landing area	*Comprehensive situational awareness* Send tactical intelligence on "small-scale changes" in the enemy's situation back to command post to support decision-making *Deception and sabotage* Send out small group detachments to lure enemy's radar systems away from invasion force's main thrust Carry jamming devices to interfere with enemy radar and ground air defense system *Fire suppression and holding territory* Remove enemy fortifications, striking hidden strongholds and covering the landing force's rear to hold the beachhead
Post-landing operations	Advance landing forces to create favorable conditions for subsequent operations while also maintaining the established sea lanes and logistics channels	*Clearing obstacles ahead of manned advance* Conduct targeted clearance of obstacles behind enemy lines to open space for the advance of ground forces and high-value crewed platforms *Early warning* Spread out over the enemy's rear areas to monitor the enemy's main attack directions *Long-range fire targeting information* Provide target instructions for long-range fire platforms located beyond enemy defense zone *Frontline combat formation* Form frontline combat formations for the most dangerous offensive missions *Close air support/loyal wingman* Provide cover for crewed aircraft

Source: Hu Hang et al., "Research on the Application of Drone Swarms in Sea Crossing and Landing."

The PLA's research on drone swarms for a Taiwan operation may be moving past the theoretical phase and into the testing and experimentation phase. According to PLA official media reporting, the PLA's amphibious forces—PLA Army amphibious combined arms brigades—began conducting exercises with drone swarms in 2021. On July 28, 2021, CCTV, the PRC's official media outlet, reported that an unnamed amphibious combined arms brigade from the PLA 73rd Group Army conducted a cross-sea island-landing operation exercise using a drone swarm for the first time.[64] The exercise, called "Crossing the Sea and Landing 119 High Ground," was described as the "first use of drone swarms as the vanguard of attack" in a large-scale island-seizure operation.[65] The video displays a drone swarm composed of an unnamed number of small rotary-wing drones deployed in a swarm formation to "first detect the enemy's situation, and then dispatch combat troops to carry out strikes."[66] The narration details that special operations forces (SOF) (described as "frogmen," presumably PLAN Marine

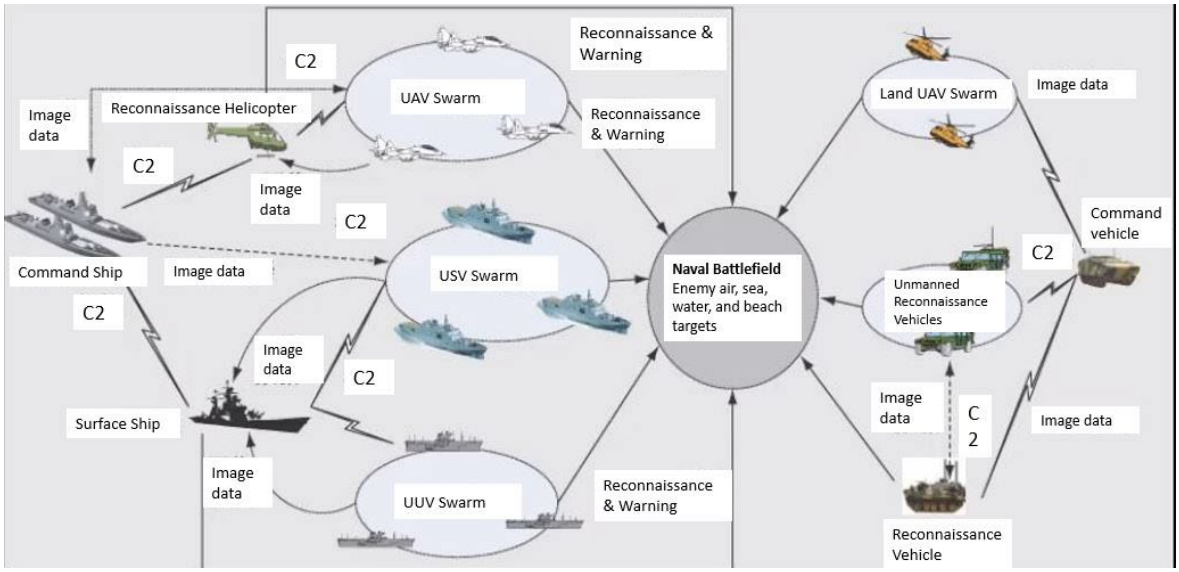
Corps SOF) had entered the island ahead of the landing operation and similarly deployed handheld drones for reconnaissance. Subsequent analysis of the 2021 exercise in the journal *Weapon* states that the swarm drones deployed during the "Crossing the Sea" exercise were "used for reconnaissance and surveillance, some were equipped with electronic equipment for interference, and some launched suicide attacks."[67] See Figure 3 for an image from the 2021 PLA exercise.

Figure 3. PLA drone swarm deployed during the 2021 large-scale island-seizure exercise

Source: "Crossing the Sea to Seize the Island, the Drone Swarm Takes the Lead in Attack!"

In 2022 an article from *Command, Control, and Simulation* coauthored by PLA members Yue Lijun and Zhao Chaoxian, and Wang Fan from the Jiangsu Institute of Automation, discussed the role of uncrewed platforms for naval combat to support an amphibious operation. The authors state that drones, uncrewed surface vehicles (USVs), uncrewed underwater vehicles (UUVs), and uncrewed combat vehicles can be used either autonomously or as swarms combined with crewed platforms to conduct ISR, minesweeping, and firepower strikes during an amphibious operation.[68] The article describes the C2 structure for uncrewed systems during an amphibious operation, with a command ship at sea "directing the shipborne helicopters, surface ships, UAVs, USVs, and UUVs to conduct coordinated detection, obtain images, data, electromagnetic, and other air, sea, and underwater intelligence, and transmit them back to the command ship for unified situation processing."[69] Figure 4 is a diagram extracted from the article depicting the authors' concept of naval C2 for uncrewed assets in support of an amphibious operation.

Figure 4. Conceptual C2 chart for uncrewed systems in naval combat operations



Source: Yue Lijun, Wang Fan, and Zhao Chaoxian, "Concept of Coordinated Use and Command and Control." Translation by CNA.

Recent writings directly correlate lessons from Russia and Ukraine with how the PLA can use drone swarms to fight against Taiwan. For example, an article from 2023 in the PRC journal *Scientific and Technological Innovation* written by authors from the PLAN's Dalian Naval Academy argues that the PLAN should apply battlefield damage assessment lessons from drone use in Ukraine to "using drones to combat Taiwan."[70] The authors state that "in future operations against Taiwan, UAVs will surely become the 'killer weapon,'" profoundly changing the form of combat. According to the authors, drones will be used for the following three primary combat missions in a Taiwan military operation:[71]

- **Early warning support for ship formations.** PLAN ships are vulnerable to incoming attack from antiship missiles because "the ship's sea warning radar [is] affected by the sea battlefield environment and the curvature of the earth, and its early warning detection range is limited to the visual range." There is also a blind spot in radar detection for incoming missiles at a height of 10 meters. UAVs dispatched to ships are proposed to detect incoming antiship missiles such as Taiwan's Hsiung Feng III (a third-generation antiship missile).
- **ISR.** Uncrewed ISR aircraft are superior to satellite and crewed assets in terms of flexibility and endurance. ISR drones can carry a variety of airborne monitoring and detection equipment and conduct long-term and real-time monitoring and reconnaissance of key sea areas around Taiwan. ISR drones can also break through the enemy's air defenses and reach the skies above Taiwan's surrounding islands for

close reconnaissance, obtain more detailed information, and convey it promptly to the command ship, providing the formation's command post with timely and accurate command decisions based on the actual battlefield conditions.

- **Electronic warfare.** Drones can conduct electromagnetic suppression on enemy air defense radars, communication command systems, and other targets by releasing active chaff bombs, emitting electromagnetic waves, and using other active and passive jamming methods. Taiwan uses the Changbai phased array radar operating on S-band frequency, and if the radar is used for fire control, it is vulnerable because its array must be very large to ensure accuracy. Therefore, drones from the PRC mainland would be able to blind Taiwan's defenses and paralyze the communication command system ahead of the assault forces.

A June 2024 article from *Command, Control, and Simulation* written by lead author Chen Huijie, an engineer with the PLA, describes the research and simulation testing of the PLA to impose and maintain a blockade on an unnamed island using only uncrewed platforms. The article describes a scenario with a "regional island" roughly shaped like Taiwan that was fortified with a large number of air defense missile launchers while enemy surface ships and submarines patrolled the vicinity. According to the research team, "given the presence of widely dispersed, highly concealed, and time-sensitive mobile threats on the island and its adjacent waters, employing traditional manned forces for reconnaissance and assaults poses a challenge of low cost-effectiveness." [72] The research team conducted multiple simulations, with the PLA deploying four types of drones launched from mainland China military bases:

- **Medium and large long-endurance drones for reconnaissance,** including WZ-10, WZ-7, and WZ-9 Shendiao drones with a maximum altitude of more than 20 kilometers. These drones are unable to be attacked by most air defense missiles.
- **Tactical strike drones,** including the CH-4, Wing Loong-3, and twin-tailed Scorpion (Tengden TB-001 MALE UAV).
- **Small composite-wing drones** such as the BZK-06, used to fill in the gaps at low and medium altitudes, to make up for the blind spots and insufficient resolution of large drones in high-altitude ground observation, and to conduct close reconnaissance of targets that need confirmation of target data.
- **Anti-radiation cruise missiles** such as the PLA's Y-35 long-range cruise missile, with a 1,200-kilometer range designed to detect and destroy an enemy's radio emission source.

The results of the simulations showed that deploying more or higher performance drones "did not necessarily yield better results" and that within a combat area, "once the scale and diversity of drone formations reached a certain threshold, they could effectively control the island and

its surrounding waters, suppressing the island's armed forces and thwarting external aid."[73] Figure 5 provides a translation of a graphic in the article illustrating the drone formation.

Figure 5. Drone formation for island-blocking scenario

Source: Chen Huijie et al., "Mission-Level Simulation Design and Practice of Swarms." Translation by CNA.

4.2 Development of countermeasures

Faced with the advancements in global drone and drone swarm technology by the world's leading militaries, PRC SMEs describe a growing need to develop countermeasures to protect against offensive drone swarms. PRC authors writing in a 2024 article appearing in the journal *Laser and Infrared*, a technical journal affiliated with the PRC defense industrial complex, state that "small drone swarms and unmanned boats" are increasingly posing a great threat to China's maritime fleets.[74] The authors conclude that the PLAN's fleets are "in urgent need of an effective, fast and cost-effective defense method."[75]

In addition to the PLA researching, developing, and testing drones over the past few years, the PRC is examining how to counter drone swarms. Writings in PRC technical journals from late 2023 and 2024 divide counter–drone swarm warfare into four functions: detection, soft kill, hard destruction, and camouflage.[76] A summary of three recent technical

journal articles describing the mechanisms and main technologies involved in each approach is outlined in Table 2.

Table 2. Counter-drone mechanism and technologies

Function	Action	Technology
Detection or tracking	Determine the location, range, and behavior pattern of the drones in a swarm to distinguish between friendly and enemy drones and provide targeting information for subsequent counter-swarm operations	Satellites, radar, radio, optoelectronics, acoustic detectors, infrared detection
Soft kill through interference or blocking technology	Interfere with drone swarms' navigation systems, remote control connection, telemetry system, or mission payload by blocking communications, signal deception, sensor blinding, and network intrusion	EW weapons, cyberattacks, microwave interference, laser jamming, acoustic interference
Hard kill or kinetic kill	Damage drone platforms, mission payloads, and system modes such as ground control stations, drone nests, or communication relay stations with kinetic strikes	Conventional air defense munitions, directed energy weapons, microwave weapons, armed drone swarms
Camouflage or deception	Use camouflage and dummies to obstruct or confuse enemy drone reconnaissance by obscuring the position of targets or simulating false targets	Smoke screens, false target dummies, terrain concealment, net covers for target

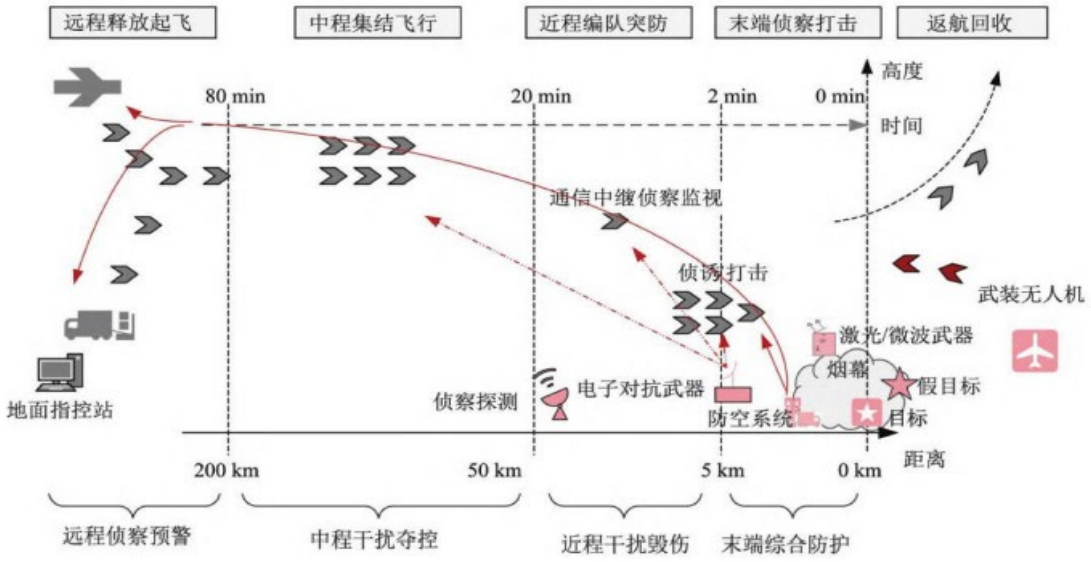
Source: Zhang Pengfei et al., "Current Status and Prospects of Key Technologies for Countering UAV Swarms," *Journal of Artillery Launch and Control* (2023). ("When communication is blocked, the function of the swarm is limited or even useless."); Xie Weipeng, Wu Tong, and Qi Tongshuai, "Analysis on the Application of Tactics and Methods in Anti-UAV Swarm Warfare."; Huang Xiaoyang et al., "Research Trends and Countermeasures of UAV Swarm Warfare."

A May 2024 article in the *Journal of the China Academy of Electronics and Information Technology* outlines how the functions listed above combine to neutralize enemy drone swarms at different phases of the swarm's trajectory toward its target:

- **Long-range "reconnaissance and early warning" phase (>200 kilometers from target)**
  - Detection: Satellites, radar, radio detection, and high-altitude reconnaissance drones start tracking the enemy drone swarm as far from the target as possible. ISR assets try to identify the location of the swarm's launch platforms and ground control stations.
  - Hard destruction: Long-range artillery target drone nests and launch platforms.
- **Mid-range "interference and control" phase (200 to 50 kilometers from target)**
  - Detection: Ground reconnaissance assets, early warning radar, and early warning aircraft track the swarm's location, size, flight altitude, and flight speed to provide targeting information for subsequent air strikes on the swarm.
  - Soft kill: EW assets are mobilized to interfere with or deceive communications between the swarm and ground stations and among the drones within the swarm.
  - Hard destruction: air defense missiles target the swarm.
- **Short-range "interference and damage" phase (50 to 5 kilometers from target)**
  - Detection: Radar, radio detection, optoelectrical infrared, sound detection, and reconnaissance drones form a multidimensional drone-swarm tracking system.
  - Soft kill or hard destruction: Directional electromagnetic interference, microwave weapons, precision laser weapons, anti-aircraft artillery, and armed drones attack the swarm.
- **Terminal "comprehensive protections" phase (less than 5 kilometers from target)**
  - Soft kill: EW assets interfere with swarm communications.
  - Hard kill: Lasers, high-power microwaves, directed energy (DE) weapons, dense-array artillery, and multi-barrel rapid-fire guns launch saturation strikes on the swarm.
  - Camouflage: Smokescreens confuse UAV sensors. False targets with similar infrared and radar reflection characteristics are used as diversions.[77]

See Figure 6 for a translation of a graphic found in the journal article illustrating the tactics, methods, and timeline proposed for anti–drone swarm warfare.

Figure 6. Proposed diagram illustrating the counter-drone combat process



Source: Xie Weipeng, Wu Tong, and Qi Tongshuai, "Analysis on the Application of Tactics and Methods in Anti-UAV Swarm Warfare." Translation by CNA.

Writings from the last two years found in PRC technical journals show that the PLA and military research institutes are tracking the progress of the US and other countries' research on counter–UAV swarm warfare.[78] For example, a November 2023 article by researchers at the North University of China's Intelligent Weapons Research Institute claims that the US, Russia, and Israel consider DE weapons to be the most important anti-UAV defense technology. The report further assesses that these countries consider high-power microwave weapons more suitable for anti–UAV swarm operations than high-energy lasers because of the wide damage range of microwave blasts, which allows the weapon to target multiple drones simultaneously.[79]

Other recent writings in PRC technical journals show that the PLAN is experimentally testing countermeasures for drone swarm attacks on naval warships. A February 2024 article by researchers at the PRC Naval University of Engineering and Naval Aviation University, for example, proposes and tests a model for calculating the effective strike distance of shipborne laser weapons targeting drones constructed of different materials under a range of visibility conditions. The article describes different mechanisms by which a laser can damage a UAV, including irradiating the drone's electro-optical reconnaissance sensors, burning the UAV's wings or fuselage, and igniting the drone's fuel tank, batteries, or onboard warhead. The article provides the results of computer simulation tests of the model.[80]

5. Conclusion

The PRC has been developing and testing uncrewed platforms since the 1960s but has largely lagged behind the world's leading military powers technologically in uncrewed systems, particularly in autonomous and semi-autonomous drone swarm research. An examination and analysis of PRC writings from 2019 through 2024 indicates an intent to accelerate and advance the PLA's development, testing, and use of uncrewed platforms, especially for drone swarm technology, in part because of the perceived threat from advancements in US drone capabilities. PRC writings suggest that the widespread use of drones in recent conflicts and the use of drones by Ukraine and Russia in the Russia-Ukraine war is drawing further PRC attention to drone warfare. PRC writings from the past four years demonstrate that the PLA is exploring the use of uncrewed platforms and testing drone swarm technology for use in a possible military takeover of Taiwan. In addition, the PRC is examining global militaries' development of drones and drone swarms to develop its own counter–drone swarm methods and technologies.

5.1 Implications for the joint force

As the PLA develops and advances its own autonomous drone swarm capabilities, the US joint force could be faced with a PLA force keenly aware of both the value and the advantage of drone swarm warfare. Some of the implications for the joint force include the following:

- PLA researchers are closely watching the development of US drone technology and examining US defense publications for identified weaknesses in drone development.
- PLA researchers are aware of the increasing risk that drone swarms pose to PRC maritime forces.
- If the joint force acted to protect Taiwan in an attempted military takeover by the PRC, US and allied forces could face several advanced PLA uncrewed systems, including ISR, strike, and autonomous drone swarm platforms, in the Taiwan Strait.
- In a conflict scenario, the PLA could deploy drone swarms from land-, sea-, or air-based platforms for antiship and other naval combat missions, potentially diversifying and extending its current capabilities.

Figures

Abbreviations

AI	artificial intelligence
AVIC	Aviation Industry Corporation of China
C-UAS	counter–uncrewed aircraft system
C2	command and control
CCTV	China Central Television
CETC	China Electronic Technology Group Corporation
DE	directed energy
EW	electronic warfare
FYP	Five-Year Plan
ISR	intelligence, surveillance, and reconnaissance
MALE	medium-altitude long-endurance
NORINCO	China North Industries Group Corporation Limited
NPS	Naval Postgraduate School
NUDT	National University of Defense Technology
PLA	People's Liberation Army
PLAAF	PLA Air Force
PLAN	PLA Navy
PRC	People's Republic of China
SME	subject matter expert
SOF	special operations forces
UAV	uncrewed aerial vehicle
UCAV	uncrewed combat aerial vehicle
USN	US Navy
USV	uncrewed surface vehicle
UUV	uncrewed underwater vehicle
UxS	uncrewed systems

Notes

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