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Swarms over the Strait

Drone Warfare in a Future Fight to Defend Taiwan

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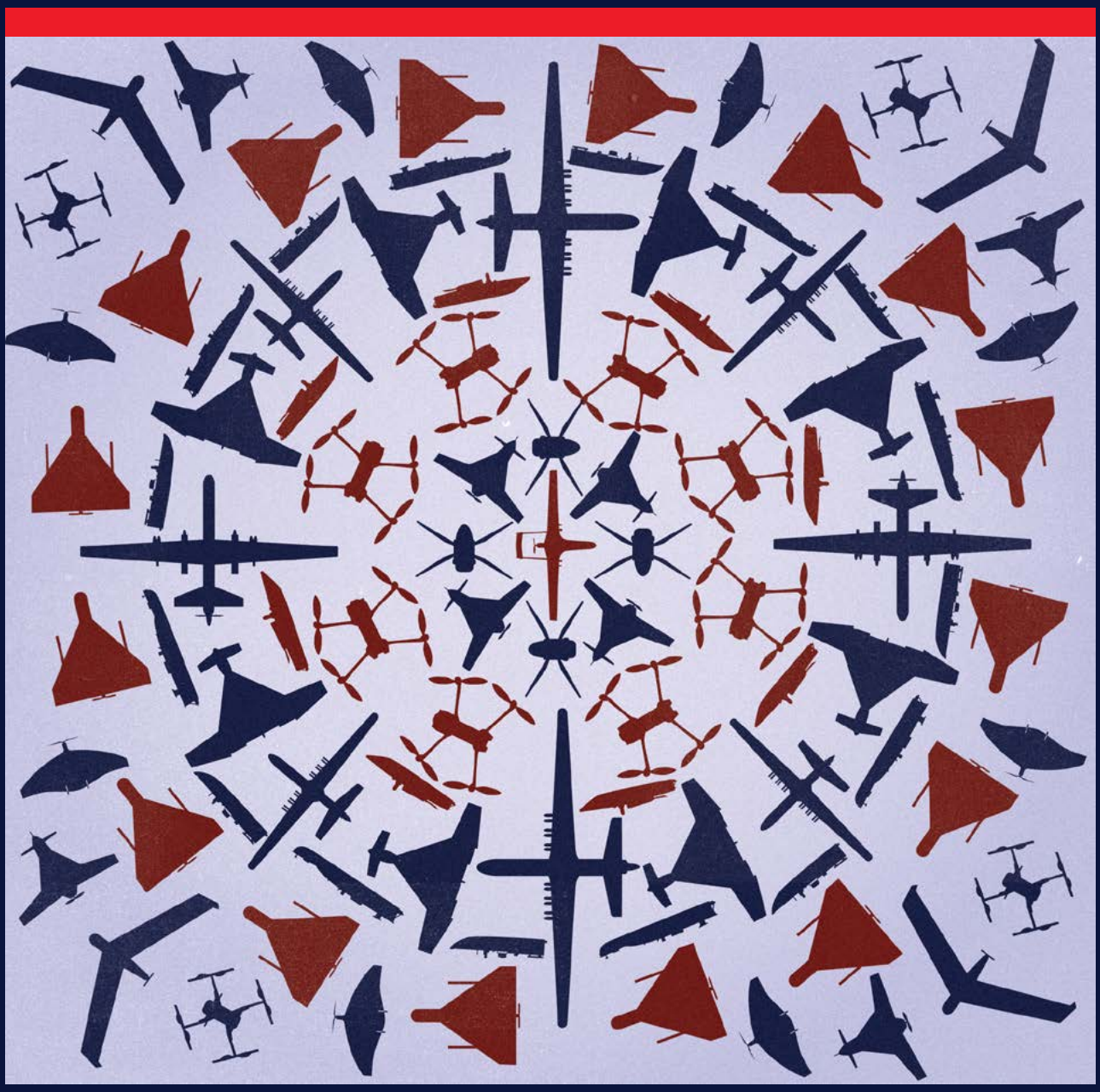

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Pettyjohn has authored or coauthored reports on a wide range of issues, including drones, defense strategy and budgets, nuclear deterrence and escalation management, readiness and responsiveness, the role of airpower in defeating the Islamic State of Iraq and Syria, gray zone competition with Russia, possible warfighting scenarios with North Korea, and command and control of multinational NATO amphibious forces. Additionally, she has crafted a large body of work on the United States' overseas posture, which explores the operational requirements, its vulnerability to attack, and the political access challenges that the United States faces.

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About the Defense Program

Over the past 15 years, CNAS has defined the future of U.S. defense strategy. Building on this legacy, the CNAS Defense Program team continues to develop high-level concepts and concrete recommendations to ensure U.S. military preeminence into the future and to reverse the erosion of U.S. military advantages vis-à-vis China and, to a lesser extent, Russia. Specific areas of study include concentrating on great-power competition, developing a force structure and innovative operational concepts adapted for this more challenging era, and making hard choices to effect necessary change.

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Executive Summary

Drones have transformed battlefields in Libya, Nagorno-Karabakh, and Ukraine, but in a companion report, *Evolution Not Revolution: Drone Warfare in Russia's 2022 Invasion of Ukraine*, Stacie Pettyjohn finds that today's drones have not yet revolutionized warfare and only present an evolution to existing ways of fighting. This report details the ways that drones have proliferated and impacted warfare in recent conflicts, with an eye toward their likely effect on a potential future American effort to defeat a Chinese invasion of Taiwan. The authors identify a range of ways that drones could be employed in this scenario to execute key missions for the United States, Taiwan, and China, and find that all parties could make extensive use of drones to rapidly close kill chains.

The United States is betting that it can out-innovate China and use drones to defeat a People's Liberation Army (PLA) invasion of Taiwan. Here, the United States should view Ukraine as a cautionary tale. Ukraine consistently has pioneered new approaches to drone warfare, but Russia has rapidly adapted and scaled drone production in a way that Ukraine cannot match. Technological and tactical innovations are necessary but not sufficient. Mass production of an affordable mix of drones is also needed to support a large and likely protracted conflict. The research found that the geography of the Indo-Pacific significantly disadvantages the United States, which needs drones with long range and considerable endurance that will inevitably cost more than the drones used in Ukraine, Nagorno-Karabakh, and Libya. Today, China is positioned to take advantage of its large fleet of drones, which could provide it with an edge in a war over Taiwan. The United States and Taiwan need to close this gap rapidly and develop a layered system of counterdrone defenses or risk being on the losing side of a war. Washington must also find a way to supply allies and partners, such as Taiwan, with military and commercial drones. And the Pentagon must consider how these diverse technologies enable new operational concepts and doctrine. Ultimately, the United States must recognize that while drones alone would not win a war against China to defend Taiwan, they have become a key part of the competition and the United States cannot afford to remain behind.

Recommendations: Preparing for the Pacing Scenario

The findings from this analysis yielded the following recommendations for the United States and Taiwan.

For the United States

The U.S. Department of Defense (DoD) needs to acquire more "good enough" longer-range drones for this fight in the Pacific. The DoD must develop and procure drones with the range to perform useful missions in this theater that can be purchased in sufficient quantities to make up for the many that will inevitably be lost in combat.

The United States needs a diverse fleet of aerial drones that includes a mix of higher-end and cheaper systems. In addition to acquiring "good enough" long-range drones for target acquisition and strike, the United States should have a smaller number of stealthy drones that can conduct surveillance in highly contested airspace and provide targeting information for standoff missile strikes. More sophisticated drones will also likely be needed as a part of the collaborative combat aircraft program.

The United States should invest in autonomous kamikaze drones for attacking ships. Affordable kamikaze drones with relatively simple autonomy could overwhelm the Chinese navy's air defenses and damage or destroy the invasion fleet.

The United States should consider pre-positioning short- and medium-range drones on Taiwan. Smaller drones face a time-distance problem and will be difficult to put in place once a war has begun. Doing so would require tying up in-demand transport assets, and deployment missions would be quite risky once the shooting begins. However, the operational benefit of such a sensitive decision must be carefully weighed against the geostrategic risk.

The DoD must develop and refine operational concepts and tactics for drone employment specific to U.S. challenges in a fight in the Indo-Pacific, such as those outlined in this report. This task includes considering how U.S. forces will get drones into the theater before a conflict or quickly after one begins, and how to team drones with crewed platforms. It also includes defensive counter-counterdrone measures to make "good enough" drones more survivable where possible. These concepts should include drone technology that the United States has today and what it is developing for the future.

The United States needs to invest in training drone pilots so they are skilled and can operate closely with crewed systems. Since most drones the United States develops would likely be remotely piloted or semiautonomous, the DoD needs to invest in training large numbers of drone pilots and implement a rigorous program to test and train them to operate alongside crewed platforms across all domains.

The U.S. Department of Defense urgently needs to invest in a range of counterdrone capabilities, including layered, high-capacity air defenses and electronic warfare systems. The U.S. military should prepare to counter large, diverse adversary drone fleets by investing in cheaper, proven technologies and higher-end future technologies that could defend against drone swarms. The DoD should explore efforts to repurpose existing technologies, such as the Vampire system created for Ukraine, and find gun- or cannon-based systems that can be fielded quickly and are much cheaper than missile interceptors.

The DoD and Congress, in partnership with U.S. industry, need to build both the commercial and military drone industrial base to scale production and create surge capacity. Although drones have proved not to be survivable, the United States can achieve some resiliency in its drone fleet by developing the capacity to rapidly reconstitute platforms lost in a conflict. This will require a more robust drone industrial base.

The United States should advocate for changes to the Missile Technology Control Regime (MTCR) and look at alternatives for stemming drone proliferation. It should continue to advocate for changes to the MTCR controls on Category I drones to ensure its allies have the types of drones needed for operations in the Indo-Pacific.

The DoD should work with Congress, the State Department, and the National Security Council to reform its export control and foreign military sales process so it can more quickly deliver capabilities to allies and partners. The United States must be able quickly to provide allies and partners with drone and counterdrone technologies in a timely and predictable manner.

The DoD and Congress should consider whether the United States and its allies and partners can leverage the drone industrial capabilities of allies. The United States and its allies and partners need to find trusted and affordable non-Chinese sources for military and commercial drones.

For Taiwan

Taiwan needs to foster its commercial and military drone industrial base. This effort should prioritize large numbers of kamikaze drones and other short- and medium-range aerial drones that do not require runways to operate, as well as drone boats and undersea drones.

Taiwan should arm its ground forces with first-person-view (FPV) kamikaze drones to provide additional cost-effective short-range precision fires. FPV drones could be used by Taiwanese defenders against PLA landing forces. Given their extremely low cost, Taiwan should build large numbers of these simple systems and invest in technologies that could provide autonomous terminal guidance for contested environments.

Taiwanese forces need to integrate short- and medium-range drones with their ground-based fires units and stockpile large amounts of artillery shells, mortars, rockets, and missiles. In Nagorno-Karabakh and Ukraine drones were most effective as a part of a ground-based fires complex and helped to turn unguided artillery into precision weapons. Taiwan should focus on building the capabilities for these drone-fires reconnaissance-strike complexes.

Taiwan should develop battle management software to integrate drones with ground-based fires units. To rapidly close kill chains, drones need to be linked to artillery units. Taiwan should develop map-based software that will accelerate information sharing to, in turn, accelerate targeting timelines and enable highly responsive fires against emergent targets.

The Taiwanese air force and army should develop operational concepts and tactics and focus on integrating and sharing information between drones and fires units and with allies. In addition to developing battle networks that enhance Taiwanese forces' situational awareness, Taiwan and the United States should explore ways for Taiwan to share targeting information with the United States and multinational partners while under attack. This enhanced air-to-ground coordination would be necessary to mount an effective defense against an invasion.

Taiwan should acquire kamikaze drone boats and underwater drones to bolster its defenses. Ukrainian forces have successfully denied the Russian navy control over parts of the Black Sea through a combination of kamikaze drone boats and antiship missiles. Taiwan should use the same combination of capabilities along with underwater drones to prevent Chinese ships from reaching the shore.

Taiwanese forces need to begin training on commercial, military, and especially FPV drones. It takes time to learn how to effectively operate drones and integrate them into operations with other types of forces. Taiwan needs to establish a robust training pipeline for its drone operators of all types so that it has a large, skilled cadre of operators.

The Taiwanese military needs to invest in a robust system of counterdrone capabilities, including layered, high-capacity, mobile air defenses, and electronic warfare systems. In addition to long-range air defenses, Taiwan needs to bolster its short-range air defense system significantly.

INTRODUCTION

On battlefields in Libya, Nagorno-Karabakh, and Ukraine, combatants have used uncrewed aerial vehicles (UAVs), or drones, to great effect, leading some analysts to conclude that they are fundamentally changing the character of war.[1] In Libya, a 2019 offensive by General Khalifa Haftar's Libyan National Army (LNA) was supported by Chinese-made drones, leaving the United Nations–backed Government of National Accord (GNA) clinging to power in Tripoli. Then, in late 2019, Turkey provided the GNA with Bayraktar TB2 medium-altitude drones and air defenses, enabling GNA forces to control the skies over Tripoli and repel the LNA attack. Similarly, in the lopsided 2020 war over Nagorno-Karabakh, Azerbaijan's fleet of Turkish TB2s and Israeli drones destroyed Armenian air defenses and precisely attacked rear echelon forces. Observers hailed drones as the pivotal capability responsible for Azerbaijan's decisive victory.[2] Now, in the ongoing Ukraine war that began in 2022, drones are playing an unprecedented role. Both Russia and Ukraine have extensively employed military-grade as well as commercial drones for surveillance, artillery fire targeting, and strike missions. Additionally, Ukrainian and Russian forces have made extensive use of kamikaze drones to conduct battlefield precision strikes and attack enemy targets deep behind the front lines.[3] Many now see drones as a key capability for achieving victory—or at least avoiding defeat.

In Ukraine, small drones are making it difficult to mass forces or conduct offensive operations, but their effects remain localized, and most drones remain piloted by humans who control and coordinate their actions.

These recent conflicts have led to a range of conclusions about the future of warfare. Technology enthusiasts maintain that drones are fundamentally changing the character of war. They argue that drones allow actors to field a relatively cheap air force that is disposable yet able to deliver firepower through mass and resiliency.[4] There are also hotly contested claims about drones rendering tanks obsolete or replacing existing weapons such as artillery.[5] Another camp holds that drones are an evolutionary improvement to existing technology. These skeptics argue that air defenses can easily counter drones, which means that uncrewed aircraft are only valuable for countering terrorists and nonstate actors, but not effective against nations with modern militaries.[6] According to Antonio Calcara and his coauthors, the purported revolutionary effects of drones are "at least premature and probably exaggerated."[7]

In between these two extremes, there is a third camp that argues that drones have been most effective when used with other capabilities, such as artillery, to rapidly close kill chains.[8] Military forces undertake a series of actions, called kill chains, which consist of collecting information on the environment, deciding what to do, and then acting.[9] Typically, kill chains refer to a targeting cycle, which involves finding potential targets, confirming the target, precisely locating it, engaging it with a weapon, and then assessing whether the attack had the desired effect.[10] Armed drones can perform every step in the kill chain themselves, but unarmed drones—that perform the front-end tasks in the kill chain (find, fix, track, and target) and then share this information with artillery units or other drones that fire on or engage the target—have had the biggest impact on the battlefield. In Ukraine, drones allow defenders to quickly detect an attacking force and concentrate fires on it, thereby making offensive maneuvers prohibitively costly.[11] These drone debates, however, have not been extensively scrutinized or systematically examined across a range of cases.

The authors conclude that the tempered drone optimists are correct. Drones—particularly when they are paired with other systems—are transforming the battlefield, but this is an evolutionary rather than a revolutionary change. In Ukraine, small drones are making it difficult to mass forces or conduct offensive operations, but their effects remain localized, and most drones remain piloted by humans who control and coordinate their actions. Drones are not substitutes for crewed aircraft, artillery, or missiles, but rather complements to existing weapons. As drones more broadly share real-time information, become more autonomous, and shape doctrine and organizational structures, they may revolutionize warfare, but that day is yet to come.

This report explores the impact drones could have on strategic competition and a high-end conflict with China, and what drones could mean for future warfare. The 2018 *National Defense Strategy* (NDS) shifted the focus of the U.S. Department of Defense (DoD) from counterterrorism operations in the Middle East to great power competition with China and Russia. It identified China as the priority challenge, tasking the DoD with developing the capabilities and concepts required to stop a Chinese fait accompl*i* attack. The 2022 NDS confirmed that focus,

noting that the United States is engaged in a strategic competition with China and identifying Beijing as the Defense Department's "pacing challenge."[12]

Drones already play a role in peacetime competition with China today. In peacetime, China has used gray zone tactics involving drones to harass and intimidate other nations in an attempt to expand control over international waters and disputed features in East Asia.[13] Long loiter times and ranges allow Chinese drones to frequently patrol the skies over the East and South China Seas and, increasingly, near Taiwan.[14] The United States has deployed its large military drones to the Indo-Pacific, establishing an Air Force intelligence, surveillance, and reconnaissance (ISR) drone squadron in Japan and a Marine Corps drone squadron in Hawaii.[15] China and the United States also compete globally, as each seeks to expand its influence over third parties, often through military sales.[16] Drones have become a hot item in the international arms marketplace and an increasingly important diplomatic tool.[17] The United States has been limited in its ability to use drone diplomacy because of its adherence to a Cold War–era arms control agreement, the Missile Technology Control Regime (MTCR). In contrast, China and Turkey, which are not party to the MTCR, have become leading exporters of armed military drones, while Chinese companies simultaneously dominate the commercial drone market.[18]

Drones would also impact the outcome of a potential future war between the United States and China. Many believe that drones may help the United States and Taiwan to deter and, if necessary, defeat China in a war.[19] A 2020 RAND Corporation report concludes that hundreds of networked, low-cost drones could guide American long-range antiship missiles toward a Chinese invasion fleet and would be a key capability needed to defeat China and successfully defend Taiwan.[20] Similarly, proponents of air denial strategy argue that using "sufficiently large numbers of smaller, cheaper weapons," including ground-based air defenses and drone swarms, "in a distributed way" would prevent China from gaining air superiority.[21] Others have focused on the potential for drones to offer the U.S. military affordable mass and thereby offset the quantitative advantage of the Chinese military.[22] For instance, in August 2023, Deputy Secretary of Defense Kathleen Hicks announced the replicator initiative, which seeks to produce thousands of "attritable autonomous systems" in less than two years.[23] Replicator aims to apply lessons from Ukraine to the Indo-Pacific theater—mainly, that thousands of cheap drones can help a determined defender mount an effective resistance against a larger aggressor.[24] Taiwan also is trying to emulate Ukrainian success by manufacturing thousands of drones as a part of its defensive strategy by mid-2024.[25]

These initiatives beg several questions: Have the United States and its Indo-Pacific partners learned the right lessons from recent conflicts, including Ukraine? Will the types of drones used in Ukraine and other wars play important roles in a potential U.S.-China war? What roles and missions have drones performed in recent wars, and which tactics have been the most effective? Would these approaches also be useful in a war over Taiwan? Could drones provide the United States and its allies and partners an edge over China and enable a successful defense of Taiwan?

To answer these questions and further explore the roles drones are playing in the competition between the United States and China, the authors took a mixed methods approach. The authors developed a novel dataset of instances of pursuit and actual transfers of military drones between January 1995 and September 2023 and used this dataset to identify trends in drone diplomacy and drone proliferation over the last almost 30 years. Second, the authors conducted three case studies of recent wars in which drones played a significant role: the 2019–2020 battle for Tripoli in the Libyan civil war, the 2020 Nagorno-Karabakh War, and the ongoing war in Ukraine, from February 2022–September 2023.[26] From this historical analysis, the authors identified types of drones employed in recent conflicts and considered their effectiveness in different missions and at different parts of various kill chains. Third, to consider the role of drones in a war between the United States and China over Taiwan, the authors conducted a tabletop exercise that sought to develop innovative operational concepts involving drones.

If China were to invade Taiwan today, Chinese forces are better positioned to leverage drones than the United States or Taiwan.

The authors conclude that if China were to invade Taiwan today, Chinese forces are better positioned to leverage drones than the United States or Taiwan. China already has a large and diverse fleet of relatively inexpensive drones that it could employ to find and attack U.S. and Taiwanese forces. This stands in contrast to American and Taiwanese forces, who do not have large inventories of drones or the right mix of drones to successfully defeat a Chinese invasion. The geography of the

Indo-Pacific and the distances American forces would need to operate from would put the United States at a disadvantage in a Taiwan scenario. The United States must rapidly acquire longer-range drones with more endurance to close this gap, while developing a layered system of defenses to counter Chinese drones. Taiwan also needs to improve its air defenses and to acquire more short- and medium-range drones across different domains. At the same time, Washington and Taipei need to develop more sophisticated and autonomous drones for the future.

The remainder of this report is divided into four chapters. The first chapter lays out a typology of drones. The second examines how drones have proliferated globally and how the cast of characters has changed along with the drones themselves. Chapter 3 explores how drones have been used in recent conflicts in Libya, Nagorno-Karabakh, and Ukraine and concludes with comparative conclusions from these three case studies. The fourth chapter examines the roles that drones could play in a future war over Taiwan between China and the United States, presenting notional drone and counter-drone operational concepts for each nation's military. The report concludes with overall findings and recommendations to U.S. and Taiwanese policymakers. The appendix provides more details about the drone pursuit and transfer dataset.

CHAPTER 1

A Typology for Today's Drones

There is no widely accepted way to classify drones. Some methods differentiate between armed or unarmed drones, but as the war in Ukraine has shown, almost any drone can be modified to become an offensive weapon. Kelley Sayler, an expert in advanced defense technologies, focused on two other factors: how accessible a drone is and its level of technological sophistication and infrastructural requirements. This schema resulted in four types of drones: hobbyist, midsize military and commercial, large military-specific, and stealth combat drones.[27] There is an inverse relationship between these two factors, with hobbyist drones being highly accessible and relatively low tech, while stealthy combat drones are difficult to obtain and require very sophisticated military technologies.

The DoD divides uncrewed UAVs into five groups that differ by weight, operating altitude, and speed.[28] Groups one and two consist of small drones weighing less than 55 pounds and flying below 3,500 feet at relatively slow speeds. Group three is an expansive middle group of "tactical" drones ranging from 55 pounds to 1,320 pounds and flying at medium altitudes, while groups four and five are drones that weigh more than 1,320 pounds and fly at medium to high altitudes at any airspeed.[29] Both the Sayler and DoD typologies identify important and fundamental factors about the airframe's capabilities, weight, range, and endurance, which directly correlate with cost. However, the DoD's framework is limited because it only focuses on military drones and excludes commercial off-the-shelf (COTS) or do-it-yourself (DIY) drones, which have played an important role, especially in Ukraine. Furthermore, both typologies overlook an increasingly significant attribute: whether a drone is intended to be reusable or is a one-way system.

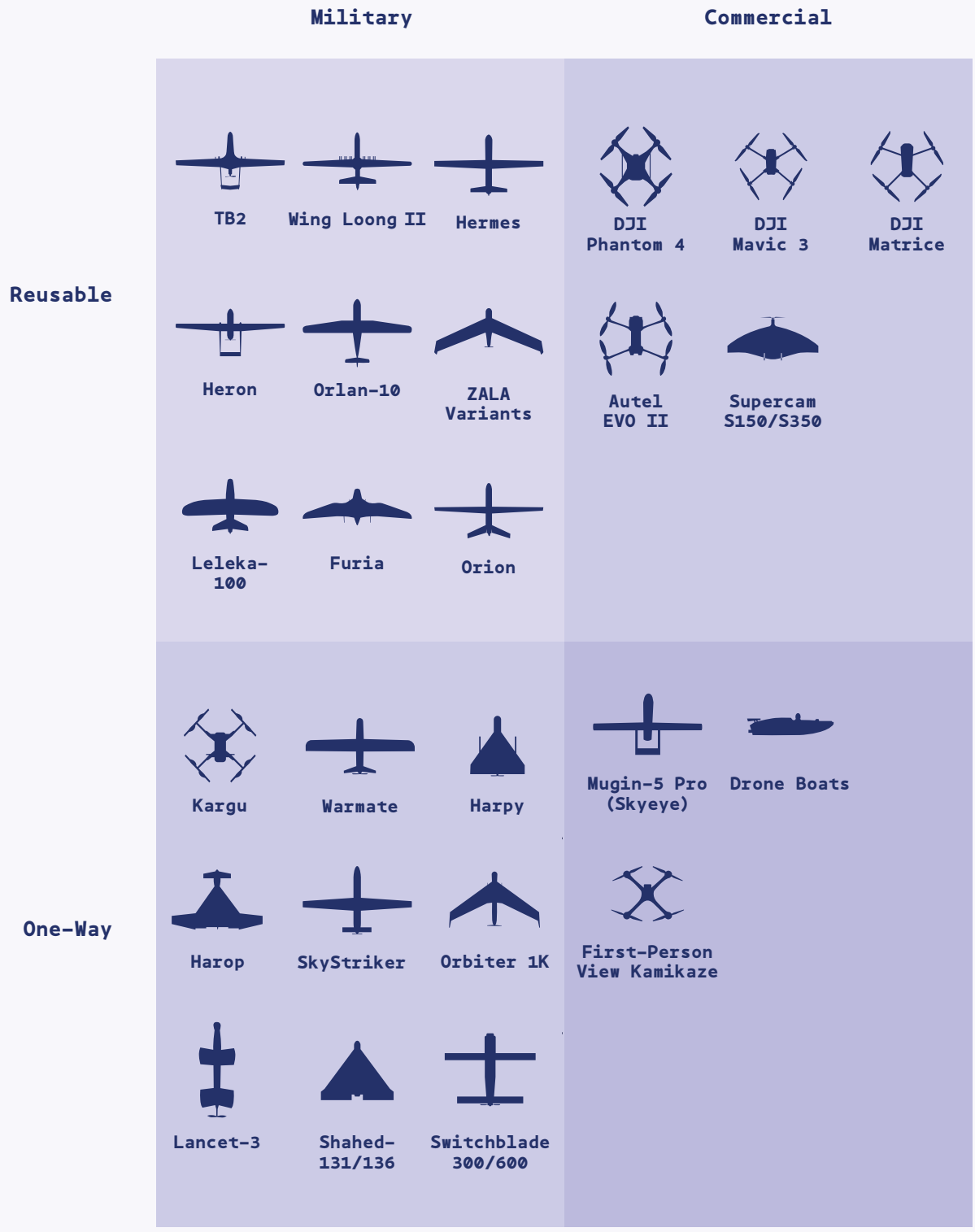
Based on key differences observed in the three case studies examined, this report classifies drones by two major attributes: whether they are built for commercial or military use and whether they are *intended* to be single-use or reusable systems.[30] These two variables and examples of different drones that fit into each category are displayed in Figure 1.

In the first attribute, the authors draw on Sayler, differentiating between drones built for the commercial market or do-it-yourself drones assembled entirely from commercial off-the-shelf parts and drones built specifically for military use. This distinction matters because commercially available or DIY drones made from commercial or dual-use subcomponents are widely available and quite affordable. These drones have GPS and high-definition cameras and are remotely operated with smartphones or controllers that stream real-time video feeds.[31] Most commercial drones are quadcopters used by the agricultural industry, by photographers, or for recreational racing. Because they are marketed to amateur users, they tend to be relatively easy to operate, although first-person-view (FPV) racing drones require additional skill. The downside of these systems is they tend to be small, with low endurance and comparatively small payload capacity, and must be modified to be armed or hardened against electronic attack. Common examples of reusable commercial drones used by Russian and Ukrainian troops in the ongoing Ukraine war include the Chinese DJI Mavic 3, DJI Matrice, and Autel EVO II quadcopters.

Commercially available or DIY drones made from commercial or dual-use subcomponents are widely available and quite affordable.

In contrast, military drones are built specifically for professional military personnel use in a combat setting. This means the systems tend to have additional features that harden them against attacks and equip them for offensive operations by either carrying weapons or being integrated into a broader battle network. Military drones may carry sophisticated payloads ranging from precision weapons to jammers. They also may be unarmed but have sensors to help them to accurately calculate the range to a target or to illuminate targets that can then be engaged by other weapons. Military drones require specialized training and include additional features to hide from or protect against interference or attack. For example, they may be resistant to jamming and cyberattacks and, in addition to cameras, have sensors that can pick up signals or electronic intelligence. In Libya, belligerents relied most heavily on the Chinese Chengdu Aircraft Industry Group (CAIG) Wing Loong and the Turkish Bayraktar TB2.[32] During the Nagorno-Karabakh War, Azerbaijan also used the TB2, as well as the Israeli Elbit Hermes and the Israeli Aerospace Industries (IAI) Heron military drones.[33] In the Ukraine war, Russia's most common military drones are the Special Technology Center Orlan-10 and ZALA Aero 421 variants, while the Ukrainians have the DEVIRO Leleka-100, Athlon Avia Furia, and Ukrspecsystems People's Drone-1 (PD-1). Russia and Ukraine have a smaller number of larger medium-altitude long-endurance (MALE) drones, including the Russian Forpost-R (the Russian variant of the IAI Searcher) and the Kronstadt Group Orion for the Russian forces, and TB2s for the Ukrainian forces.[34]

Figure 1 | Examples of Different Types of Drones



Stacie Pettyjohn, *Evolution Not Revolution: Drone Warfare in Russia's 2022 Invasion of Ukraine* (Washington, DC: Center for a New American Security, February 2024), 6, https://www.cnas.org/publications/reports/evolution-not-revolution.

The other key attribute is whether a drone is intended to fly multiple missions or is a single-use weapon more akin to a munition. The former is often a more expensive system because it is expected to return after completing a sortie and to fly again. Additionally, reusable drones tend to be configured for multiple different missions, most notably ISR and sometimes strike. In contrast, single-use drones tend to be cheaper systems primarily used for strikes. Single-use drones, also known as Kamikaze drones, take advantage of the fact that there is no human in the cockpit and therefore can use kinetic force as well as explosives to damage their targets. These drones are also called loitering munitions because they can search for targets after they have been launched. They are in many respects similar to cruise missiles, especially if they fly to preprogrammed coordinates. Many kamikaze drones are controlled by humans or may have autonomous systems that identify and engage targets even if the connection to the human operator is broken. A limited number of kamikaze drones were employed in the battle for Tripoli, although a report of a fully autonomous Kargu drew international attention.[35] In Nagorno-Karabakh, Azerbaijani forces used the IAI Harop and the Elbit SkyStriker, often in conjunction with military drones, to strike enemy air defenses and vehicles.[36] In the Ukraine war, both Russia and Ukraine have made extensive use of kamikaze drones, including military-grade systems and commercial FPV drones. Only Ukraine has developed and employed kamikaze maritime drone boats.[37]

Over the three conflicts examined, military drones have been used extensively, but commercial drones and kamikaze drones have seen increased use over time. Subsequent chapters on three case studies discuss how the availability and use of certain drones have evolved and what this may mean for future competition and conflict. The next chapter examines the proliferation of military drones and considers the implications of drone diplomacy for the competition with China.

CHAPTER 2

Proliferation and the Global Drone Landscape

It is well established that drones have proliferated across the globe.[38] Many countries desire the prestige and reduction of risk to operators that military drones provide. Additionally, drones' affordability and ease of operation compared with crewed aircraft make military drones relatively accessible to a wide range of actors. Recent wars with large-scale use of commercial and military drones have boosted sales and increased interest, as first-person-view videos of drone strikes flood social media feeds. Drones play a geopolitical role as well, as exporting nations use arms transfers to expand their influence and weaken rivals. The arrival of new producers has created supply shocks in the international drone market, first with China in 2010 and more recently with Turkey in 2018. Like the body of suppliers, the types of military drones being supplied have evolved. Historically, countries largely acquired unarmed drones for intelligence, surveillance, and reconnaissance (ISR) missions. Today, more countries are acquiring armed military and kamikaze drones through both international trade and indigenous production. In particular, both the United States and China have large and sophisticated military drone programs and plans. Given current trends in the availability of drones, it is fair to expect that most actors—state or nonstate—will employ a variety of military and commercial drones in the future.

To better understand these trends, the authors created a unique dataset, building on a dataset created by Michael Horowitz, Joshua Schwartz, and Matthew Fuhrmann.[39] Where the Horowitz et al. dataset focuses exclusively on armed drone sales, the Center for a New American Security (CNAS) dataset includes all transfers of military drones, including unarmed drones, armed drones, and kamikaze drones (i.e., loitering munitions), regardless of size and capability.[40] This new dataset captures "drone transfers"—which include foreign military sales, direct commercial sales, leases, gifts, and secondary proliferation—from all countries between 1995 and September 1, 2023. The dataset also documents what the authors called "drone pursuit," which includes instances of solicitation to purchase drones, rejected sales, and canceled sales. The dataset includes all documented transfers and instances of pursuit, but it is important to note that transfers are not always publicly disclosed, and transactions by some countries skirt international arms tracking efforts. Additionally, this dataset excludes the millions of commercial off-the-shelf drones purchased, which users can convert into intelligence assets and deadly weapons.[41] Thus, this novel dataset presents a record of attempted and successful international transfers of military armed and unarmed drones over 28 years.

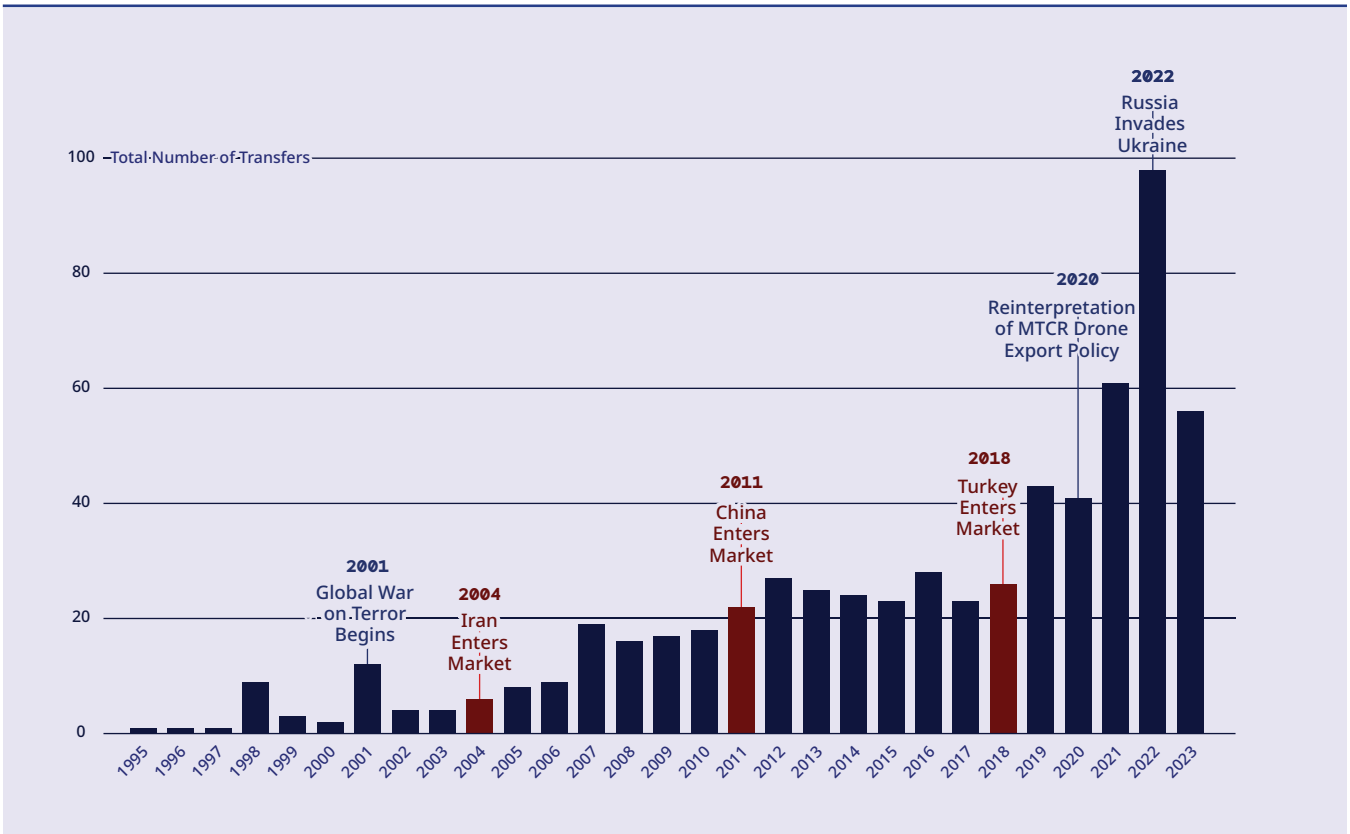
Military conflict has been a significant driver of global drone proliferation. The 9/11 terror attacks and the beginning of the Global War on Terror triggered the first phase of proliferation. In this era, drones became the preferred weapon of the United States for hunting terrorists and managing irregular threats. In 2002, only eight drone transfers occurred globally; in 2015, there were 32—a 300 percent increase. However, the number of states with drones, especially armed drones, remained low. This was because the United States, one of the few producers of armed drones at the time, leased and sold military drones to the same small group of allied nations, such as Australia, the United Kingdom, and Italy, that had deployed forces to Iraq and Afghanistan.

Since 2007, the United States has completed the sale of armed reusable drones only to four countries: the United Kingdom, Spain, France, and the Netherlands.[42] This is because U.S. military drone exports are regulated by the Missile Technology Control Regime (MTCR). Established in 1987, the MTCR is a multinational supply-side effort aimed at controlling the proliferation of missiles, rockets, and drones capable of delivering weapons of mass destruction, namely chemical, biological, and nuclear weapons.[43] Unlike other arms control regimes, the MTCR is not a legal treaty, but a voluntary, politically binding agreement among partner nations to self-regulate exports of sensitive systems and technology. The MTCR lists missile-relevant transfers in two categories. Category I items include rocket and drone systems "capable of delivering a payload of at least 500 kg to a range of at least 300 km." These weapons and their major subsystems and related technology are "subject to a strong presumption of denial," and transfers of production facilities for Category I items are explicitly prohibited. Category II items refer to missile-related components and technology, drones with smaller payload capacities, and dual-use equipment, and their sales are evaluated case-by-case.[44] These restrictions limit the transfer of both armed and unarmed models of MALE and high-altitude long-endurance (HALE) drones and their technology, such as the MQ-1 Predator, MQ-9 Reaper, and RQ-4 Global Hawk.[45]

Due to the presumption of denial for all potential drone sales under Category I, it is difficult for any nation to purchase high-end military drones from the United States.[46] Critics of the MTCR argue that the classification of military drones under Category I weakens the military and diplomatic position of the United States and has failed to curb drone proliferation.[47] Unable to purchase American drones, some states have developed indigenous military drone programs, and a few have

Figure 2 | Military Drone Transfers over Time, 1995–2023

There has been a steady increase in military drone transfers since their emergence in the mid-1990s. The rise of new sellers such as China and Turkey, coupled with the prominent role drones have played in recent conflicts, has led to a rapid increase in drone proliferation in recent years, despite supply-chain disruptions caused by the COVID-19 pandemic. For more on the dataset, see the appendix. This figure includes pending and completed transfers. For pending transfers, the date of agreement was used; for completed transfers, the date of first delivery (when available) or year of identification or completion. There are four additional transfers excluded from this graph due to the year of transfer being unknown. Additionally, year of market entry is determined based on the year of first foreign sale.



Molly Campbell, CNAS Drone Proliferation Dataset, Version 1 (Center for a New American Security, 2024, publication forthcoming).

become exporters themselves.[48] Turkey provides the leading example of how American export restrictions have driven indigenous drone development. Between 2007 and 2012, Turkey made numerous requests to purchase American armed drones, namely the General Atomics (GA) MQ-1 Predator.[49] The drawn-out acquisition process and ultimate denial of purchase pushed Turkey to pursue military self-sufficiency. Speaking at an American think tank in 2016, then-Turkish undersecretary for defence industries İsmail Demir quipped that he "would like to thank" the U.S. government for not approving Turkish projects, "because it forced us to develop our own systems."[50]

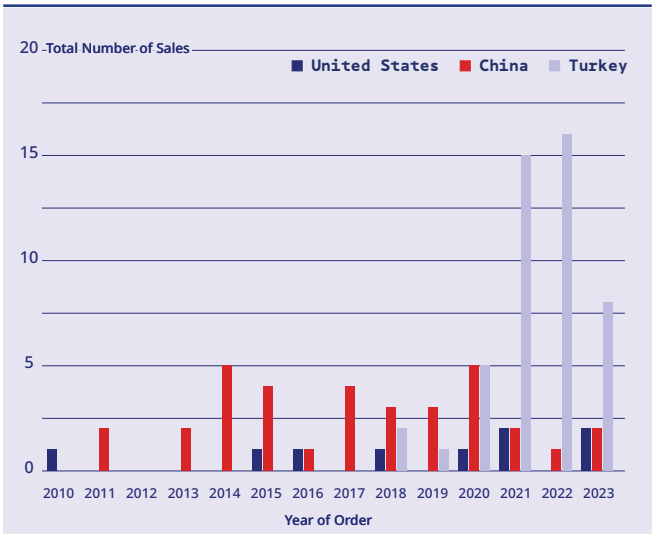
Not all countries pursue indigenous drone production when turned away by Washington; some turn to China. China debuted its military drones internationally in 2011, and firms began signing export agreements that same year, though China had already made its market entry in 2010, with the sale of unarmed ASN-209 drones to Egypt.[51] The impact on the global drone market was almost immediate, given the low price of China Aerospace Science and Technology Corporation (CASC) CH-3, CH-4, and CAIG Wing Loong I and II drones, and Beijing's nonadherence to the MTCR.[52] China's willingness to sell to almost anyone with no strings attached led to a spike in armed drone proliferation. From 2011 to 2019, China sold armed drones to 17 countries.[53] The so-called China Shock reached its height in 2014 with seven total sales, five of which were armed drones. These new drone users included active conflict zones such as Ethiopia, Sudan, and the Democratic Republic of the Congo, and unstable regimes such as Myanmar.[54] Even without the MTCR, it is unlikely the United States would sell lethal military drones to such nations. In that sense, the United States is not in direct competition with China over drone sales.[55]

Sometimes, however, even close American partners become frustrated with Washington's reluctance to sell armed drones and end up purchasing Chinese drones for lack of other options. Jordan is frequently cited as an example of U.S. export policy failure. In 2014, the United States denied Jordan's request for unarmed Predator XP drones.[56] In a letter to President Barack Obama urging approval for the sale, then–U.S. representative Duncan Hunter (R-CA), claimed that the administration's decision was pushing Jordan, a major non-NATO ally, to buy armed drones from China. Hunter argued that the decision opened a new market "for China to export its technology" and that "any incorporation of Chinese assets will directly harm U.S. interoperability."[57] Jordan subsequently purchased six Chinese-armed CH-4Bs in 2015.[58]

Between 2018 and September 2023, Turkey, with its highly sought-after TB2 armed drone, has rapidly eclipsed China in military drone transfers (see Figure 3). In 2022, after only four years of exporting military drones, Turkey shattered China annual sale record with 18 total sales. Since 2018, China, Turkey, and the United States have made a combined total of 69 sales of armed military drones to 40 different nations. Turkey made 65 percent of the sales, and China accounted for another 26 percent, while the United States only provided 8 percent.[59] Priced around $5 million, TB2s are more expensive than the $1 million to $4 million per-model Wing Loong I or CH-4, but are significantly cheaper than the $32 million GA MQ-9 Reaper.[60] Perhaps unsurprisingly, users of Chinese drones have found that they got what they paid for. High crash rates and persistent maintenance issues have prompted some countries, such as Iraq, to pursue alternatives to the unreliable Chinese drones.[61] The TB2, in contrast, is widely considered "good enough" for operations against terrorists or insurgents—not quite the quality of U.S. and Israeli systems, but better than comparable Chinese models.[62] Geopolitically, NATO membership makes Turkish drones even more attractive to European buyers and others unable to purchase from the United States but wary of purchasing from China. Baykar, the TB2's manufacturer, also has a quick turnaround; most orders are placed and fulfilled within a year. In contrast, Chinese and American suppliers frequently take three to five years to complete an order. In one example, South Korea ordered four Northrop Grumman RQ-4B Global Hawk drones from the United States in August 2014; the final plane was not delivered until October 2020.[63]

Figure 3 | Armed Drone Sales, 2010–2023

The entrance of China and subsequently Turkey into the military drone marketplace has dramatically increased the number of global armed drone transfers. Even after reinterpreting the Missile Technology Control Regime Category I in July 2020, the United States has rarely exported its armed military drones. For more on the dataset, see the appendix.

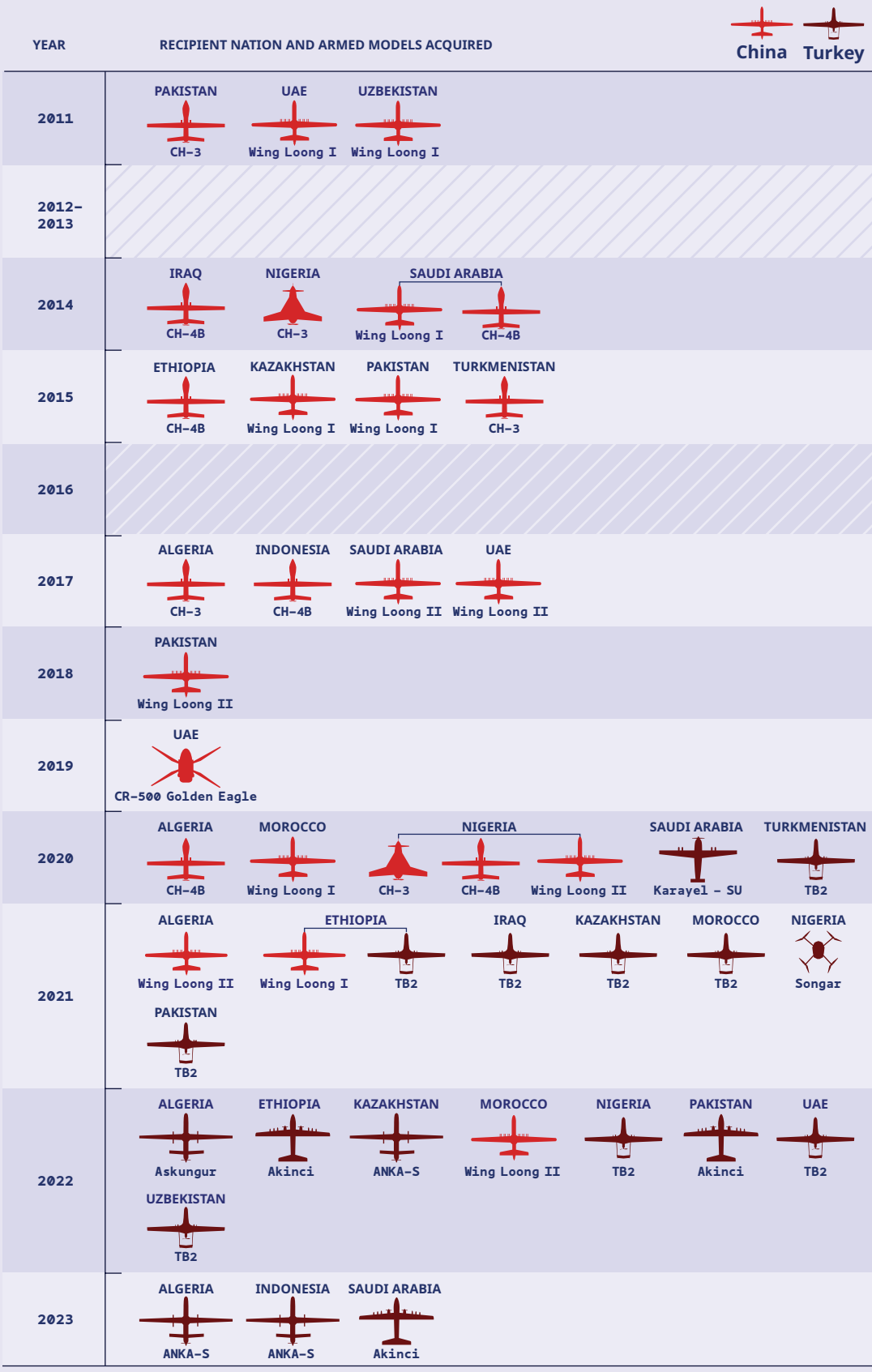


Molly Campbell, CNAS Drone Proliferation Dataset, Version 1 (Center for a New American Security, 2024, publication forthcoming).

In the last three years, at least 13 countries have expressed interest in purchasing armed drones from Turkey, including NATO allies such as Finland and Italy.[64] The TB2 gained international recognition after the drone's successful deployments in the Libyan civil war and the 2020 war between Azerbaijan and Armenia in Nagorno-Karabakh, which will be discussed at length in the following chapters. The perceived "battle-tested" capabilities of the TB2, combined with the shortcomings of Chinese drones, led dissatisfied buyers of Chinese military drones to turn to Turkey.

Therefore, Turkey has not only expanded the military drone market by bringing in first-time buyers, but it has also cut into China's market share. For example, Iraq ordered 20 armed CH-4B drones from China in 2014, to be delivered in 2016.[65] Within a year of delivery, eight aircraft crashed, and the remaining 12 were grounded from 2017 to 2022 due to their age and "contractual problems," though U.S. government sources cite delays in Chinese supply shipments.[66] The Stockholm International Peace Research Institute (SIPRI) reports that Iraq subsequently purchased eight TB2s in 2021.[67] Of the 21 nations that have purchased armed drones from China, nearly half went on to purchase Turkish armed drones (see Figure 4).

Figure 4 | Countries with Chinese and Turkish Armed Drones[68]

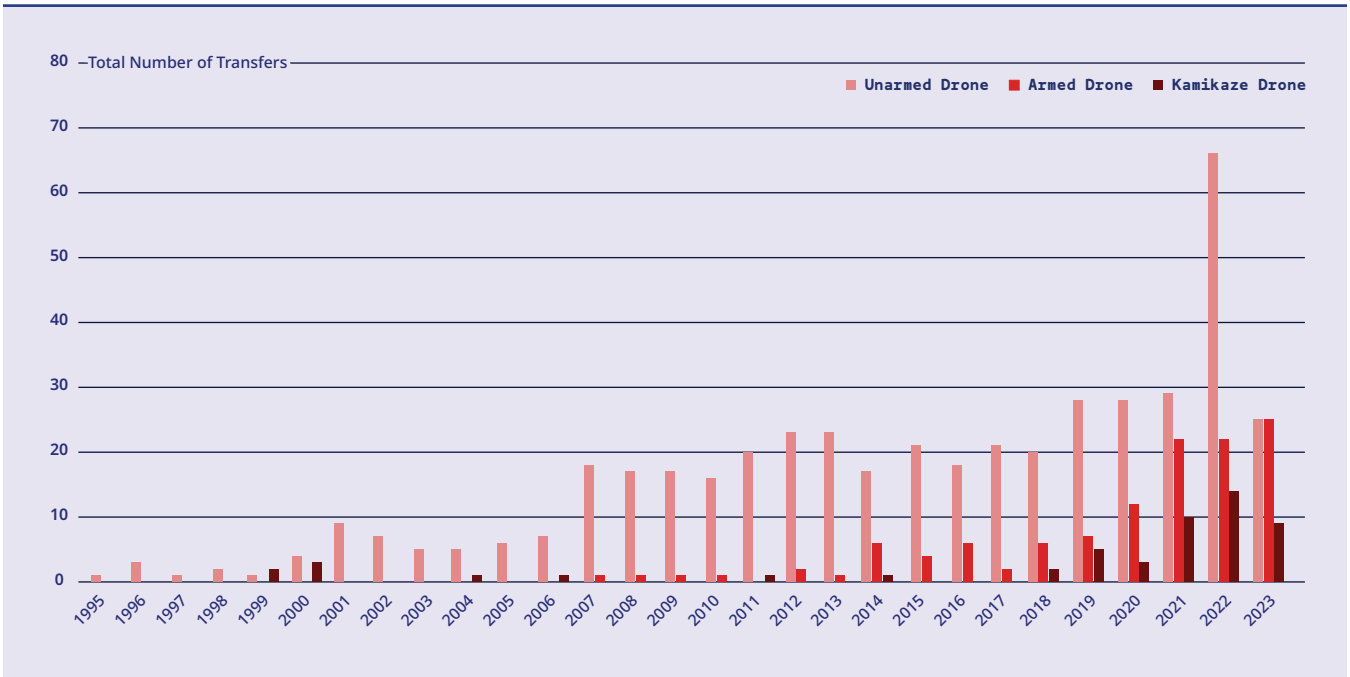


Overall, the author's analysis identified 633 drone transfers between 1995 and 2023; 112 of these transfers were to the Indo-Pacific region.[69] India, Australia, and Thailand led the region in total instances of drone acquisitions, while the United States and Israel were far and away the top suppliers.[70] However, in the case of armed drones, Indonesia and India led in acquisitions, and China and Israel were top suppliers.[71] Israel has provided a number of armed IAI Heron TPs to India—the only nation other than Germany to receive the sophisticated drone—as well as large quantities of Harpy, IAI Harop, and SkyStriker kamikaze drones. In contrast, the United States has only made one sale of armed drones to an Indo-Pacific nation. In June 2023, after nearly seven years of discussion, India finalized the purchase of 31 armed MQ-9B Predator drones from the United States for an estimated $3 billion.[72]

Notably, the armed drone sale to India was finalized after the United States shifted its export policy in 2020. The Trump administration reinterpreted MTCR categories, reclassifying drones with a maximum airspeed less than 500 miles per hour as Category II, thereby removing the "strong presumption of denial" on most potential drone sales. In a press release, the State Department said the policy change would "remove barriers to the global UAS market and avoid ceding export opportunities to competitors where such self-imposed restrictions are unwarranted."[73] Since this shift, there have been more U.S. exports of unarmed MALE drones to Indo-Pacific allies such as Japan and Taiwan. These transfers allow the United States to more actively wield drone transfers as a diplomatic tool. For example, while India already possessed both foreign and indigenously produced armed military drones, the agreement with Washington eased India's longtime reliance on Russian military aid and bolstered India's capabilities against its regional competitors Pakistan and China. Even with reforms to the MTCR, however, the long timelines and significant uncertainty associated with drone deals and foreign military sales generally undermine the ability of the United States to supply allies and partners with key capabilities. Furthermore, political or policy shifts in either the seeking or supplying nation may result in cancellation or protracted delivery. Such was the case in 2022, when the Australian Ministry of Defence suddenly pulled out of a $1.3 billion deal to purchase armed MQ-9B SkyGuardians, citing budget realignment toward personnel funding, after waiting seven years and spending $7.4 million.[74]

Figure 5 | Drone Transfers by Configuration, 1995–2023

While unarmed drones remain ubiquitous, an increase in transfers of armed drones and loitering munitions has driven global proliferation in recent years. Loitering munitions have seen greater interest since Azerbaijan's successful use of such weapons in the 2020 Nagorno-Karabakh War. There are two transfers of unarmed drones and two transfers of kamikaze drones excluded from this graph due to the year of transfer being unknown. For more on the proliferation dataset, see the appendix



Molly Campbell, CNAS Drone Proliferation Dataset, Version 1 (Center for a New American Security, 2024, publication forthcoming).

In Europe, the Russian invasion of Ukraine has made Ukraine a top recipient of U.S.-made military drones and is largely responsible for the massive increase in drone transfers in 2022. Before the February 2022 invasion, Ukraine had made only four documented drone purchases. Between February 2022 and September 2023, there were an estimated 32 transfers, including 13 from the United States. Notably, the United States and Poland have supplied large amounts of lethal WB Electronics Warmate and AeroVironment Switchblade loitering munitions to Ukrainian forces. While kamikaze drones such as the Israeli Harpy and Harop have existed since the mid-1990s, interest has increased since their successful use in Nagorno-Karabakh and Ukraine (see Figure 5). Iran is another top supplier of kamikaze drones and has exported large amounts of its Iran Aircraft Manufacturing Industrial Company (HESA) Ababil and Shahed systems to authoritarian regimes such as Russia and Tajikistan and to terrorist groups such as Hezbollah, the Houthis, and the Palestinian Islamic Jihad.[75]

In addition to supplying other nations, great powers have also grown and diversified their own drone arsenals. Since 2009, Russia has been building up its military drone fleet, especially military ISR drones, which are critical nodes in its ground-based fires complex.[76] As the war in Ukraine has progressed, Russia has further invested in its drone production and after a slow start has scaled military and kamikaze drone production. Likewise, China has developed a diverse fleet of aerial drones, drone boats, and uncrewed underwater vehicles (UUVs) over the past decade, with a focus on ISR and targeting roles. China has also invested in developing a variety of kamikaze drones. After purchasing Israeli-made Harpy kamikaze drones, Beijing indigenously developed a similar capability, named the ASN-301.[77] China also has the WS-43, which is a large kamikaze drone with a 485-pound warhead that can fly about 37 miles and loiter for 30 minutes.[78] On the other end of the spectrum, China has the man-portable tube-launched CH-901 kamikaze and at industry events has showcased a truck intended to launch swarms of small kamikaze drones.[79] Beijing has also dedicated intellectual resources to studying drones and incorporated them across its four military branches.[80] While many of the first drones of the People's Liberation Army (PLA) resembled U.S. MALE and HALE models, the PLA also is fielding advanced drones that are stealthy and jet powered. As it looks toward the future, China is exploring autonomous drones operating in swarms or teaming with crewed aircraft for air-to-air and air-to-ground missions.[81]

The United States has a large fleet of MALE and HALE drones that it acquired for counterterrorism operations as well as a range of tactical drones used by ground forces for ISR. While American drones have been relatively expensive and intended to be reused, the United States—learning from the war in Ukraine—plans to procure thousands of attritable drones by 2025.[82] Additionally, the U.S. Air Force and Navy are developing a collaborative combat aircraft (CCA)—a drone loyal wingman—to team with the next-generation crewed fighter, while the Marines are exploring drones and drone boats for ISR missions and the Army is building low-cost small drones for air-launched effects.[83] With its future drones, the Pentagon also aims to field systems with more autonomy in contrast to its current fleet of remotely piloted drones.

In the last 10 years, the commercial drone market exploded, with greater numbers of companies providing increasingly advanced and easy-to-operate drones at low prices.[84] Unlike with military drones, one country overwhelmingly dominates the commercial market. According to one estimate, Chinese companies, which receive significant government subsidies, produce more than 90 percent of the commercial drones available.[85] China cornered the market in 2013 when Da Jiang Innovations (DJI) released its first Phantom drone, a quadcopter with simple, quickly mastered controls that cost less than $1,000.[86] With the Phantom and then Mavic series of drones, which outperform most rivals, DJI has dominated the global and U.S. commercial drone market.[87] In December 2020, the U.S. Commerce Department added DJI to its entity list for enabling human rights violations in China, a claim that DJI denies.[88] Still, in 2021, DJI had a 76 percent share of the U.S. drone market while its closest competitor only had 4 percent, although Autel Robotics, another Chinese drone company, has recently gained popularity in the United States.[89]

Lessons Learned from Drone Proliferation

Over the last 30 years, there has been a steady diffusion of drone technology, with more states and nonstate actors acquiring uncrewed aircraft. The days of Israeli and American domination of the drone market are long gone. China, Russia, and Iran have developed cheap military drones, integrated them into their force structures and planning, and are willing to sell them to interested buyers. Consequently, the last decade has witnessed a tremendous surge in military drone sales. In 2022, the last full year that the authors had data on drone sales, six

new countries acquired military drones, all being armed Bayraktar TB2 drones from Turkey.[90] That same year, an additional eight nations had expressed an interest in acquiring military drone but had not yet signed a contract—a doubling in interest from 2021. Chinese drone sales peaked in 2014, and by 2021 Turkey had overtaken China as the largest supplier.[91] The good press that Turkish drones have received from battlefields in Libya, Nagorno-Karabakh, and Ukraine, along with Turkey's short timelines for delivery, has propelled Turkey to the top of the military drone market. While the larger, more expensive, and reusable military-grade drones ruled the market early on, the sale of military kamikaze drones has jumped recently and, given their utility in Ukraine, is likely to continue to grow.[92] The United States' self-restraint has given rise to competition from China and Turkey, limiting Washington's ability to shape drone proliferation and employ drone diplomacy, narrowing one avenue of U.S. influence.

Since 2013, the commercial drone market has also exploded, with increasingly more advanced and easier-to-operate quadcopters available for a few thousand dollars.[93] Not surprisingly, the potential military utility of commercial drones was quickly recognized. Commercial drones do not offer one-for-one alternatives to military drone capabilities, but they make aerial surveillance and strike exceedingly more accessible, as demonstrated on battlefields in Libya and most notably in Ukraine. Yet Chinese companies have cornered the commercial drone market, and few companies can match the performance and cost of Chinese drones due to the scale of their market share. Concerns about cybersecurity and espionage have not broken China's stranglehold on the market or limited the use of Chinese quadcopters on battlefields in Ukraine. But Chinese drones will not be an option for countries that might find themselves on the opposite side of a war with China, such as Taiwan, the United States, or Japan. If China were to get into a conflict, it would likely cut off commercial drone sales to its opponent and potentially hack into any Chinese commercial drones that an adversary already owns.

Chinese companies have cornered the commercial drone market, and few companies can match the performance and cost of Chinese drones due to the scale of their market share.

Because of military and commercial proliferation, drones are providing inexpensive ISR and precision strike capabilities to actors that previously could not afford them. For instance, nonstate actors such as the Islamic State of Iraq and Syria (ISIS) used commercial quadcopters to attack American and Iraqi troops, while the Houthis are employing long-range kamikaze drones to attack ships in the Red Sea.[94] Neither group could afford a traditional air force nor likely learn how to operate and maintain it, but they can afford drones. Cheap drones, military or commercial, have not leveled the battlefield but do present an asymmetric challenge with no easy or universal solution.

The United States and its allies and partners face the dual challenges of defending against the growing threat posed by drones and leveraging drones for their own operations. They are behind in both aspects of this competition. In recognition of the growing risk posed by small drones, the Pentagon in 2019 established the Joint Counter-small Unmanned Aircraft Systems Office (JCO) led by the Army, but it has been underresourced and has moved too slowly.[95] The threat has far outpaced the technological counters that the JCO is developing. Currently, the United States is overreliant on expensive air defense interceptors and needs to find more cost-effective layered defenses to deal with the full spectrum of drone threats.[96] The U.S. military also needs to devote more attention to integrating drones across the services and with allies and partners. For instance, U.S. Marine Corps regiments—units with more than 2,000 personnel—reportedly have only two drones each, both of which are older unarmed models.[97] In contrast, Russian and Ukrainian squads—units of around 10 people—have multiple commercial quadcopters and hundreds of FPV kamikaze drones each. Washington's adherence to the increasingly irrelevant MTCR has left many American allies and partners without drones, and the law should be revised. But the United States and its allies need to broaden their focus beyond MALE and HALE drones to include other types, especially kamikaze drones. As the United States seeks to counter the threat posed by drones and to incorporate them in their force structures, it should study the role of drones in recent wars in Libya, Nagorno-Karabakh, and Ukraine, which will be discussed in the following chapters.

CHAPTER 3

Historical Case Studies of Drone Use

This chapter consists of three brief historical case studies and a comparative analysis. The first case focuses on one battle in the Libyan civil war because this engagement saw concentrated drone activity uncharacteristic of the greater conflict. The second case focuses on the entirety of the Second Nagorno-Karabakh War, which was relatively short and characterized by drone use from beginning to end. The final case focuses on the Ukraine war from its start in February 2022 to September 2023, when the research for this report concluded. Each case study offers background on the conflict before discussing the military, commercial, and kamikaze drones used. These sections describe the missions for which actors employed various drone types, adaptations made by the users, and the efficacy of various systems and tactics. Each case concludes with findings. The final section in this chapter offers conclusions drawn from cross-case comparisons.

The Battle for Tripoli (April 2019–May 2020)

The battle for Tripoli was a major engagement in the ongoing Libyan civil war and the first instance in which both belligerents extensively employed military drones.[98] In this battle, the self-styled Libyan National Army, led by strongman and former General Khalifa Haftar, faced the UN–recognized Government of National Accord.[99] While the greater war has consisted of many local battles fought by smaller groups, the LNA and GNA have been the dominant factions, first clashing when the government was divided in 2014 and continuing to fight as recently as August 2023.[100] The battle can be divided into two phases. In the first, the LNA had the upper hand, due in large part to the GNA's inadequate air defenses and Emirati drones. In the second phase, the GNA recovered and prevailed with support from Turkey in the form of drones, mercenaries, and ground- and sea-based air defenses. While the factions primarily used only two military drone models and employed them as one would a crewed attack aircraft, their experience confirmed the value of drones as surveillance and strike platforms. Their use in this war also captured the imagination of many other states and nonstate actors who saw great promise in these relatively cheap capabilities.

Background: The Libyan Civil War before the Battle for Tripoli

Throughout the war, each side benefited from the support of international partners who routinely violated UN arms embargoes by providing weapons, including aircraft and drones. Some partners, such as Turkey and Russia, also sent mercenaries and provided financial, planning, logistics, and maintenance support, and some took active (although not admitted) roles as operators of the equipment they provided.[101] Where the LNA received support from Russia, Egypt, the United Arab Emirates, Saudi Arabia, and France, the GNA had support from Turkey, Qatar, and Italy.[102] Thus, the Libyan civil war was an intense proxy war where international actors fueled the fighting and determined its course.[103]

Drones played a limited role in the Libyan civil war before the 2019–2020 battle for Tripoli.[104] Between 2014 and 2019, the LNA, the GNA, and various Islamist extremist groups fought over political power, territory, and Libya's vast oil resources using artillery and mostly crewed air strikes for fire support. Both the GNA and the LNA inherited portions of Libya's antiquated, Gadhafi-era air force, but the LNA had received the preponderance of aircraft, and its fleet was bolstered by donations from Egypt and the United Arab Emirates.[105] Consequently, the LNA relied heavily on air strikes, conducting 1,262 between 2012 and May 20, 2018, as a part of its offensive operations, while the GNA executed only 54 air strikes, or 4 percent as many as the LNA, over the same period.[106] But both parties had trouble maintaining their aging fleets, replacing aircraft lost to attrition, and training maintainers and pilots, and consequently turned to international parties for additional airpower.[107] They hired mercenaries to fly their planes, sought spare parts from third parties, such as Russia, and asked outside powers to directly play a role in air operations.[108]

The LNA's strong stance against Islamist extremist groups earned it international support, notably in the form of airpower, providing an advantage over rival militias.[109] Emirati and Egyptian aircraft reportedly flew ISR sorties and conducted air strikes in support of Haftar's forces around Benghazi and the city of Derna.[110] Emirati-owned Chinese-made Wing Loongs were the first military drones used in the fighting around Benghazi in 2016, although their appearance caused some confusion as observers misidentified them as American MQ-9s, the primary large military drone Libyans had seen to date during U.S. counterterrorism operations.[111] The Emiratis had deployed three Wing Loong drones and six AT-802 Air Tractor crewed aircraft at the recently expanded al-Khadim air base. The Emiratis quickly began to rely on the Wing Loongs, which could fly farther than the Air Tractors.[112] According to Islamist militias in Benghazi in October 2016, the drones conducted 41 air strikes, three times as many as the 13 Air Tractor attacks in the city.[113] In 2017, international airpower helped reverse prior

LNA losses, and in 2018 the United Arab Emirates used Wing Loongs to help seize Derna.[114] These drones would feature even more prominently in operations as Haftar's forces turned their sights to the distant target of Tripoli.

The Battle for Tripoli Phase I (April–October 2019)

The battle for Tripoli began in April 2019, when the LNA launched a surprise bid for the capital city.[115] Despite the LNA having the element of surprise and approaching Tripoli from multiple axes, the GNA resistance dashed Haftar's hopes for a swift victory and stopped the LNA offensive in the suburbs.[116] As the battle quickly devolved into a war of attrition, the LNA sought to break the stalemate by leveraging its superior airpower.

During the first month, crewed aircraft flew the preponderance of sorties, but by May armed drones played a growing role as fighter jets were shot down or rendered inoperable due to inadequate maintenance.[117] Emirati-operated Wing Loong drones launched precision strikes against GNA forces, destroying vehicles, artillery, and weapons stores. Because the GNA only had antiquated antiaircraft artillery and man-portable air defense systems (MANPADS), its troops could not defend themselves against the high-flying drones.[118] Around the same time, Turkish arms, which consisted of Kirpi mine-resistant personnel carriers and four TB2 armed drones, had reached the GNA, giving its forces a boost.[119] Ankara did not publicly acknowledge its support, but the TB2s first were noticed when the GNA began launching nighttime bombing raids, which would have been difficult to do with its crewed jets.[120] This initial shipment of TB2s could only operate relatively close to the front lines because line-of-sight communications limited their range.[121] Nonetheless, with this firepower directed at LNA troops, the GNA was able to push out the LNA from it base in Gharyan. Yet overall, the effect of the Turkish arms in this phase was minimal because of the small numbers of drones provided, their restricted ranges, and their vulnerability to attack on the ground by the LNA.[122] Furthermore, the LNA had several Pantsir-S1 and Hawk surface-to-air missiles (SAMs) provided by the Emiratis, which shielded the LNA's forces from the GNA's TB2s.[123]

Even after the GNA received a second shipment of eight TB2s, the LNA continued to dominate the Libyan airspace with its Chinese drones, and its offensive gained further momentum in the fall of 2019 when the Wagner Group, a Russian private military force, arrived.[124] The United Arab Emirates reportedly paid the salaries of the Russian mercenaries who advised the LNA fighters and, aided by commercial and military drones, made the LNA's attacks more lethal and precise.[125] Wagner snipers picked off exposed GNA troops, while Wagner advisors selected targets for drone or artillery strikes and coordinated LNA movements, helping the Libyan forces perform complex maneuvers.[126] As a result, the GNA fighters' morale declined precipitously, and the LNA made steady gains, prompting another intervention by Ankara.[127]

The Battle for Tripoli Phase II (November 2019–October 2020)

In the fall of 2019, Ghassan Salame, the UN special representative for Libya, stated that Libya was "probably the largest drone war theater now in the world."[128] According to the UN, the LNA had conducted 850 drone strikes by January 2020, far outpacing the GNA's total of 250 crewed and uncrewed air strikes.[129] Drone strikes and Russian mercenaries had enabled the LNA to press its offensive and to make territorial gains against the GNA during the first six months of fighting. These trends reversed in the second phase of the battle for Tripoli.

The tides began shifting in the GNA's favor after it signed a formal military cooperation accord with Turkey in November 2019.[130] Turkey went from providing limited, unacknowledged support to the GNA to a full-throated public embrace that included the deployment of Turkish troops and forces. Turkey subsequently increased its support in the form of air defenses, drones, artillery, ammunition, warships, military advisors, and Syrian mercenaries.[131] Haftar's supporters also provided additional assistance to the LNA and as a result the fighting intensified in the new year.[132] In this fighting, Turkish air defenses gave the GNA air superiority over Tripoli and Misrata, enabling it to use drones to conduct precision strikes against LNA forces and bases and drive Haftar's demoralized and overstretched forces out of the capital.

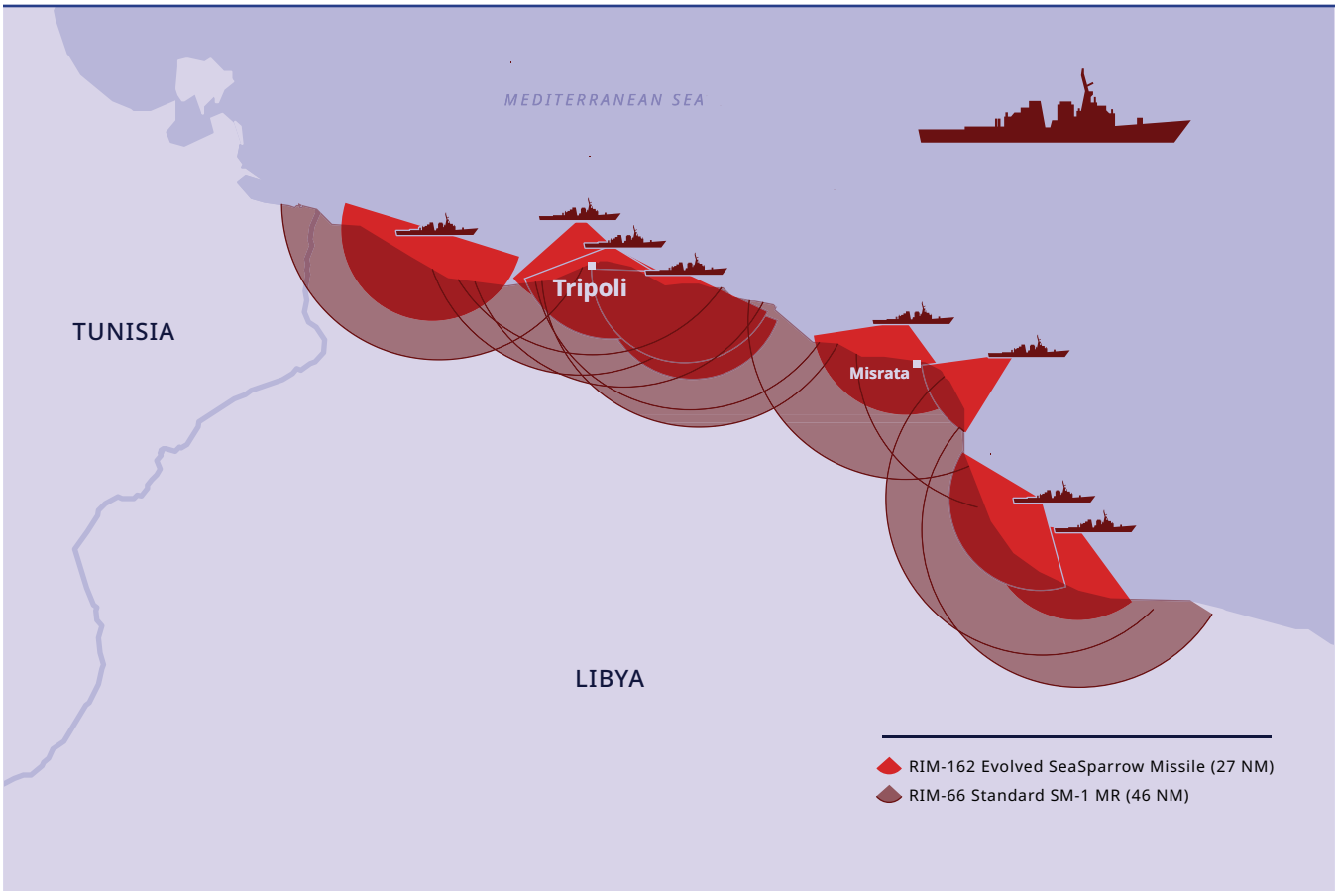
Ankara began fulfilling its commitment by sending Syrian mercenaries to bolster the GNA's ranks in December, but the delivery of large quantities of additional hardware was not possible until the new year, when Turkey devised a way to slip arms shipments by the watchful eyes of the LNA's Wing Loong drones.[133] In January 2020, a slowing of hostilities and a nominal 24-hour ceasefire provided a window for Turkey to deliver air defense systems, which would protect the GNA's ports and airfields from further LNA interdiction strikes. During this brief reprieve, the GNA received and quickly began operating its new air defenses, which made it possible for three additional ships to unload their cargo by March, significantly bolstering the

GNA's capability and capacity.[134] Yet it was the layered Turkish air defenses that made the biggest difference on the battlefield.[135] This robust system consisted of six Hawk medium-range surface-to-air missile batteries placed at the Mitiga and Misrata airports, 12 Korkut 35mm self-propelled antiaircraft guns, possibly Hisar short-range SAMs, Stinger MANPADS, and KORAL ground-based electronic warfare (EW) capabilities.[136] Four Turkish Gabya-class guided-missile frigates operating in the Mediterranean also provided early warning and extended the GNA's long-range air defense umbrella along the Libyan coast (see Figure 6).[137] As LNA aircraft losses around the Tripoli-Misrata area piled up, LNA fighter and attack aircraft, helicopter, and drone activity slowed over the region, largely stopping by January.[138] The LNA was left to rely on artillery and mortar fire to conduct strikes on the capital.[139] With the LNA set back on its heels, the GNA's Turkish drones went on the offensive.[140] Consequently, in February the United Arab Emirates relocated its Wing Loong drones to Uthman air base in Egypt to reduce their vulnerability.[141] Because of their very long ranges, the Wing Loongs could still conduct operations over Tripoli from the safety of Egyptian territory.

On March 27, the GNA began Operation Peace Storm, a counteroffensive conceived by Turkish advisors and resembling a recent Turkish military operation in Idlib, Syria.[142] At this point, the Turks reportedly took control of the targeting for the drones, sometimes cutting the GNA entirely out of decision-making, and systematically attacked LNA troops, artillery, and air defenses.[143] The infusion of tens of thousands of Syrian mercenaries supported by drone strikes and artillery powered the GNA's attack and overwhelmed the Sudanese and Chadian fighters who fought alongside the LNA.[144] Turkish frigates provided mobile air cover and even occasionally fired on LNA positions.[145] A Turkish E-7 surveillance aircraft collected signals intelligence and helped locate and target electronic attacks against any Emirati drones that ventured into the GNA's airspace.[146] On April 14, GNA

Figure 6 | GNA Sea-Based Air Defense around Tripoli

Turkish-supplied air defenses helped create a bubble around Tripoli that would eventually afford the Government of National Accord the advantage in air operations over the city.



Map adapted from the 2021 *Final Report of the Panel of Experts on Libya Established Pursuant to Security Council Resolution 1973 (2011)*, UN Report S/2021/229, United Nations Security Council, March 8, 2021, https://undocs.org/S/2019/229.

forces advanced toward Tunisia, capturing three towns west of Tripoli, and simultaneously made gains on a southeastern axis advancing toward Tarhuna.[147] Drones were used in advance of the ground attack to soften the LNA's defenses, while GNA air defenses shot down two Wing Loong drones and one helicopter.[148] Ultimately, this combination of air and ground capabilities enabled the GNA and Turks to break the siege of Tripoli.[149]

As the LNA's air defenses throughout the region were systematically eliminated and its fighters faced the constant threat of attack from GNA drones, the LNA troops' will to fight plummeted. Without additional support from their external benefactors, the LNA's already thin ranks dwindled and eventually all its troops pulled out from Tripoli and surrounding areas.[150] As they withdrew, GNA TB2s and Kargu kamikaze drones chased and attacked retreating LNA troops.[151] The air war ended when both parties signed a ceasefire in October 2020.[152]

Military Drones: The Wing Loong and the TB2

The battle for Tripoli pitted two large military drones against each other: the Wing Loong and the TB2.[153] LNA troops were supported by the Wing Loong I and II medium-altitude long-endurance drones manufactured by the Chengdu Aircraft Industry Group. The Wing Loongs operated from al-Jufra, al-Khadim, and Uthman air bases, which are relatively far from Tripoli, but because the drones are equipped with satellite communications, they could reach almost anywhere in Libya. A Wing Loong drone provided intelligence and strike capabilities and was capable of flying at night and carrying 10 to 12 Blue Arrow antitank air-to-surface weapons.[154] Typically, three Wing Loong drones operated at a time.[155] The LNA used them to target the GNA drone fleet on the ground and to strike GNA ground positions and supply and logistics nodes. In some cases, there were reports of the LNA using a "double tap" tactic in which it would conduct a first strike and then a second after initial responders came in.[156] The Wing Loongs also were effective as antivehicle and antipersonnel weapons. LNA troops were known to employ the Tripoli tactic—a maneuver in which they seized territory and then quickly retreated to draw GNA forces into an exposed area where they were bombarded from the air or by artillery fire.[157]

The GNA's airpower was primarily provided by the Bayraktar TB2, another armed MALE drone that was smaller than the Wing Loongs but relied on line-of-sight communications, limiting its operational range to 93 miles. The TB2s were based in Misrata and Mitiga.

Both sides recognized that airpower could tip the scales on the battlefield and therefore each sought to destroy the other's fleet of drones and its command ground stations.

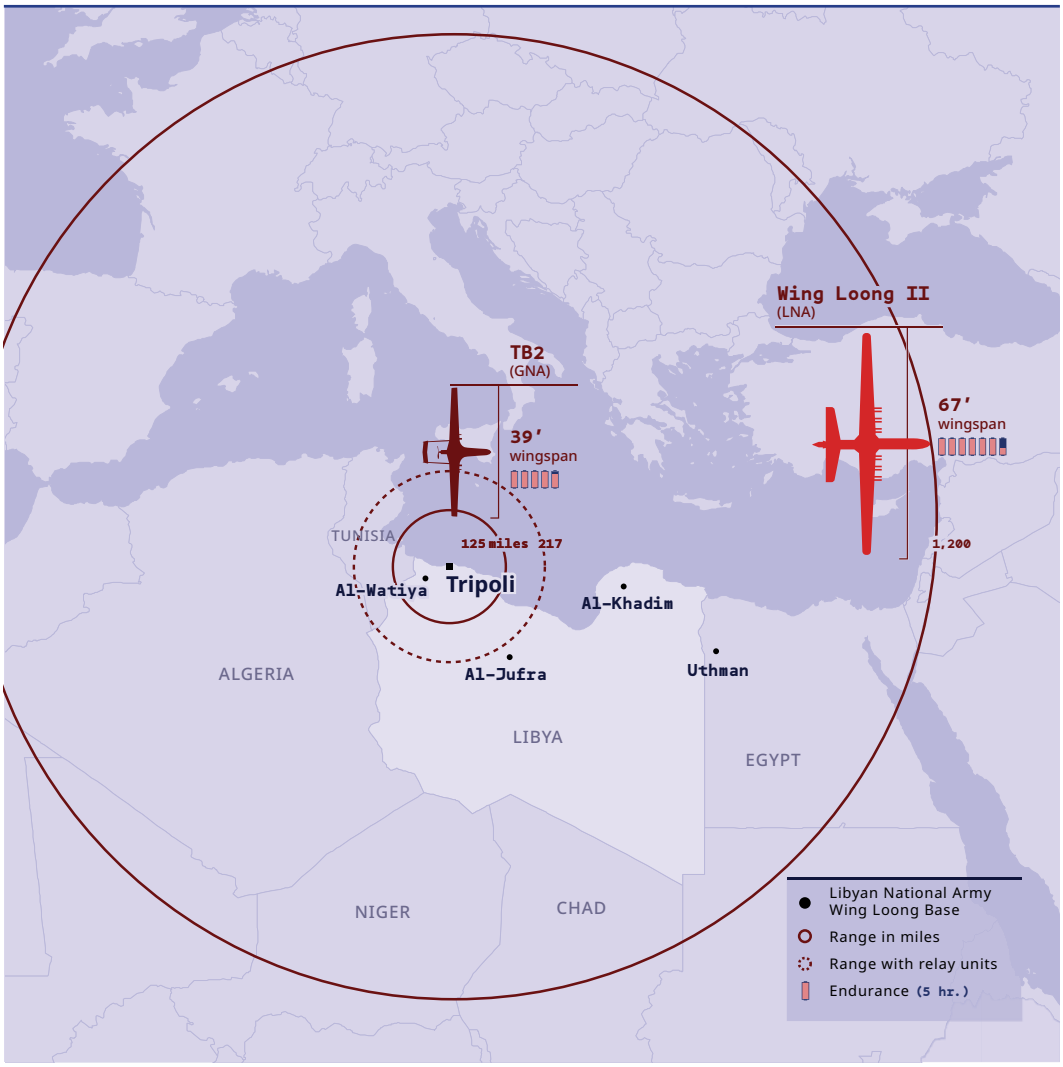
The TB2 carries four laser-guided munitions with an explosive weight one-eighth of the Wing Loong II's payload.[158] Turkey initially sent four TB2s and then an additional eight by June 2019 and a third shipment in August.[159]

Both sides recognized that airpower could tip the scales on the battlefield and therefore each sought to destroy the other's fleet of drones and its command ground stations.[160] In this battle of the airfields the GNA was sorely outmatched. The Wing Loongs could strike any air base in Libya and because the GNA did not have adequate air defenses, the parked TB2s were easy targets, as was the base infrastructure being built to support the drones' operations.[161] By the beginning of July, most if not all of the first shipment of TB2s had been destroyed, primarily by Emirati drone attacks on the GNA's bases.[162] Drones from later shipments fared no better; some were downed by LNA SAMs, but most of the TB2s were destroyed at their bases by Wing Loongs that spotted them returning from a mission.[163] Some TB2 shipments were lost to LNA interdiction strikes before the drones were operational.[164]

The GNA sought to reduce the vulnerability of these drones on the ground by not operating them from fixed air bases, instead taking off and landing from roads. By dramatically expanding the number of potential operating locations, the GNA made it more difficult for LNA aircraft to search for and find the parked TB2s. Additionally, by July 2019, the GNA had deployed ground relay stations that extended the TB2's range (see Figure 7).[165] By dispersing the drones on the ground and extending their range in the air, the GNA enabled the TB2 to strike more distant targets. For instance, in July 2019, the TB2s attacked two IL-76 transport aircraft parked at al-Jufra air base offloading supplies for the LNA.[166] Nonetheless, the TB2s remained vulnerable on the ground and lacked the range to attack most of the Wing Loong air bases. And despite additional precautions, the GNA could not effectively shelter its TB2s from LNA air attacks. The GNA lost seven more drones by October 2019.[167]

Figure 7 | Wing Loong and TB2 Ranges[168]

The TB2 was inferior to the Wing Loong II across many metrics. Most notably, its inferior range required that it operate from locations within the Libyan National Army's reach, and thus the Government of National Accord lost several of these drones in the early days of the battle.



Graphic adapted from the 2019 *Final Report of the Panel of Experts on Libya Established Pursuant to Security Council Resolution 1973 (2011)*, UN Report S/2019/915, United Nations Security Council, December 9, 2019, 33, https://www.securitycouncilreport.org/atf/cf/%7B65BFCF9B-6D27-4E9C-8CD3-CF6E4FF96FF9%7D/S_2019_914.pdf.

In addition to the TB2s and Wing Loongs, other military drones were employed in this war, although in small numbers, which limited their impact. In addition to the TB2, there is evidence that the GNA used the Anka-S for longer-range strikes, and smaller unarmed drones such as the Orbiter 3 for surveillance.[169] The Anka MALE drone is longer-range than the TB2 because it uses satellite communication and was primarily employed to interdict LNA logistics.[170] The LNA similarly conducted ISR with a limited number of smaller drones, including the Orlan-10, Mohajer-2, S-100 Camcopter, and Yabhon.[171] Little is known about how these systems were employed.

Military drones were used in suppression and destruction of enemy air defenses (SEAD/DEAD), but at significant risk and cost. Using practices Turkish forces adopted in Syria, multiple TB2s were often sent out for SEAD missions in an attempt to overwhelm air defenses.[172] Turkish propaganda created a mythology surrounding the TB2s as Pantsir-killers, but the reality was more complicated. In SEAD operations, the GNA used drone-based ISR and human intelligence to find LNA Pantsirs when they were at their most vulnerable.[173] Many of the vaunted Pantsir kills were against systems that were not operating, either because they were moving as a part of a convoy, or the air defense system had not been turned on. In these instances, there was little risk to the TB2s, which were able to get close to the SAM and destroy it.[174] Going against Pantsirs, it is likely that the TB2s had a few lucky shots, and the Pantsir operators were not particularly skilled or cautious.[175]

A final battle at al-Watiya air base in May 2020 provides one example of how the TB2s took advantage of poor LNA tactics. On May 5, the GNA launched a ground offensive on al-Watiya, an important logistics hub, headquarters, and airfield less than a hundred miles from Tripoli.[176] On May 16, TB2 drones observed LNA Pantsir air defense systems arriving at the base. Before the Pantsirs were activated, GNA drones conducted air strikes against hardened aircraft shelters

where the SAMs were parked, which destroyed one Pantsir and damaged another.[177] Some question whether the TB2s' relatively small MAM-L or MAM-C precision-guided munitions (PGMs) could have destroyed the one hardened shelter or whether another ship or aircraft using a larger missile or bomb participated in the attack.[178] After the destruction of the SAMs at al-Watiya, LNA forces fled and the GNA occupied the base on May 18.[179] In this case, the Pantsirs hit were still in the shipping container.[180] In other instances, the GNA's use of the KORAL ground-based electronic warfare systems to find and blind air defense radars also facilitated TB2 attacks.[181] Eventually, LNA air defenders stopped turning on their radars and instead relied on passive sensors, which enabled them to shoot down several TB2s, but they did so too late to change the battle's outcome.

Furthermore, because TB2s may have destroyed multiple Pantsirs, it was speculated that they had special properties that protected them from the short-range air defense systems or that the specific Pantsir systems given to the LNA may not have had their radars optimized for counterdrone operations.[182] In truth, the TB2 was vulnerable to air defenses, as were the Wing Loongs.[183] By one count, 25 large military drones crashed in the first six months of 2020 in Libya, 16 of which were TB2s and 9 of which were Wing Loongs.[184] Pantsirs downed TB2s and even, in a case of friendly fire, one of their own Wing Loongs.[185]

In the battle for Tripoli, military drones provided a cheap air force and, when combined with ground-based air defenses, enabled control of the skies.

Military drones played an important role as tools of information and psychological warfare.[186] Drones were seen as symbols of power and technological prowess and instilled fear in ground forces who dreaded being stalked and attacked from slow-moving uncrewed aircraft. Especially brutal attacks, such as the January 2020 attack on a military academy that killed 26 GNA cadets, reinforced these fears.[187] Because of attacks like these, drones often had a psychological effect on the fighters disproportionate to their tactical effect. One expert called drones "the ideal weapons for a drawn-out campaign aimed at undermining the morale of opponents."[188]

In the battle for Tripoli, military drones provided a cheap air force and, when combined with ground-based air defenses, enabled control of the skies. Both the Wing Loong IIs and TB2s were employed like crewed aircraft to find enemy ground troops and launch air-to-ground strikes. The TB2s also played an important role

Figure 8 | Kill Chains in the Battle for Tripoli

Mission	Find & Cue	Track & Target	Engage	Assess	IF NOT DESTROYED	Reattack
SEAD/DEAD	Human intelligence locates SAM when vulnerable	TB2 finds SAM and acquires targeting data	TB2 fires MAM-C/L to strike SAM	TB2 assesses whether SAM is destroyed		TB2 launches more PGMs
Ground Attack	TB2 locates enemy vehicle or troops	TB2 follows enemy target and acquires targeting data	TB2 fires MAM-C/L TB2 passes targeting data to artillery unit that fires	TB2 assesses damage		TB2 reattacks Artillery adjusts aim and fires again
Counter-Airbase	Wing Loong observes TB2 returning to base	Wing Loong follows TB2 and targets the landing spot/ground control station	Wing Loong drops Blue Arrow on parked TB2s and ground stations	Wing Loong assesses damage		Wing Loong reattacks or shares targeting data with another Wing Loong which reattacks
Indirect Fires	Phantom 4 looks for enemy vehicles or forces	Phantom 4 acquires precise targeting data	Targeting data passed to mortar, rocket, or howitzer unit that fires	Phantom 4 assesses damage		Phantom 4 helps adjust artillery fires, which reengages

in SEAD/DEAD missions, especially when combined with ground-based EW systems. There was no drone air-to-air combat, and air superiority was obtained by offensive counterair operations and ground-based air defenses, which were effective counters to the Wing Loong IIs and TB2s. Ultimately, the primary role of military drones was for direct ground attack. Most of the drone attacks were akin to interdiction strikes as neither drone truly provided close air support to ground forces. While drones were sometimes used together in coordinated attacks and with ground-based fires, there was no sophisticated air-ground coordination by either party. The precision-guided weapons they carried did have an advantage over both sides' Soviet-era crewed aircraft and dumb bombs.

Commercial Drones: The Phantom 4 and Others

Although commercial drones did not receive as much press as the military systems, GNA and LNA troops extensively used a few models, such as the DJI Phantom 4 or DJI Inspire.[189] These drones were commonly seen and heard overhead during the battle for Tripoli, but both sides used these mostly unarmed systems to enhance the situational awareness of small units and to assist in targeting mortars and artillery fire, to aid in maneuver, and to conduct battle damage assessment (BDA).[190] For example, there is evidence LNA forces assisted by Wagner troops used them to direct mortar fire and precision-guided artillery at GNA positions and that the GNA used a COTS drone to monitor areas around Sirte in March 2020.[191] Most of the commercial drones available at this time were unreliable and the control link between the operator and the drone was easy to jam.[192] Both parties used handheld EW counter-drone systems to jam and disable enemy systems.[193]

At the time, the Phantom 4, built by the Chinese company DJI, accounted for a large portion of the market, but it is no longer in production and was rather rudimentary compared with current models. The Phantom 4 was a small quadcopter, weighing three pounds with an endurance of 28 minutes.[194] It was operated remotely through a screen and could transmit video to an operator up to two miles away. At their low price points—the Phantom 4 cost less than $2,000—these systems provided tolerably attritable short-range ISR capability. After January 2020, Turkey provided the GNA with military-grade mini-UAVs that could perform similar missions and were more jam-resistant.

Some larger, pricier commercial drones were also used for intelligence missions, including the Chilong CL-11 vertical takeoff and landing drone and the even larger Mugin Skyeye drone, both Chinese-made, but it is unclear which parties employed these fixed-wing commercial systems or how exactly they were used.[195] In general, these saw much less use than smaller, cheaper COTS systems.

Kamikaze Drones: The Kargu, the Warmate, and Others

The GNA also employed a limited number of kamikaze drones to attack enemy logistics convoys and retreating LNA forces. These drones were effective antipersonnel and antivehicle weapons. One of these was the Kargu-2 loitering munition, first fielded in January 2020 by the GNA.[196] The Kargu is a 15-pound Turkish-made quadcopter that can carry a three-pound warhead (high-explosive fragmentation, shape-charge, or thermometric).[197] At least one Polish Warmate loitering munition was also used but has not been attributed to one belligerent, and it is unclear how many of these kamikaze drones were employed.[198] The Warmate is 12 pounds and can fly for a little over an hour, compared with the Kargu's 30-minute endurance. Both can reach speeds of at least 90 miles per hour.[199] The Warmate can carry high-explosive, armor-piercing, or thermobaric warheads just under two pounds.[200] Additionally, the crash remains of a larger Israeli Harpy kamikaze drone were found in April 2020. Little is known about who used it, but it may have been a part of the GNA attempts to suppress and destroy LNA air defenses.[201]

A UN report claims that the Kargu-2 is a fully autonomous weapon and that it was "programmed to attack targets without requiring data connectivity between the operator and the munition: in effect, a true 'fire, forget and find' capability."[202] STM, the manufacturer of the Kargu-2, disputes these claims, arguing that the drone's autonomy is limited to flight planning, takeoff, and landing and that the drone does not have the capability to decide whether to engage a target.[203] It is difficult to determine whether the drone was operating fully autonomously or not, but given the general sophistication of the Kargu technology and the skill level of its operators, it is probably right to be skeptical of the claim that it engaged in fully autonomous attacks.

Lessons Learned from the Battle of Tripoli

Though initially used sparingly, by December 2019, a UN report concluded that drones had become "the main means to conduct air strikes and drop precision-guided munitions."[204] However, drones were

not, as some have asserted, decisive in Libya. It was surprising to many observers when the TB2 appeared to outperform the more expensive and capable Wing Loong IIs, but this simple comparison of the two drones overlooks other factors. The level and continuity of external support shaped the balance of power, with Turkey playing an outsized role, especially after Emirati, Egyptian, and Russian support diminished. Turkey's support, which included drones but also critical air defense capabilities, mercenaries, and military expertise, turned the tide in the GNA's favor in fall 2019. Geography also played a role; Haftar's LNA forces were stretched over 560 miles from Benghazi, fighting a brutal urban battle against GNA militias who were defending their hometown. Under these conditions, LNA morale was low and declined further as its forces were relentlessly hunted by GNA drones.

Lessons learned from the Battle for Tripoli include:

The TB2 drone succeeded in SEAD/DEAD operations, but at significant cost. The GNA was willing to put its TB2s at risk and sent packages of multiple drones to destroy LNA ground-based air defenses. Consequently, many TB2s were shot down by LNA SAMs, but they were eventually able to neutralize the LNA's ground-based air defenses, which exposed LNA troops to additional air strikes. The TB2s' greatest successes against the Russian Pantsir air defense system appear to have been due to human intelligence that enabled strikes when the SAMs were not operating.

When one party had air superiority, MALE drones armed with precision munitions enabled dynamic air-to-ground operations against enemy personnel and vehicles. In Libya, there were no large, preplanned drone strike campaigns, but rather MALE drones searched for enemy targets of opportunity. Drone air strikes were not closely coordinated with ground force operations but offered additional firepower that helped to attrite enemy forces.

On their own, MALE drones could not attain air superiority because they could only undertake counter-air-base attacks against enemy drones. The LNA and GNA drones could not control the air because they could not defend troops from incoming aerial attacks beyond attacking enemy air bases.[205] Their precision munitions could hit parked drones and ground control stations but could not shoot down enemy drones. In this counter-air-base fight, range mattered. The Wing Loong drones were advantaged because their satellite communications meant that they could be based outside of the TB2's range.

Military and commercial drones provided intelligence and helped aim artillery, improving effectiveness of ground-based fires. There is little information on how drones were connected to artillery units and neither side had sophisticated air-ground coordination. However rudimentary the connections, because commercial quadcopters were prevalent, both sides used them for target acquisition and to adjust mortar, rocket, and howitzer fire. At times, the MALE drones were also used in this role.

MALE drones were vulnerable to ground-based air defenses. Even antiquated surface-to-air missiles were effective in shooting down MALE drones in Libya. Turkish electronic warfare systems also likely countered the LNA's Wing Loong drones. Ultimately, it was Turkey's layered system of ground- and sea-based air defenses coupled with many more TB2s that enabled the GNA to win the battle of Tripoli.

Military drones were not more survivable than crewed aircraft but do allow riskier missions. Because TB2s did not have crews on board, Turkey was willing to send these aircraft on missions where some losses were expected.

International regimes were ineffective at limiting drone proliferation, and uncrewed systems may encourage third-party intervention in wars. Throughout the Libyan civil war, each side benefited from the support of international partners who routinely violated UN arms embargoes by providing weapons, including crewed aircraft as well as drones. In general, the third parties generally preferred to avoid large and costly commitments of their own forces. Drones, therefore, offered a deniable option for providing direct military support at less cost and risk than crewed platforms.

Operating military drones to their full effect is a skill requiring training and experience. One observer claimed these drones in Libya provided "an instant air force" that could be "gifted to troops that are untrained in using air power."[206] In truth, both the LNA and GNA benefited from experienced Emirati and Turkish drone operators.[207]

The Second Nagorno-Karabakh War (September 27–November 10, 2020)

The Second Nagorno-Karabakh War, which spanned just 44 days in fall 2020, was characterized by its intensity and the starkly asymmetric and innovative use of drones by Azerbaijani forces. In this war, Azerbaijan and Armenia fought over the disputed Nagorno-Karabakh region, internationally recognized as part of Azerbaijan but home to a majority ethnic Armenian population. During the First Nagorno-Karabakh War (1988–1994), which was spurred by the dissolution of the Soviet Union, Armenians in Nagorno-Karabakh established the self-declared breakaway Republic of Artsakh. Armenia backed Artsakh and successfully defeated Azerbaijan, leaving the secessionist region nominally independent, but de facto a part of Armenia.[208] Despite occasional flare-ups, Nagorno-Karabakh was essentially a frozen conflict with the "line of contact"—the boundary established with the 1994 ceasefire—remaining largely unchanged for more than two decades (see Figure 9). After tensions rose again to a boiling point in 2020, Azerbaijani forces aided by Turkish forces employed military and kamikaze drones to overpower and steadily attrite the troops of Armenia and Nagorno-Karabakh before gradually advancing and making progress toward the center of the region. The war ended with Azerbaijan decisively defeating Armenia and recapturing much of the territory previously under Armenian control, including the strategic city of Shusha.[209] Many observers attributed Azerbaijan's success to its revolutionary use of drones. Drones indeed provided critical airpower and supported Azerbaijan's ground-based fires, but well-trained special forces also contributed to Baku's success.

Although the first war did not result in a peace settlement or international recognition of Nagorno-Karabakh's independence, Armenian and Artsakh forces secured control over the bulk of the region in the 1994 ceasefire agreement. Over the next two and half decades, Armenia and Nagorno-Karabakh focused on reinforcing their defenses within the disputed area but made relatively few investments to upgrade their military capabilities.[210] In contrast, Azerbaijan's defense spending throughout the 2010s quadrupled that of Armenia and included significant purchases of modern weapons from Russia, Israel, and Turkey.[211]

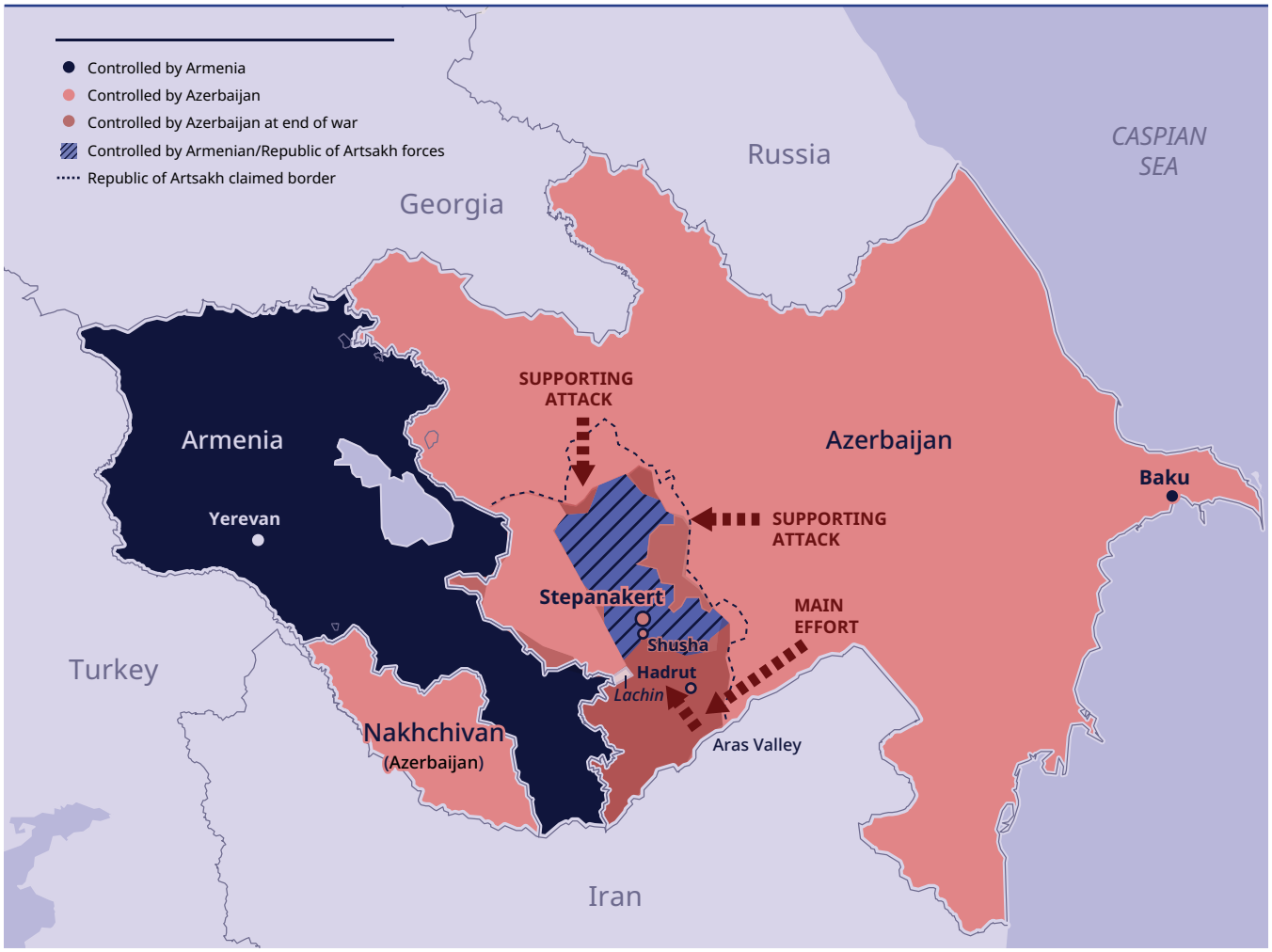
Both countries had a mix of Soviet-era equipment inherited from the Soviet Union or purchased from Russia, which Azerbaijan supplemented with more modern and capable weapons from a wider array of suppliers. Russia had long supplied both countries with weapons in the name of maintaining a military balance between them, although it held closer ties with Armenia as its ally under the Collective Security Treaty Organization, often subsidizing its arms purchases.[212] When Russia became seemingly less willing to sell Azerbaijan its more advanced weapons, Azerbaijan's leaders turned to Turkey and Israel, which willingly provided advanced artillery and multiple launch rocket systems (MLRS).[213] Azerbaijan emphasized purchasing drones and EW systems, including the Turkish KORAL to support SEAD/DEAD operations and the Belarussian Groza-S to counter enemy drones.[214] To complement its new arsenal, Azerbaijan sent its officers to train with the Turks and learn from their experience employing these weapons in Syria and Libya.[215] Armenian military practice, by contrast, remained heavily influenced by Russian tradition.[216] Azerbaijan's diversity in weapons, better-trained forces, and generally greater military spending over the years shifted the balance of power between the two rivals such that by 2020, Azerbaijan had the quantitative and qualitative edge.[217] A hubris resulting from their victory in 1994 seemed to blind Armenia's leaders to the growing threat posed by Azerbaijan's modernized forces.[218]

Armenia also placed an outsized confidence in the protection provided by the terrain of Nagorno-Karabakh. Its rugged geography shaped the fighting but would not be as determinative as Armenia hoped. It predictably limited the paths available for the Azerbaijani offensive and stymied Azerbaijan's attacks in the heavily defended mountainous north and northeast. Ultimately, however, the terrain did not provide the protection Armenian forces counted on because Azerbaijani forces concentrated their offensive on the southern flatlands, taking the longer but less fortified route toward the Lachin corridor. That singular path was Armenia's one main passage to Nagorno-Karabakh and became a focal point of the Azerbaijani invasion.[219] Baku also seized the initiative with a large surprise attack, catching Armenian forces flat-footed and, with relentless assaults from Azerbaijani drones and ground-based fires, unable to regroup and reverse the steady losses.

That surprise attack came on the morning of September 27, with an Azerbaijani ground assault supported by rocket, artillery, and drone attacks on three different fronts. Azerbaijani drones supported by the KORAL EW system quickly hit known fixed Armenian air defenses in preplanned strikes.[220] After several days of hard fighting and little progress, Azerbaijan's forces increasingly focused their drone and artillery strikes on Armenia's mobile air defenses.[221] By mid-October,

Figure 9 | Azerbaijani Axes of Attack

Azerbaijani forces launched two supporting attacks in the north and northeast to support their main effort in the south of the Nagorno-Karabakh region.



Map adapted from Evan Centanni and Djordje Djukic in "Nagorno-Karabakh Control Map & Timeline: Artsakh Withdrawals–December 1, 2020," Political Geography Now, December 1, 2020, https://www.polgeonow.com/2020/12/nagorno-karabakh-control-map-after-ceasefire-withdrawals.html.

coordinated Azerbaijani military and kamikaze drones and artillery fires had dismantled the medium- and short-range air defenses in Nagorno-Karabakh, leaving Armenian forces exposed as most only had man-portable air defense systems that were not effective against high-flying drones.[222] With these tactics, Azerbaijan soon established air superiority.[223] However, Azerbaijan's success in SEAD/DEAD operations was as much about the deficiencies of Armenian defenses as it was about the tactical brilliance of Azerbaijani drone operators.[224] Moreover, despite the attrition inflicted on Armenian defenders, Azerbaijani forces gained little territory, especially in the north, and suffered considerable losses in the first few weeks of the war.[225] Once they had largely eliminated the air defense threat, Azerbaijani forces could operate their drones freely over Nagorno-Karabakh, striking Armenian EW systems, command and control nodes, artillery and rocket forces, tanks, armored vehicles, logistics convoys, lines of communication, and troops themselves.[226] If Armenian vehicles operated in the open, they were vulnerable to drone attacks and artillery fire guided by drone spotters. Having lost most of their supporting fires and vehicles, Armenian troops could slowly maneuver on foot or try to remain hidden in their trenches and thus, not surprisingly, struggled to conduct counterattacks.[227]

Despite obtaining air superiority, Azerbaijan's northern offensives were halted, leading it to focus on approaching central Nagorno-Karabakh from its soft underbelly where Azerbaijan could effectively integrate its armored forces with other advanced capabilities.[228] In addition to drones, Azerbaijan made extensive

use of its special operations forces (SOF) in its main assault.[229] Small SOF teams covertly entered Armenian-controlled towns and seized positions after drone strikes destroyed or disrupted Armenian defenses. SOF also called for drone fires to support their operations and directed drone and artillery fires toward key targets.[230] With drones and SOF locating, targeting, and attacking Armenian defenders in advance of large-scale mechanized assaults, Azerbaijani forces steadily gained ground in the relatively flat Aras River valley along the border with Iran in the second half of October.[231]

As Azerbaijani forces gained momentum in the easily navigated southern terrain, they still had to move north toward the objectives of the Lachin corridor and Nagorno-Karabakh's most populated cities. The Azerbaijani forces advancing toward Lachin met fierce resistance and were halted south of the critical Armenian line of contact.[232] At the same time, Azerbaijani forces attacked along other axes and by October 16 had seized Hadrut, which was a big blow to Armenian troops' morale.[233]

From Hadrut, Azerbaijani forces hoped to progress to capture Shusha, a town with both strategic geography and high symbolic significance to both sides, but in late October they became bogged down and subsequently switched tactics. Instead of leading with a large ground offensive supported by drones, Azerbaijani SOF (400 of about 1,000 highly capable soldiers trained by Turkey and Pakistan) advanced on the city through the forests and over cliffs so that they could simultaneously conduct a surprise assault from multiple directions.[234] The attack was successful, and with Azerbaijani forces fully in control of Shusha, an armistice was signed on November 9. At the war's end, Azerbaijan had reclaimed the territories surrounding Nagorno-Karabakh that had been lost in 1994 and a third of the Nagorno-Karabakh region. Once again, the armistice did not resolve the underlying dispute between Azerbaijan and Armenia, and tensions in Nagorno-Karabakh remained high. Russian peacekeepers stationed at the Lachin corridor did little to defuse the new volatile situation.[235] Azerbaijan rapidly seized the rest of the region in September 2023 and raised its flag over Stepanakert.[236]

Notably, throughout the war, neither side made much use of its crewed air forces due to a combination of factors. First, by October 3, Turkey had deployed F-16 fighters to Azerbaijan's Ganja air base. Although the Turkish fighters did not participate in operations during the war, which would have been a significant escalation, their presence appears to have been an implicit threat that deterred Armenia from using its crewed air force.[237] Additionally, Armenia's air forces suffered from poor readiness, which may have contributed to the decision to keep them grounded. Armenia's air forces included a squadron of Su-25 attack aircraft, Su-30 fighters, and a handful of attack and ISR helicopters, but they did not have the missiles required to make use of these aircraft.[238]

Azerbaijan, which held the advantage in crewed aircraft, instead elected to use its cheaper armed drones and loitering munitions, which offered a precision strike capability that did not put at risk any pilots.[239] Azerbaijani crewed aircraft mainly remained outside the range of Armenian strategic air defenses and were used for standoff strikes.[240] In this instance, drones also may have been preferred because of their relatively slow speeds and long endurance, which made them better suited to patrol the skies and search for emergent Armenian targets. Uncrewed systems offered precision at a lower cost and lower risk to Azerbaijani lives.

Additionally, both sides sparingly used their tactical ballistic missiles to attack cities and civilian infrastructure. Ballistic missiles offered longer ranges and more firepower than air strikes.[241] Drones, with their much smaller payloads, did not offer a substitute here. Instead, this restraint could be explained by the small size of both nations' short-range ballistic missile arsenals and a mutual hesitance to escalate the war, especially with Turkey threatening to intervene on Azerbaijan's behalf and Russia lurking in the background.[242] Moreover, plentiful long-range rockets provided the capability to reach most desired battlefield targets and helped keep the war confined geographically.[243]

Military Drones: the TB2, Hermes, and Orlan-10

Azerbaijan had a vast advantage over Armenia in military drones. The TB2 was Azerbaijan's main armed military drone.[244] Azerbaijan entered the war with up to 50 TB2s and some of the more expensive Israeli systems, including the Hermes 450, Hermes 900, and Heron TP MALEs.[245] The tactical Hermes 450 and the larger, longer-range Hermes 900 and Heron TP carry an array of sophisticated sensors for aerial surveillance.[246] Once Armenia's SAMs had been destroyed, Azerbaijan flew these Israeli drones to surveil the battlefield and identify targets that could either be engaged by artillery fires or armed military or kamikaze drones.[247]

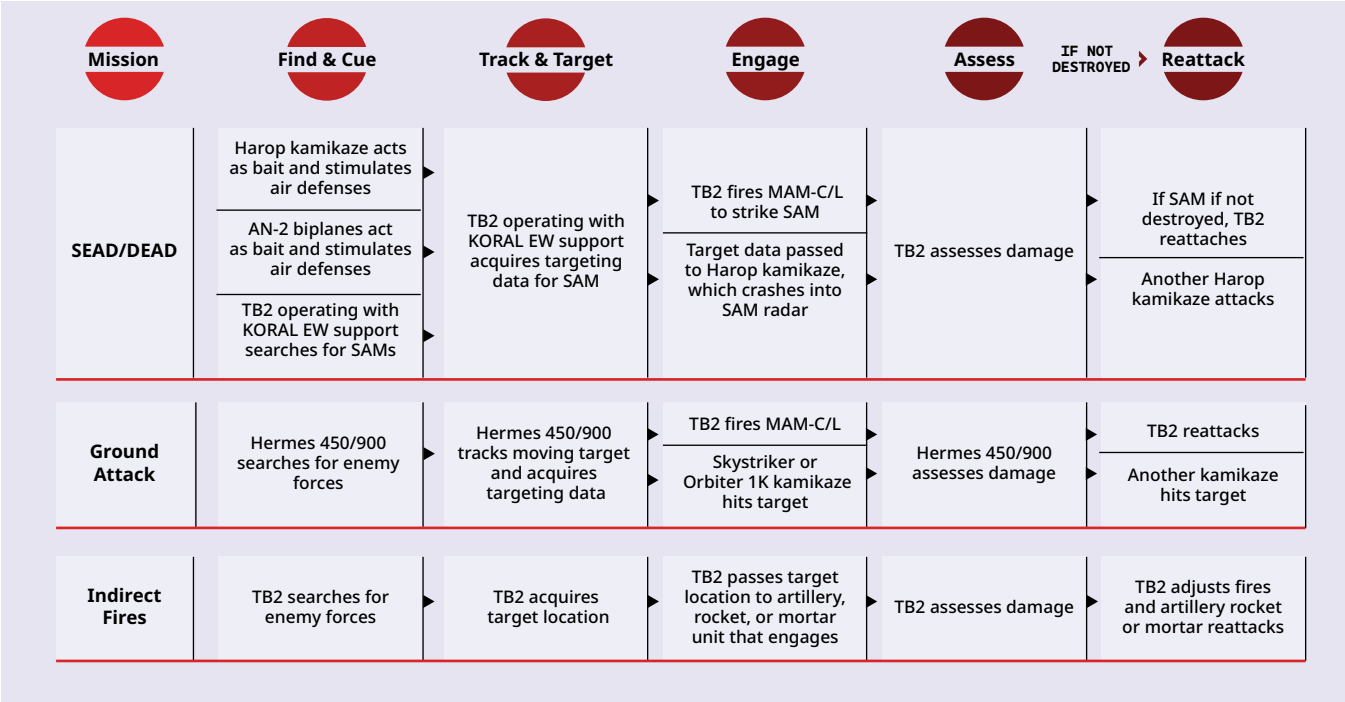
Armenian drones were far behind in quantity and quality. Armenia had not invested heavily in uncrewed systems, despite receiving a preview of Azerbaijani drones in four days of fighting in 2016.[248] Armenia's military drone fleet consisted largely of indigenous drones and Russian Orlan-10 reconnaissance drones

provided by Russia during the war.[249] Orlan-10s are small, short-ranged, and used for reconnaissance and targeting missions.[250] One video shows an Orlan-10 helping direct artillery fire on a column of Azerbaijani soldiers.[251] But Armenia had far too few of these systems to have changed the dynamics on the battlefield. Azerbaijan claims to have destroyed 22 Armenian drones over the course of the war.[252]

With Turkish assistance, Azerbaijan's military used the TB2 to great effect.[253] Although they did not publicly acknowledge their role, Turks operated the drones in addition to planning their operations, applying lessons from drone operations in Syria and Libya.[254] Turkish military officers reportedly took an even larger role in directing the fighting two weeks into the war, when it became clear that Azerbaijan's initial offensive had not gained much ground.[255] TB2s supported SEAD/DEAD operations, at times flying above kamikaze drones that were fired to stimulate Armenia's mobile SAMs and obtaining targeting coordinates for the SAMs once they revealed themselves. The TB2s could then either drop a laser-guided bomb on the air defense system or pass the information to artillery units or kamikaze drones, which engaged the target. At times, the TB2s seemed impervious to Armenian air defenses despite their large electromagnetic signature, taking out 16 9K33 Osas—the "mainstay" of Armenian air defenses—without many losses.[256] TB2s could target these systems without entering their detection range, and when they did enter that bubble, Osas did not register the TB2s, due in large part to the KORAL EW system.[257]

Yet Azerbaijan's success in SEAD/DEAD was more due to limitations in Armenia's air defenses, Azerbaijan's advantage in EW, and Armenian troops' failure to use tactical best practices than it was due to TB2s or other Azerbaijani drones. Armenian air defenses were made of mostly antiquated short-, medium-, and long-range mobile Soviet-era SAMs, man-portable air defenses, and Russian EW systems.[258] Some of these systems should have been able to intercept medium-altitude drones such as the TB2 and Hermes, but Armenia held most of its more advanced and long-range air defenses in reserve.[259] In Nagorno-Karabakh, Armenia's air defenses were relatively sparse and its short-range air defenses were particularly outdated, with radars that were not built to identify slow-moving objects, such as drones.[260] Additionally, Armenian operators were not adequately trained in and prepared for counterdrone operations. More generally, Armenian air defenders performed poorly and deviated from standard tactics for air defense operations. As evidence of this, Armenian mobile SAMs were left in "relatively exposed fixed positions" instead of rapidly moving from one well-concealed location to another.[261] Because of Armenia's inadequate air defenses and Azerbaijani use of drones to conduct SEAD/DEAD operations, Azerbaijan claimed to have destroyed a total

Figure 10 | Kill Chains in the Second Nagorno-Karabakh War



of 40 Osas through various means, in addition to seven S-300 TELs, two S-300 detection stations, an S-300 radar, five Tor systems, four Kub systems, and a Krug system.[262] Azerbaijan had similar gaps in its short-range air defense capabilities, but Armenia did not opt to use its crewed air force to attempt to exploit them because of poor readiness and concerns about escalation.

Once Armenia's air defenses were disabled, Azerbaijan's high-altitude military drones could loiter over Nagorno-Karabakh and hunt down any exposed or moving Armenian military vehicles, including tanks. Because of their endurance, the drones were able to conduct long missions and systematically pick off Armenian vehicles with precision strikes.[263] According to Oryx, Azerbaijan damaged 255 Armenian tanks but only destroyed 57 percent of the tanks hit.[264] The TB2 struck 86 tanks directly. TB2s were also critical to Azerbaijan interdiction strikes against Armenian reserve forces and key lines of communication. It is unclear how the TB2s—many of which arrived just before the war began—were connected with artillery units, but evidence suggests that there was a relatively high degree of coordination.[265] Some suspect that Turkish military officers helped to integrate the military drones with ground-based fires and conducted the most challenging drone operations, such as a strike that killed the military commander of Artsakh forces.[266] Figure 10 outlines how different types of drones worked with other systems to close kill chains.

TB2s along with unarmed military drones played equally if not more important roles collecting intelligence and enabling Azerbaijani forces to dynamically find and rapidly engage emergent targets. Using tactics reminiscent of those successfully employed by Turkish forces in Syria, Azerbaijani troops effectively integrated military drone operations with tube and rocket artillery fires to destroy Armenian armored vehicles often sitting in revetments that offered no protection against air attack and indirect fires.[267] When hunting for Armenian targets, Azerbaijani drones could focus their searches on the limited road network, loitering overhead for hours and leaving channelized Armenian forces few places to hide from the eyes in the sky. Drones identified a target, fixed and tracked its position, and then passed this information to howitzers, multiple launch rocket systems, and kamikaze drones that engaged the target. The drones would then assess whether the target had been destroyed or whether it needed to be reattacked.

Military drones were also used heavily in the information war that took place alongside this conflict.[268] Azerbaijan had been flexing its social media muscles before the war even started, with pictures of its new military acquisitions and vows to restore control of the region.[269] Both sides made highly unlikely claims about enemy losses, including an Armenian claim that its forces had destroyed 12 TB2s, with no photo evidence.[270] Azerbaijani President Ilham Aliyev released a long list—which has been widely questioned—of the Armenian equipment Azerbaijani forces allegedly destroyed and captured, to include the air defense kills previously discussed.[271]

Commercial Drones

Commercial drones played a limited role in Nagorno-Karabakh. Azerbaijani forces may have used some, including the DJI Mavic, in their attack on Shusha, but did not publicize their use.[272] If commercial drones were used in that attack, their use appears very limited.[273] Armenian forces may have made limited use of commercial quadcopters for intelligence, but this also did not appear common.[274]

That is not to say that there was not a potential role for commercial drones in the conflict. For instance, commercial drones could have helped both sides during Azerbaijan's offensive toward Shusha, especially as cloud cover and bad weather prevented higher-flying drones, such as the TB2, from operating. Should the frozen Nagorno-Karabakh conflict become hot again, commercial drones may feature more prominently. In summer 2023, an Armenian Mavic drone was downed in Azerbaijan-held territory near Lachin, which perhaps shows Armenia learning from the hard-won lessons of this war or from observation of the ongoing war in Ukraine.[275]

Kamikaze Drones: The Kargu, Harop, SkyStriker, Orbiter 1K, and An-2

Azerbaijani forces employed kamikaze drones to devastating effect in this war. These drones included the Turkish Kargu and the Israeli Harop and SkyStriker loitering munitions.[276] These systems could precisely strike moving objects such as vehicles and mobile SAMs by using electro-optical/infrared seekers to find targets and make late-stage course adjustments. The Harop, equipped with sensors that detect radar emissions, was particularly suited for SEAD/DEAD missions. Azerbaijani forces coordinated military drones, which acquired targets, and then passed the information to kamikaze drones, which conducted the strikes (see Figure 10). Over the course of the war, kamikaze drones destroyed at least three Osas and three S-300PS launchers.[277] They also took losses, proving more vulnerable than the TB2s to Osa fire.[278]

In addition to these more exquisite Turkish and Israeli capabilities, Azerbaijan also used old Soviet An-2 biplanes as uncrewed bait for Armenian air defenses.[279] Azerbaijan "converted" the old planes to uncrewed systems by having pilots point them in the general direction of Armenian air defenses and strap belts onto the controls before jumping out.[280] This was part of a bait and kill SEAD/DEAD tactic to trick mobile air defenses into exposing themselves. The An-2 biplanes were the low-flying lure to bait Armenian air defense radars to turn on and to draw SAMs fires, and in the process expose themselves. Military drones flying at higher altitudes would locate the SAMs and direct armed Harop kamikaze drones to strike the air defense systems.[281] Azerbaijan used almost 50 biplanes for this purpose.[282]

For Azerbaijan, the early stages of the war saw more military drone use, but as special operations forces took on a greater role, so did the Turkish Kargu. SOF teams infiltrating Armenian towns used Kargus primarily for tactical reconnaissance, while the more visible TB2s stayed behind with the main ground force to catch the Armenians off guard.[283] These drones were especially useful for reconnaissance when the weather was not suited for larger military drones, as was the case at the start of the fight for Shusha.[284] Forest fires before the assault left a heavy fog that inhibited the use of military drones for several days. Azerbaijani forces largely won the city without military drones by securing a key supply route and preventing Armenian reinforcements from reaching the city.[285] In the absence of Azerbaijani military drones, Armenian tanks and armored vehicles effectively launched several counterattacks, all of which were repelled by Azerbaijani SOF and conventional forces that had arrived on November 6.[286] When the fog cleared the next day, TB2 drones were used to solidify victory in Shusha.

There were very few accounts of Armenian kamikaze strikes during the war. One was an unknown kamikaze drone targeting an Azerbaijani air defense battery control center. The Armenian Ministry of Defense also published a video of an Armenian-made kamikaze that was reportedly being used in the fighting.

Lessons Learned from the Second Nagorno-Karabakh War

In the Second Nagorno-Karabakh War, Azerbaijan's victory was in many ways overdetermined, with drones contributing to but not entirely explaining the war's outcome. Turkey also provided significant military support to Baku, and the presence of Turkish fighters likely stopped Armenia from trying to use its crewed fleet of aircraft. In this lopsided air fight, only Azerbaijan had significant numbers of drones, and it used them to effectively dismantle Armenia's old ground-based air defenses without putting Azerbaijani pilots in harm's way. This left Armenia's forces vulnerable to Azerbaijani drones, which hunted them down and either directly engaged them or provided targeting coordinates to artillery or kamikaze drone units that closed the kill chain. Even after pummeling Armenian troops with precise drone and artillery strikes, Azerbaijani ground forces encountered significant resistance and were not able to achieve their objective—the Lachin corridor. Changing its tactics, Azerbaijan withheld its general purpose troops and deployed its highly trained special forces teams with kamikaze drones and antitank missiles to capture the strategic city of Shusha.

Lessons learned from the Nagorno-Karabakh War include:

Drones can be used in a preplanned attack to take enemy forces by surprise. Turkey helped Azerbaijan plan deliberate drone strikes in the opening phase of the war against fixed targets, which helped Azerbaijani forces to gain the upper hand. This deliberate campaign weakened Armenia's defenses and its troops' morale but did not immediately lead to capitulation.

MALE and kamikaze drones supported by EW systems can be very effective at SEAD/DEAD operations. In Nagorno-Karabakh, Azerbaijan used electronic attacks to blind Armenian air defense radars so TB2s could approach Armenian SAMs and obtain targeting coordinates. Then kamikaze drones, especially radar-homing Harops loitering nearby, could swoop in to engage the SAMs. Azerbaijan lost very little of its robust drone fleet over the course of the war because Armenian forces were ill-prepared for the drone threat and failed to adapt. Azerbaijani SEAD tactics, which created multiple simultaneous threats for air defenders to respond to and effectively used EW to enable drone operations, were sound.

Innovative use of improvised or unsophisticated drones can have outsize effects. Azerbaijani forces' innovative use of An-2 biplanes as kamikaze drones supported important early SEAD/DEAD missions and helped Azeri forces to seize the initiative. These deception tactics may be most effective in the opening stages of a war when a defender can be caught off guard. When successful, they offer a low-cost way of locating mobile air defenses.

If one side has air superiority, MALE drones can conduct dynamic air-to-ground operations and acquire targeting information to enable precise ground-based fires. As the Nagorno-Karabakh War continued, TB2s were able to conduct dynamic targeting and strike from the air on mobile targets, including mobile SAMs, tanks, armored vehicles, logistics convoys, and personnel. Equally, if not more importantly, TB2s and other MALE drones found, fixed, tracked, and targeted Armenian forces and passed this information to tube and rocket artillery units that precisely engaged these targets.

In a one-sided drone fight, military and kamikaze drones integrated with artillery can enable maneuver. In early stages of the Second Nagorno-Karabakh War, drones connected to ground-based fires to attrite the Armenian forces, softening their defenses before launching a ground assault. Additionally, Azerbaijani SOF used Kargu kamikaze drones for reconnaissance and as spotters, enabling SOF maneuver and infiltration in urban areas. In part, Azerbaijani forces were able to maneuver and successfully launch offensive operations because Armenian forces did not have equally good intelligence on their locations.

Drones allow riskier missions and are seen as less escalatory than the use of crewed aircraft. Both Azerbaijan and Armenia largely refrained from employing crewed aircraft throughout the war. Armenia may have been deterred by Turkish F-16s stationed in Azerbaijan during the war.

The Ukraine War (February 2022–September 2023)

While the previous two cases received press for the shocking and at times innovative use of uncrewed technology, the ongoing war in Ukraine dwarfs these conflicts in numbers of drones used and lost and the scale of ongoing innovation. For this reason, it has earned the title of "first full-scale drone war."[287] To capture the scale of drone use and lessons learned for this conflict, CNAS published a separate report, *Evolution, Not Revolution: Drone Warfare in Russia's 2022 Invasion of Ukraine*.[288] The following summary includes the key points expanded upon in that report.

The war began on February 24, 2022, with Russia's invasion of eastern Ukraine. Since September 2023, when the research for this report concluded, the war has progressed through several phases and, as of this report's publishing, appears far from its conclusion. Each stage of the war in Ukraine has seen increased use of drones of all types performing a diverse set of missions as operators experimented and learned on the fly. There have been two battles waged concurrently: the close fight and the deep fight.[289] The close fight has occurred between troops in contact or near the front lines, while the deep fight has consisted of long-range attacks against strategic targets. The close fight, thus far, can be divided into six major phases, detailed below. The deep fight was largely one-sided, with Russia dominating in 2022, but became more symmetrical in 2023 as Russia's stockpiles of long-range cruise and ballistic missiles dwindled and as Ukraine began fielding its own long-range kamikaze drones to match those of Russia.

Each stage of the war in Ukraine has seen increased use of drones of all types performing a diverse set of missions as operators experimented and learned on the fly.

The Ukraine War Phase I: Coup de Main Decapitation Strike (February 24–28, 2022)

The first phase was Russia's initial failed decapitation strike. In this phase, Russian forces directed a large-scale campaign of air and missile strikes focused on military targets, including Ukrainian air bases, command and control infrastructure, munitions stores, and air defenses.[290] To bait Ukrainian air defense radars into exposing themselves, Russia deployed E95M combat training target drones as decoys.[291] This was one of the few uses of Russian drones in the opening phase of the war. Moscow believed Ukrainian resistance would be minimal and that through a large show of force and rapid assault, Russia could achieve a coup de main in several days.

After the missile strikes, Russia's unrealistic strategy had shorthanded, unprepared battalion tactical groups racing into Ukraine along multiple axes of advance, leaving them vulnerable to Ukrainian counterattacks.[292] Russian forces invaded southern Ukraine from Crimea, advanced toward Kharkiv from the east, and conducted a fixing operation in Donbas, but the main Russian attack was focused on Kyiv.[293]

In these first few days, Ukrainian military forces and volunteers used a wide array of drones in their defensive operations. The Ukrainian air force flew TB2s to hunt

Figure 11 | The Russian Invasion Plan

This map shows the initial axes from which Russian forces advanced in Ukraine in February 2022. While there were multiple avenues of attack, the focus was on Kyiv, the Ukrainian capital.

Map adapted from "Maps: Tracking the Russian Invasion of Ukraine," *The New York Times*, June 9, 2023, https://www.nytimes.com/interactive/2022/world/europe/ukraine-maps.html.

for and interdict Russian forces.[294] Similarly, Ukrainian ground forces employed smaller military drones, such as the Punisher and Leleka-100, and commercially adapted drones, such as the R18 and DJI Mavic, to find and track Russian troops.[295] Some armed drones, such as the R18, dropped bombs on unsuspecting Russian forces, but more often the drones provided vital intelligence to Ukrainian artillery teams or hidden Ukrainian ground teams. Ukrainian drones had free rein during this time because Russia's air defenses were operating under strict rules of engagement that limited the use of SAMs to avoid friendly fire incidents.[296] Additionally, Russian forces could not employ their EW systems, which were stuck in the back of their advancing columns of forces.

The Ukraine War Phase II: Regrouping and Reattacking (March 2022)

In the second phase, Russian forces regrouped from their shambolic initial attack and gradually transitioned to deliberate combat operations while trying to advance on their original objectives.[297] As Russia continued its offensive, the fighting became more contested, and there was a chance the much larger invading force might overwhelm Kyiv's defenses. However, the attack on Kyiv encountered fierce resistance and was quickly bogged down, with Russian troops suffering heavy casualties. By the end of March, the Russian attack on the capital had completely stalled. However, Ukraine's focus on Kyiv's defense, which included dedicating special forces and reserves, left other areas with shortfalls.[298] Russian forces had more success in their southern offensive in part because of insufficient Ukrainian artillery in the region and also because they had destroyed Ukrainian air defenses in the south in their initial cruise missile strikes.[299] On March 25, the Russian Ministry of Defense (MOD) proclaimed that, having met its initial goals, Russia's main objective would now be conquering and annexing the remainder of the Donbas region of eastern Ukraine.[300]

During this period, drones continued to play an important role in Ukrainian operations and Russian troops began to employ them in the surveillance and target acquisition roles outlined by Russian military doctrine.[301] Russian forces used their military drones, such as the ZALA, Orlan-10, Orlan-30, and Eleron-3, for situational awareness and to direct artillery strikes, while

Ukrainian forces bolstered their smaller fleet of military drones with COTS and homemade drones for the same missions.[302] Russian troops, in contrast, were slower to adopt commercial drones for tactical reconnaissance. Ukrainian forces, which included many civilian volunteers, had little choice but to rely on commercial technology and improvised weapons.

Around the same time, the airspace in Ukraine became more contested as Russian forces began operating their ground-based air defenses and EW systems.[303] With each side actively searching for its opponent's drones and employing MANPADs, antiaircraft guns, jammers, and SAMs, drone losses began to pile up. The widespread use of SAMs and EW systems, which prevented either side from obtaining complete air superiority over Ukraine, made the environment far too dangerous for MALE military drones. Russia briefly conducted strikes with Orion and Forpost drones, but several were shot down, after which such strikes largely ceased.[304] Similarly, Russian SAMs downed most of Ukraine's TB2s during this period and the much-hyped Turkish drone largely disappeared from the battlefield.[305]

The Ukraine War Phase III: Refocusing on the Donbas (April–August 2022)

By April, the Russian attack on the capital had failed, bringing about a third phase of the conflict, in which Russia refocused on annexing the remainder of the Donbas region of eastern Ukraine.[306] Battered and demoralized Russian forces retreated from Kyiv, and the front lines shifted to the eastern regions of Luhansk and Donetsk.[307] Russian forces had encircled the port city of Mariupol in early March but only subdued the city in April after a seven-week siege and massive artillery barrages.[308] To conquer the remainder of the Donbas, Russia sought to squeeze Ukrainian defenders from the north, south, and west. In early May, a senior American defense official characterized Russia's Donbas offensive as making "uneven" and "anemic" progress due to widespread risk and casualty aversion among Russian troops.[309] By late May, due to slow progress, Russia reinforced its attack from the west with troops from Mariupol and focused its efforts on encircling Sievierodonetsk and Lysychansk, the remaining two cities under Ukrainian control in Luhansk.[310] By July, Russian forces had seized both cities.[311]

As the battlefield contracted, the character of the war shifted from a war of maneuver to a war of attrition dominated by artillery duels. At this time, Russia had a 12-to-1 advantage in ground-based firepower in the Donbas, which enabled its forces to slowly grind forward after devastating an area with tube and rocket artillery.[312] Before Russian troops assaulted a Ukrainian position, they would fire an enormous number of artillery shells to weaken the defenses.[313] Lacking long-range fires, outgunned Ukrainian artillery fired back, but only had enough ammunition to fire 5,000 to 6,000 rounds a day, which was at best 30 percent of the daily Russian barrage.[314]

For both sides, drones became the principal ISR platform for ground-based fires complexes and were used at most echelons of the ground forces. Both military and commercial drones were primarily used as spotters or forward observers, sent to find time-sensitive targets for engagement by artillery units.[315] At the tactical levels, combatants used commercial or improvised drones.[316] Typically, only battalion- and higher-level echelons had fixed-wing military drones, such as the ZALA, Orlan, Furia, or Leleka-100, and they were used primarily for target acquisition.[317] Russian forces also used their superior military drone fleet for SEAD/DEAD missions and consequently gained a degree of air superiority.[318] Because of their scarcity and greater cost, MALE drones were only committed in lower-threat environments and were seldom seen on the battlefield.[319]

In general, the airspace near the front lines became more inhospitable, resulting in high losses of all types of drones. In addition to both parties more effectively operating their ground-based air defenses, Russia deployed a very dense network of EW systems along the front lines, which resulted in pervasive jamming of navigation and communications.[320] A report by the Royal United Services Institute (RUSI) estimates 90 percent of Ukrainian drones used up to this point were destroyed.[321] On average, Ukrainian quadcopters tended to survive for just three flights, while military drones survived for an average of six.[322] Ukraine also used man-portable EW guns to attrite Russian drones, but Russia's EW forces might have been their own drones' worst enemy.[323] Their EW tactics did not emphasize deconfliction or discrimination, so Russian drones suffered considerable fratricide.[324]

To replace drone losses, in July 2022 Ukrainian President Volodymyr Zelenskyy launched Ukraine's "army of drones" initiative to crowdsource funding for military drones and training and to spur donations of commercial drones.[325] In its first seven months, the program purchased several thousand drones and trained 10,000 drone pilots.[326] Similarly, the Russian government sought to bolster its military drone production, which the Russian MOD had admitted was not meeting the needs of the war.[327]

The Ukraine War Phase IV: Ukraine's Fall 2022 Offensive (September–November 2022)

By the end of summer 2022, Russia's offensive in the Donbas had stalled and the conflict settled into positional warfare. Both parties made efforts to break the stalemate, starting with Ukraine's fall 2022 counteroffensive in which it liberated the west bank of Kherson and Kharkiv.[328] During this attritional period, small tactical drones, especially commercial drones, proliferated on both sides and became ubiquitous. Additionally, as other weapons were depleted, both parties increasingly relied on kamikaze drones and loitering munitions to engage military targets and conduct strategic attacks.

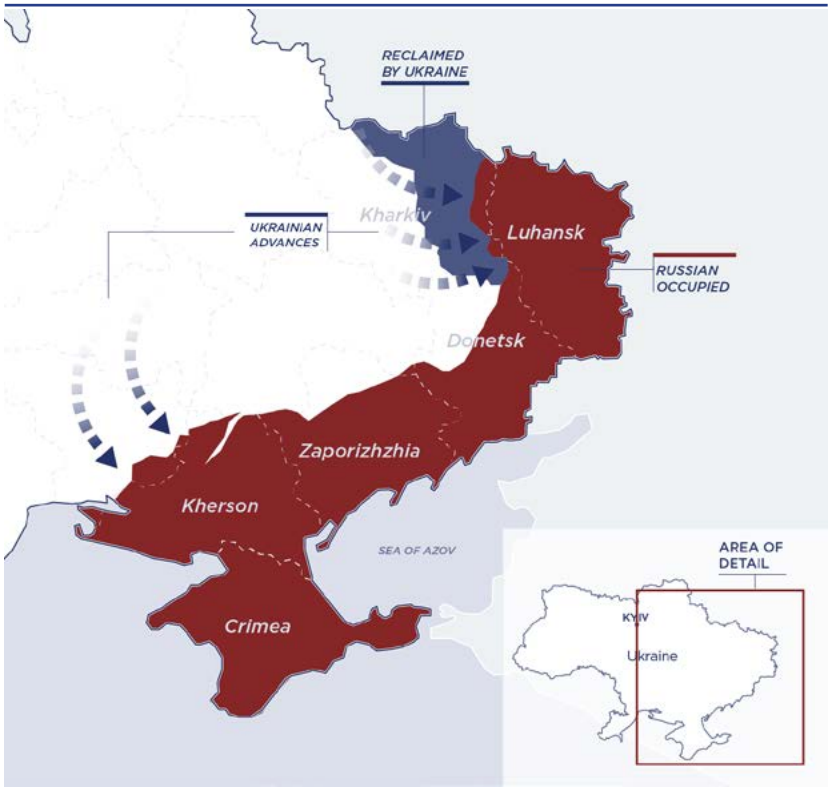
Ukraine began its counteroffensive on Kherson on August 29 and six days later on Kharkiv.[329] Before this, Ukraine received a large shipment of Western military equipment, including American-made High Mobility Artillery Rocket Systems (HIMARS) and long-range precision rockets, but still had limited ammunition and employed these fires judiciously.[330] Ukraine preceded both offensives with HIMARS attacks and benefited from targeting information provided by Western nations but, more than precision strikes, prior attrition suffered by Russian forces drove Ukraine's success in its counteroffensives.[331]

In Kharkiv, Ukrainian forces quickly penetrated the weakly defended Russian front lines and outflanked exhausted Russian defenders. Ukraine regained 2,300 square miles of territory in 10 days.[332] Ukraine did not replicate this blitzkrieg success in Kherson, where prepared defensive lines were crewed by higher-quality Russian forces augmented by reservists and new recruits.[333] This was a grinding offensive where Ukrainian forces slowly advanced village by village only after extended artillery, rocket, and drone strikes.[334] The Ukrainian offensive in northern Kherson accelerated in early October, and on November 9, Russia announced its forces were withdrawing to the eastern side of the Dnieper River.[335] Having inflicted significant losses on the Ukrainians, Russian forces deliberately retreated in an orderly fashion, which enabled them to consolidate in a more defensible position behind the river that was bolstered by reinforcements.[336]

During this period, the most important roles for drones remained intelligence and targeting for artillery units. In preparation for the attack in the Kharkiv region, Ukrainian drone teams—called *ochi*, meaning eyes—surveilled the area and compiled lists of Russian high-value targets, including ammunition stores, artillery guns, command posts, and EW systems for artillery to engage.[337] Commercial drones redirected artillery fire that missed its mark and provided battle damage assessment. Because of a shortage of Orlan-10s, which could not quickly be replaced, Russian forces in Kharkiv increasingly relied on other models of military drones and commercial drones for intelligence and target acquisition.[338] By September, the Russian MOD, which had previously impeded efforts of Russian soldiers to obtain and employ commercial drones, finally began encouraging its troops' acquisition of them and offering training on how to operate them.[339] During the battle for Kherson, artillery again dominated as Russian and Ukrainian drones located enemy targets and directed fires.[340] Because this was the priority theater, Russian forces in Kherson still had many military drones for ISR and increasingly employed Kub and Lancet-3

Figure 12 | Ukraine's Fall 2022 Offensive

Russian forces anticipated Ukrainian counterattacks in Kherson and Kharkiv but elected to send reinforcements to Kherson, leaving Kharkiv with thin defenses.



Map adapted from "Maps: Tracking the Russian Invasion of Ukraine," *The New York Times*, June 9, 2023, https://www.nytimes.com/interactive/2022/world/europe/ukraine-maps.html.

kamikaze drones to conduct precision counterbattery attacks.[341] The Ukrainian troops also used their drones for direct attack, often dropping weapons on camouflaged Russian infantry vehicles or tanks.[342]

The Ukraine War Phase V: Russia's Winter 2023 Offensive (January–May 2023)

After Ukraine's fall offensive, Russia attempted to seize the initiative in January 2023 by launching a much anticipated offensive in Donbas that sought to envelop and capture Bakhmut.[343] Russian Wagner units attacked and seized Soledar, a small mining city just north of Bakhmut.[344] Soledar was the first city Russia had taken since July 2022, but conquering it required committing significant manpower and accepting high casualty numbers.[345] Soledar ended up being one of few successes as Russian attacks faltered elsewhere due to a lack of quality forces, experienced leaders, and artillery ammunition.[346] By April 2023, the Russian counteroffensive had petered out with paltry territorial gains, with the exception of Bakhmut, which was secured in May.[347] Both sides sustained significant losses during this period, but Russia's leadership seemed willing to continue the costly offensive, believing Russia would outlast Kyiv and its Western supporters in a protracted attritional war.[348]

By early 2023, small commercial quadcopters had become ubiquitous, erasing Ukraine's initial 3-to-1 advantage in tactical drones.[349] The types of commercial drones began to change as troops on both sides increasingly sought out advanced models with thermal cameras that could be used on night missions.[350] Additionally, as other weapons were depleted, combatants relied more on kamikaze drones for precision strikes. Russia had an advantage in military kamikaze drones, but Ukrainian forces were developing creative new ways to use commercial FPV drones in similar ways.

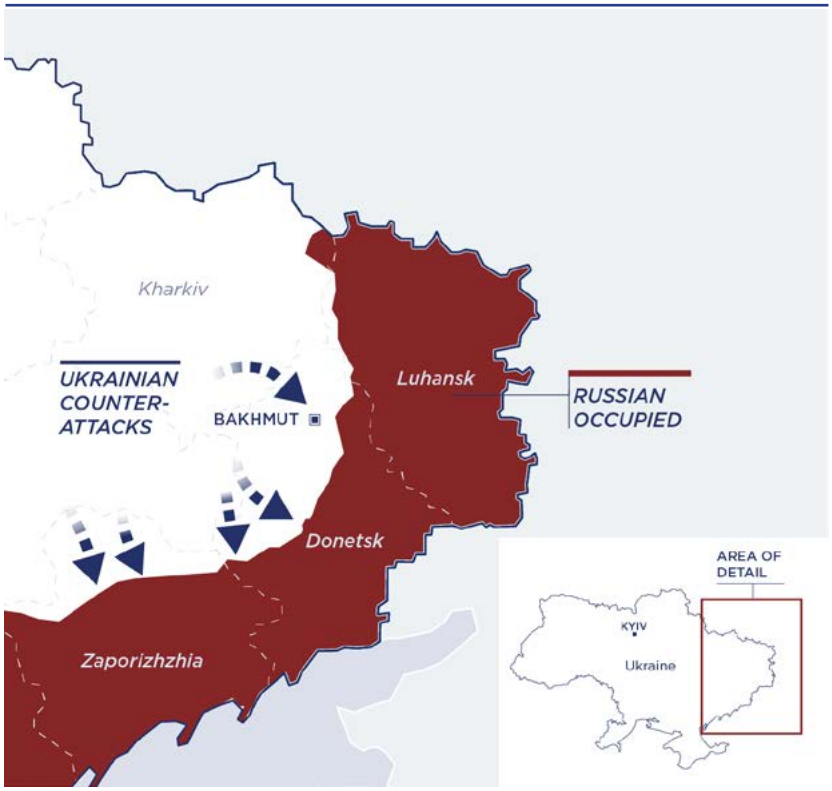
The Ukraine War Phase VI: Ukraine's Summer 2023 Counteroffensive (June–September 2023)

The sixth phase of the war, Ukraine's multipronged counteroffensive of summer 2023, began on June 4. Russian forces had used the preceding winter and spring to heavily fortify their front lines, especially in the south. The dense network of layered Russian defenses included overlapping minefields, concealed and hardened machine gun and antitank positions in the tree lines, concrete-reinforced trenches, antitank trenches, and rows of concrete barriers.[351] These defenses ensured that Ukraine's effort to breach the lines and reclaim territory would be challenging and costly. In preparation for that effort, Western nations rushed additional arms to Ukraine and trained Ukrainian forces in rudimentary combined arms operations. In addition to howitzers and artillery shells, the West provided new heavy weapons, including Leopard and Challenger main battle tanks and Bradley armored infantry fighting vehicles.[352]

The offensive had three major axes: Orikhiv, Velyka Novosilka, and Bakhmut.[353] Despite securing a number of towns near Velyka Novosilka in the second week and making gains around Bakhmut, progress quickly stalled.[354] Early on, the Ukrainians conducted a mechanized assault on the priority axis, Orikhiv, in an attempt to achieve a rapid breakthrough, but this proved too costly. Ukrainian vehicles quickly drew Russian artillery and antitank

Figure 13 | The Three Axes of Attack in Ukraine's Summer 2023 Offensive

Ukrainian forces counterattacked in Zaporizhzhia, Donetsk, and Bakhmut but made few gains in the first few months.



Map adapted from "Maps: Tracking the Russian Invasion of Ukraine," *The New York Times*, June 9, 2023, https://www.nytimes.com/interactive/2022/world/europe/ukraine-maps.html.

fires, often cued by drones. Many other Ukrainian vehicles drove into minefields and then were picked off by artillery.[355] After notable losses and few territorial gains, the Ukrainians fell back onto a more practiced and deliberate approach: seeking to significantly attrite Russian forces with artillery and long-range strikes before slowly and incrementally advancing in platoon- and company-sized units.[356] The Ukrainian offensive culminated in October and Ukrainian forces have shifted to a defensive posture across the front lines.[357] The fighting caused significant attrition on both sides, but it was unclear which side was taking more losses.[358]

During the Ukrainian counteroffensive, drones of all types have saturated the airspace, limiting maneuver near the front. Because drone-directed artillery fire has been so lethal, each side has sought various ways to defeat the other's drones and to use drones to find their opponent's counterbattery radars, howitzers, and rocket launchers. The drone-counterdrone competition has been fast-paced with quick adaptations, but given the sheer number of drones, it also has been increasingly driven by cost considerations.[359] Ukrainian forces have continued to rely on drones as spotters for ground-based fires but adapted their tactics, only flying drones when they found EW gaps and frequently changing radio frequencies to evade Russia's layered EW systems.[360] They also increasingly experiment with drones made from foam or plastic that are less likely to be seen by Russian radars and, if they are detected and lost, are cheap enough to be easily replaced.[361] The other cheap drones that proliferated were the FPV racing drones modified into kamikaze drones, which provided an affordable way to attack mobile targets, especially people and fast-moving vehicles.[362] By June, Russian forces had emulated Ukrainians and regularly were employing commercial or DIY racing drones to run down Ukrainian vehicles and troops.[363] Ukrainian and Russian volunteers have produced tens of thousands of cheap FPV drones a month, as they have been rapidly expended.

The omnipresent Russian military and commercial drones have made it difficult for Ukraine to mass forces, break through defensive lines, and exploit advances. Russia's defense industry increased production of ISR drones, such as the Orlan-10 and ZALA, as well as Lancet-3 kamikaze.[364] Ukraine does not have sufficient air defenses to defend everywhere and has sought to preserve these critical weapons by keeping them safer in rear areas. Even when Ukrainian SAMs could have shot down an Orlan-10, they often have not, preferring not to expend a scarce and expensive interceptor on a much cheaper drone that Russia could easily replace.[365] Consequently, largely uncontested Russian drones provide intelligence on Ukrainian force positions behind the front lines.[366] Moreover, Russian troops effectively coordinated ISR drones, kamikaze drones, and artillery fire to engage Ukrainian vehicles that approach the front.[367]

The Deep Fight: Strategic Strikes

In parallel to the close fight on the front lines, there was a largely separate ongoing battle of strategic strikes between Moscow and Kyiv. Strategic attacks are those that, independent of what is happening at the operational level, weaken an adversary's will or ability to fight and therefore may achieve overarching political goals. Historically, strategic target sets include deep military bases, the defense industry, enemy leadership, and critical economic targets, such as oil or energy.[368] Initially, Russia had a monopoly on strategic attacks because of its large stockpile of missiles. Over time, Ukraine eroded but did not eliminate this advantage using drones.

Since the first day of the invasion, Russia has employed long-range air and missile attacks, initially focusing on Ukrainian military targets before turning to defense industry and communications infrastructure target sets, and then in spring 2022, rail infrastructure and fuel storage and production.[369] As Russia's stockpiles of preferred long-range munitions were depleted, it repurposed surface-to-air and antiship missiles for land attacks, resulting in a growing number of Ukrainian civilian casualties.[370]

In response, Ukraine began to develop an indigenous capability to strike targets within Russia with long-range drones, but these efforts would not bear fruit until mid-2023.[371] The first evidence that Ukraine was using long-range kamikaze drones appeared in the summer of 2022 with an attack on a Russian oil refinery near the border, possibly using the Chinese Skyeye 5000, a commercially available drone that costs $5,000 to $10,000 on Alibaba, modified for a kamikaze mission.[372] By August, the focus of Ukraine's long-range attacks shifted from nearby targets across the Russian border to Crimea.[373] While Ukraine experimented with long-range kamikaze drone attacks, Russia purchased Iranian Shahed-136 drones to augment its dwindling stockpiles of long-range missiles and uncrewed systems.[374] Russia's first reported Shahed-136 strategic strike was in September 2022, when it fired kamikaze drones at Odessa for three consecutive days.[375]

The deep strike war escalated in October 2022. On October 7, Ukraine launched a kamikaze drone attack

140 miles north of the Ukrainian border at Shaykovka air base and damaged two Russian Tu-22M Backfire bombers.[376] On October 8, a large explosion from a truck bomb damaged the Kerch Bridge linking Crimea to Russia. The Ukrainian domestic intelligence agency later claimed responsibility.[377] Two days after the explosion, Russia began an extended air campaign aimed at Ukraine's power grid. Russia launched a massive missile and drone barrage against critical infrastructure in more than 10 Ukrainian cities, including those deep in western Ukraine.[378] The attack consisted of 95 missiles and at least 21 Shahed drones and marked a new concerted effort to make ordinary Ukrainians suffer by depriving them of electricity and heat during the cold winter months.[379] Over the next several months, Russia regularly launched complex attacks that included cruise and ballistic missiles and kamikaze drones against Ukraine's energy grid.[380] Despite damaging or destroying nearly 40 percent of Ukraine's energy infrastructure and causing rolling blackouts, the Ukrainian electrical grid did not collapse, nor did the Ukrainian public's will to fight decline.[381] The West provided additional air defenses to shoot down incoming drones and missiles.[382] Additionally, the Ukrainians refined their tactics and developed innovative solutions for defeating the long-range strikes, including a crowdsourced smartphone application for early detection of incoming missiles and drones.[383]

Ukraine's commitment to building long-range aerial kamikaze drones began to show results and since then, there has been a significant uptick in drone attacks against Russia.

This quickly became an attritional battle as Russia sought to exhaust Ukrainian air defense interceptors before it ran out of its long-range strike weapons. Over time, the salvo size and frequency of Russian strategic attacks declined as its weapons inventory ran low.[384] Concomitantly, the Ukrainian air force's rate of intercepting the smaller attacks of incoming missiles and drones improved, but its interceptor stockpiles ran low.[385] Neither side was completely exhausted, and this strategic battle was still underway at the time this report was written.

As Russian strikes on Ukraine's cities continued, Ukraine conducted novel drone attacks against deep targets in Russia and Crimea. On October 29, 2022, Ukraine launched a coordinated attack with air and maritime drone boats against the naval base on Sevastopol. Nine aerial drones and seven improvised kamikaze drone boats participated in the attack against the Russian Black Sea Fleet flagship the *Admiral Makarov*.[386] Another drone boat damaged the oil terminal in Russia at Novorossiysk in November.[387] In December, Ukrainian drone operators turned their sights on the Russian bombers that had been conducting missile strikes against many Ukrainian cities. Ukraine armed several Tu-141 Strizh 1970s-era Soviet reconnaissance drones and sent them on kamikaze strike missions against two Russian bomber air bases.[388] Two Russian bombers were reported slightly damaged at Engels airfield, 300 miles inside of Russia.[389]

In mid-2023, Ukraine's commitment to building long-range aerial kamikaze drones began to show results and since then, there has been a significant uptick in drone attacks against Russia. The BBC tabulated 190 attacks in Russia and Crimea between January and September 2, 2023.[390] These attacks used a diverse array of drones against a range of targets, including oil fields, air bases, and transportation infrastructure. A growing number of drone strikes targeted Moscow, including two drones that hit the Kremlin in May and strikes against skyscrapers in central Moscow in July.[391] Some were launched within Russia, such as the quadcopters that damaged bombers at Soltsy-2 air base near Novgorod in August 2023.[392] In addition to these kamikaze attacks, Ukraine has made extensive use of its expanding number of long-range reusable drones.[393]

Military Drones: the TB2, Orion, Furia, Orlan-10, and Others

Both the Ukrainians and Russians have used military drones extensively, but not the military drones that many might expect. The image that often springs to mind for military drones is large, high-flying, armed drones—Ukraine's TB2 or Russia's Orion—but MALE drones have played a relatively small role in this war. The most common and important Russian and Ukrainian military drones have been smaller, recoverable fixed-wing systems—Ukraine's Furia or Russia's Orlan-10—that are integrated with ground units and used primarily for surveillance, target acquisition, and battle damage assessment. Like all drones, military drones have also been used for information warfare and propaganda purposes.

As with the previous two cases, the Ukrainian drone that captured the headlines and the public imagination, at the beginning of the war was the Turkish-built TB2.[394] The TB2 was one of the few armed military drones that

Ukraine had at the war's start, and the only one that carried precise laser-guided bombs. Ukraine had 24 TB2s when the war began.[395] During the first days of the war, social media sites were littered with viral videos of TB2 attacks on Russian forces, including columns of Russian vehicles, (likely nonoperating) air defenses, trains transporting fuel, and infantry fighting vehicles.[396] In the largely permissive air environment, the TB2s patrolled the skies unmolested, enabling them to effectively interdict invading Russian forces.[397] During this time, TB2s supplemented crewed Ukrainian jets and provided a limited precision ground-attack capability, but their success was entirely contingent on Russia's decisions not to operate its air defenses and its inability to use its EW systems. Oryx, an open-source intelligence website, tallied all the successful TB2 strikes, which included 5 Russian tanks, 8 armored fighting vehicles, 9 pieces of artillery, 15 SAMs, 2 antiaircraft guns, 10 helicopters, 7 ships, 2 fuel trains, 29 other vehicles, 4 command and communications posts, and 6 other targets.[398] Given the hype and Turkish propaganda surrounding this drone, these kill numbers are likely inflated but still indicate that the TB2s offered the Ukrainian air force a ground strike capability that did not endanger its pilots and helped to attrite Russian forces in the critical first few weeks. About 10 days into the war when Russia began to activate its air defense and EW systems, TB2 losses began to appear.[399] This forced Ukraine to only commit TB2s in favorable circumstances where there were fewer air defenses, as in the case of the battle for Snake Island.[400] Nevertheless, most of the Turkish drones were shot down in March.[401]

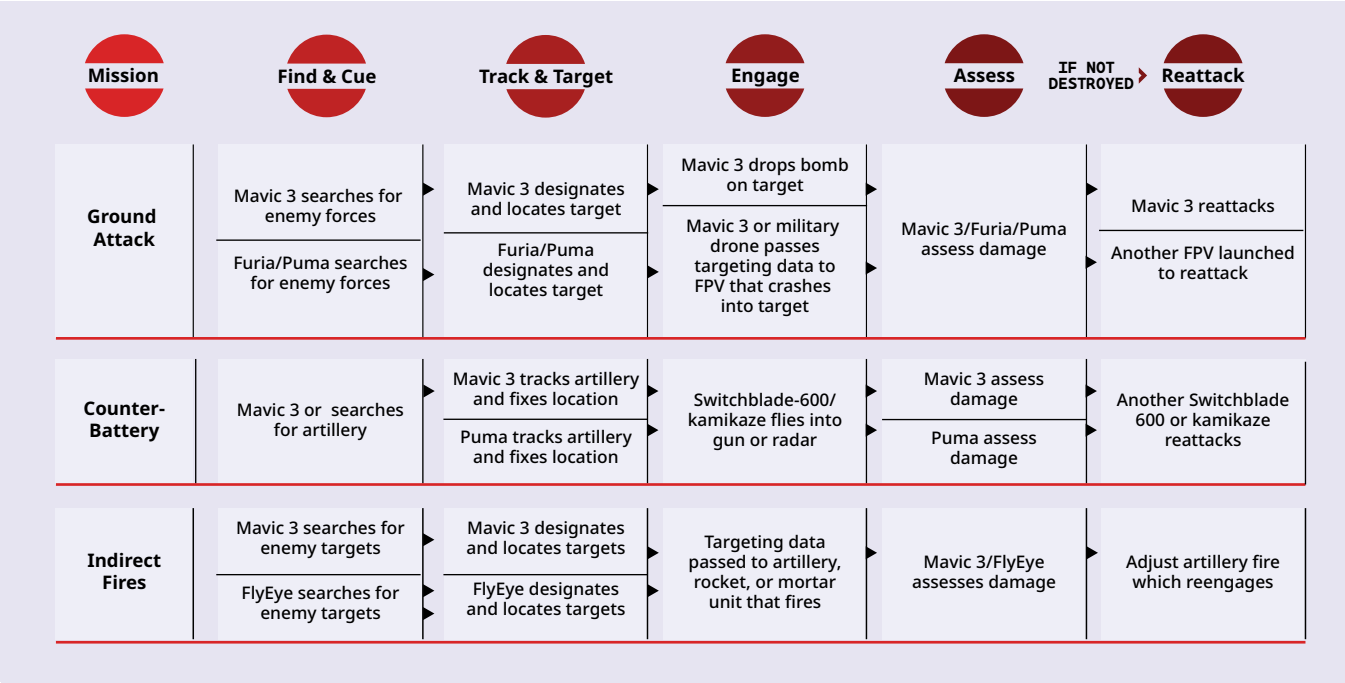
In contrast, Ukrainian forces have used smaller military drones, such as the Furia, the FlyEye, the Leleka-100, and the PD-1, continuously throughout the war. Most of these cannot fly more than 50 miles or stay aloft over 10 hours. They, therefore, are tactical systems that provide Ukrainian ground forces with previously unavailable levels of local situational awareness and improve the accuracy of indirect fires. Still, although fewer than Ukrainian quadcopters, these drones offer more capability than most commercially available models because they are often hardened against electronic attack and have extended ranges, more endurance, and better sensors.[402] Their most important missions are finding enemy targets, providing accurate target data to artillery units, adjusting fires, and assessing whether the target is destroyed. Very few of Ukraine's smaller military drones are armed.

Military drones are one area of drone warfare where Russia has largely retained an advantage, having comparatively prioritized investment in uncrewed and autonomous systems for years.[403] It has a robust fleet that includes a few armed MALE drones and a larger number of smaller, mainly unarmed drones controlled by ground forces. Russia had long-endurance armed drones such as Forpost-R and Orion, which flew some combat operations, but employed these sparingly due to Ukrainian air defenses.[404] Instead, most Russian military drones are shorter-range smaller ISR systems that supported the Russian army's reconnaissance strike complex, the network of forces that conduct targeting for artillery units, by collecting intelligence, rapidly acquiring targeting data, and passing that information to artillery units that then engaged the target.[405] Russian operational concepts aim to achieve battlefield information dominance, with military drones serving as the critical sensors and communications nodes for the Russian Strelets system.[406] This battle control network integrates feeds from multiple drones and other sensors into a computer that helps to accurately direct fires.[407] The greater collective range and endurance of Russia's drone arsenal has allowed Russia to cover larger areas and fly much longer missions, providing its forces with broader and more persistent surveillance. While Russian forces struggled to execute the idealized version of the reconnaissance strike complex even at the tactical level in Ukraine, they improved over time. Military drones have enabled more responsive, dynamic targeting of enemy forces by artillery units. With an organic drone, Russian units could accurately fire on a newly detected enemy target in three to five minutes.[408]

The Orlan-10 is the most common Russian military drone employed in Ukraine and plays a critical role in the reconnaissance strike complex. The Orlan-10 is a relatively inexpensive but capable military drone that flies above the reach of MANPADs on missions out to 75 miles and carries several different payloads.[409] While it can be armed, most in Ukraine are not.[410] Often, multiple Orlan-10s fly over an area at once, providing real-time information about the situation back to headquarters, facilitating maneuver and enabling responsive fires on emergent enemy targets.[411] Russia's many different ZALA 421-E variants tend to be slightly smaller than the Orlan-10 but provide another sophisticated ISR capability. Together, these drones provide a dense layered tactical surveillance network over the depth of the battlespace and help coordinate artillery and kamikaze drone strikes.[412]

Russian drones have also played an important role in SEAD/DEAD operations. Orlan-10s have successfully hunted for Ukrainian air defenses, marked them

Figure 14 | Kill Chains in the Ukraine War



for strike, and then passed that information to artillery units.[413] The Leer-3, an EW variant of the Orlan-10, has been used in jamming and SEAD/DEAD missions as high-flying bait to entice Ukrainian SAMs to turn on their radars and fire.[414] Then, a lower-flying Orlan-10 equipped with an electronic intelligence payload acquires targeting coordinates on the SAM that fired, while a third Orlan-10 with an electro-optical sensor designates the launcher as a target and passes this information to an artillery battery.[415] This is not a swarm in the sense that the drones are autonomously collaborating or even controlled by one operator, but the tactic has been effective. To preserve their short- and medium-ranged SAMs in the face of this threat, the Ukrainians removed them from the front lines, opening airspace for largely uncontested Orlan-10s to provide the Russians with real-time intelligence on the disposition of Ukrainian forces and their activities.[416]

The Orlan-10 variant Orlan-30 is equipped with a laser designator range finder, enabling it to illuminate targets for precision artillery strikes.[417] Given their longer range, Orlan-30s also have been observed conducting BDA for Iskander missile strikes and providing long-endurance overwatch to help cue other drones, such as the cheaper and shorter-range ZALA 421-16E5.[418] In this situation, the Orlan-30 detects a possible target and the ZALA validates the target and obtains precise coordinates, which are then passed to an FPV drone operator that crashes a kamikaze drone into that target.[419]

Commercial Drones

The widespread use of COTS drones by both parties differentiates the Ukraine war case.[420] Commercial drones are less capable than many larger military systems, but they have provided an affordable and easy-to-use tactical ISR capability that did not previously exist. They have become indispensable for ground force operations and saturate the front lines.[421] As analyst Michael Kofman observed, the presence of so many drones has made it difficult for either side to concentrate its forces, break through the defensive lines, or achieve surprise.[422] While Ukraine pioneered this space and initially was more capable of harnessing commercial technology, Russia has emulated its adversary and largely caught up.

Because this is an attritional war dominated by artillery, the most important role of commercial drones is serving as spotters for artillery units and dramatically improving the accuracy of indirect fires. It is not simply that drones can see enemy forces; because they are connected to artillery units, drones can call significant firepower onto troops that are discovered. Although in Ukraine it has become inconceivable to conduct ground operations without commercial drone scouts, these drones have not fundamentally changed the nature of the fight, which still resembles a classic artillery duel. In this duel, commercial drones perform the roles of tactical aerial reconnaissance and fire support. Even with these eyes in the sky, the battlefield is not entirely transparent;

small, dismounted units can use natural features for cover and make use of camouflage to complicate targeting.[423] Moreover, the short range and limited endurance of commercial drones combined with limited connectivity means their effects are localized.[424]

In addition to using drones for their direct effect on the battlefield, Russian and Ukrainian forces have used commercial drones for psychological effect and to influence public perceptions of the war. Moscow and Kyiv have also used the videos from drone feeds to fuel their ongoing information war and to try to shape international and domestic opinion.[425]

The role of volunteer organizations in the drone dimension of the war has also made this case unique. After the 2014 Russian invasion of Donbas, a group of Ukrainian volunteers created Aerorozvidka, a civilian organization focused on using drones for aerial reconnaissance in defense of Ukraine.[426] By February 2022, Aerorozvidka could modify commercial drones for combat and had designed and produced its own homemade drones from commercial parts, including

The most important role of commercial drones is serving as spotters for artillery units and dramatically improving the accuracy of indirect fires.

the R18 octocopter, which can carry up to four grenades.[427] Equally importantly, Ukrainian volunteers formed a cadre of highly skilled and experienced drone operators who joined forces with the Ukrainian military and brought their drones to the fight to resist the latest Russian invasion.[428] In contrast, the Russian MOD initially opposed, although it did not effectively deter, the Russian civilian-led grassroots efforts aimed at filling the Russian commercial drone gap.[429] The MOD relented in late 2022, announcing that newly mobilized soldiers could bring their own quadcopters when they deployed, but it has not enabled or supported civilian volunteer groups like the Ukrainian government has.[430]

Early in the war, there was significant variability among Ukrainian commercial drone operators in terms of their organization, tactics, equipment, and aptitude.[431] This is due largely to the fact that, during that period, the bulk of commercial drones were operated by specialized Ukrainian units, soldiers who could procure quadcopters, often with their own money, and ad hoc volunteer "wild" teams.[432] Some of these volunteer drone pilots were highly skilled.[433] Aerorozvidka offered some of the most capable operators.[434] In summer 2022, they reportedly had 50 drone teams carrying out approximately 300 drone flights a day.[435] Other high-end drone operators included Ukrainian special operations forces units and intelligence organizations such as the Security Service of Ukraine and Main Intelligence Directorate.[436] Over time, more Ukrainian troops have received training on commercial quadcopters, although a disparity still remains between specialized drone units and general purpose forces.

Ukrainian drone operations and tactics have also evolved over time. In the first few phases of the war, Ukrainian drone teams typically drove to the front lines, found hiding spots, launched their drone, searched for targets, and left when they found Russian forces or exhausted their drone's battery life.[437] As the conflict progressed and the front lines stabilized, Ukrainian forces have increasingly operated quadcopters in pairs or groups, which provides redundancy and the ability to execute different tasks simultaneously, and have been closely linked to nearby fires units.[438]

Russian forces have also used commercial drones since the war's beginning, although initially they had fewer quadcopters and their troops were less skilled than the Ukrainians at employing them.[439] Because artillery units originally were equipped with most of the military drones, regular infantry units only had commercial quadcopters for aerial reconnaissance. Yet for a long period, there were not enough commercial drones available to equip all the Russian units because of the Russian MOD's hesitance to embrace commercial technology.[440] Despite this, Russian volunteer organizations helped to fill this capability gap. Data provided by the American company Edgesource, which produces the WindtalkerX sensor that detects and tracks the location of commercial drones and their pilots, suggests that by early 2023 Russia had caught up to Ukrainian commercial drone use, resulting in a notable increase in overall commercial drone activity.[441]

Tactically, the Russians employ the quadcopters like the Ukrainians, mainly for surveillance and spotting.[442] They often fly in pairs, with one drone tasked with finding the targets, monitoring the attack, and conducting BDA, while the other drone drops the weapon.[443] Frequently, commercial Russian drones also coordinate with military drones. Small commercial drones often find Ukrainian forces and cue an Orlan-10, which precisely locates the enemy forces and passes the information to the gunline.[444] At other times, Russia has used microdrones, such as the DJI Mini or Mavic Air 2

or Air 3, to gauge the extent of electronic interference before committing larger quadcopters.[445] In this case, these microdrones act as canaries in the coal mine—early warning systems that indicate whether enemy jamming is present.

Russia and Ukraine have found a variety of ways to counter commercial drones. EW offers the most effective way to disable or destroy these drones, and Russia has invested heavily in this area.[446] A senior Ukrainian official estimated that Russia's electronic attacks have caused half of Ukraine's drone losses.[447] As a result, Ukrainian troops often refrain from sending commercial drones on missions if Russian EW systems are operating.[448] However, Russian electronic interference is common, but not continuous, both because of the limited number of EW systems and because Russian forces occasionally have to turn off their jammers to avoid friendly fire on their own drones while they are conducting offensive operations.[449] Loss numbers for commercial drones are incredibly high. According to a RUSI report, Ukraine lost approximately 10,000 drones a month, and most of those were commercial or DIY drones.[450] On average, a Ukrainian quadcopter only survives for three flights, although the most competent drone pilots can extend the life of a drone beyond a few missions.[451] Instead of hardening commercial drones against electronic attack, which is expensive and does not guarantee survival, Ukraine and Russia have simply bought greater numbers of cheap drones.[452]

Electronic interference is quite effective but often indiscriminate. One alternate approach is drone-on-drone aerial combat, where one quadcopter collides with another and attempts to knock it out of the sky or deploys a net that downs the enemy drone.[453] Ukrainian drone pilots have refined their tactics by attacking other quadcopters from above, typically a blind spot, and aiming for the enemy's fragile rotors. This type of diving attack can fatally damage the targeted drone but leave the other unscathed.[454] Given the number of quadcopters in the sky over the front lines, drone dogfighting is becoming more common, but it is still a relatively nascent tactic.

Another approach is to find and target the drone operators themselves. Most quadcopters are remotely piloted and therefore not autonomous. There usually are two or more operators.[455] Since commercial quadcopters and DIY drones have limited ranges, the operators need to be relatively proximate to the drone, which makes them vulnerable to attack. If an adversary can determine the location of operators by, for example, hijacking the drone's radio controls, the adversary can then send an armed drone to attack the operators or fire mortars or shells at them.[456] Both sides have extensively used a DJI system called AeroScope, and Ukraine has used an Edgesource system called WindtalkerX, to pinpoint operators. Ukraine eventually developed software that could be uploaded onto DJI drones to disable the tracking, and DJI stopped selling the commercial AeroScope system.[457]

Kamikaze Drones: the Lancet-3, Shahed-131/136, Switchblade 300, Warmate, and FPVs

Both sides have used a diverse range of kamikaze drones for tactical and strategic strikes throughout the war. The types of kamikaze drones used have spanned from military-grade medium-range loitering munitions, to long-range Ukrainian drones and Iranian-built Shahed-131/136s, to very short-range modified commercial FPV drones. These drones, therefore, are primarily used as strike weapons and often paired with surveillance drones in hunter-killer teams or larger drone groups.[458] While the use of kamikaze drones in Ukraine far outstrips any prior war, most of these weapons are not fully autonomous, as a human operator still selects the target and when to engage it. As in Libya, there are reports that some of these systems have autonomous capabilities, but this is hard to verify.[459] Instead, it is likely that most of the kamikaze drones used thus far in Ukraine are controlled by a human operator or hit preprogrammed coordinates.

In general, Russia has had more kamikaze drones than Ukraine. It has maintained an advantage in military-grade loitering munitions, which are capable of damaging high-priority mobile targets such as howitzers and SAMs. Russia entered the war with two military-grade loitering munitions in its inventory—the Kub-BLA and the Lancet-3. Although these Russian kamikaze drones appear similar, with two- to six-pound warheads and a range of 25 miles, they have performed very differently on the battlefield.[460] The Kub performed poorly, often missing targets or experiencing warhead malfunctions, leading the Russian forces to increasingly employ the Lancet-3s by the second half of 2022. Operated by experienced Russian drone pilots, the Lancet-3s have proved very effective, especially at counterbattery fire and SEAD/DEAD missions.[461] Since March 2023, Russia has become increasingly reliant on battlefield kamikaze drones, and they have reportedly become the preferred weapon for attacking Ukrainian artillery.[462] Typically, an unarmed military drone, such as an Orlan-10 or ZALA 421-16E, finds a target, and then operators launch a Lancet-3 to perform the strike.[463] Hunter-killer teams of ZALAs and Lancets have also been used to

immobilize armored vehicles that are then destroyed by artillery fire.[464] Improvements to the latest variant of the Lancet-3, including arming it with a heavier 11-pound warhead, have enhanced its performance.[465] Although Russian loitering munitions can be deadly, the Ukrainians have developed many counters, including using small-arms fire and shoulder-fired MANPADs to shoot down the slow-moving drone.[466] One of the most prevalent counters has been a simple metal screen or mesh net that stops the drone short of the target and forces it to detonate prematurely.[467] Decoys have also effectively fooled loitering munitions.[468]

By comparison, Ukraine has not employed military kamikaze drones to significant effect on the battlefield. In general, Ukrainian kamikaze drones, such as the Switchblade 300, Warmate, Drone40, or RAM II, are smaller than the Russian drones and optimized for attacks on personnel or tanks.[469] For instance, the tube-launched Switchblade 300 is a small drone with a 15-minute loiter time that Ukrainian special forces have used primarily against exposed Russian troops, but the system is reportedly not user-friendly and frequently fails due to Russian jamming.[470] Ukraine does not have large numbers of loitering munitions for SEAD or counterbattery missions but has tried to fill this capability gap with the larger Switchblade 600 and Polish-made Warmate kamikaze drones.[471] There are few reports of how the Switchblade 600 has performed. The Warmate has been effective, but Ukraine likely has not acquired large numbers of these drones, in contrast with Russia, which has ramped up production of Lancet-3s.[472] Because kamikaze drones can only be used once, many are required to appreciably affect the battlefield.

Ukrainian and Russian forces have increasingly relied on cheap commercial or DIY FPV kamikaze drones, which can be quickly manufactured by volunteers and purchased in large numbers.[473] These small drones designed for racing are controlled by pilots wearing augmented-reality headsets, and are modified to carry grenades. These drones' powerful engines allow them to carry slightly larger payloads than typical commercial drones, up to five pounds of explosives, but still pack a much smaller punch than artillery or antitank missiles.[474] Pilots try to crash the kamikaze drones into the most vulnerable point on a target. Although there are many videos of FPV drones seemingly successfully striking targets, it is unclear whether these systems do enough damage to seriously harm or disable them. FPV drones are very fast and highly maneuverable, but require more pilot training than typical commercial drones. Skilled pilots can use this payload to disable or destroy even armored vehicles by aiming for their weak points, such as open doors or windows.[475] Unlike other drones, FPVs are not used much for surveillance because their speed and limited endurance makes them better suited for strike. Initially, Ukraine led the way in FPV experimentation but, seeing Ukrainian success, Russia once again played the role of the fast follower and adopted FPVs. Russian volunteers set up their own factories to build FPV drones and have produced tens of thousands of drones a month that have made an impact on the battlefield.[476]

July 2022 saw the first recorded instance of a Ukrainian FPV racing drone flying through the open doorway of a house to reach its target.[477] Since then, Ukrainian FPV production has ramped up to thousands of drones a month, enabling troops to use these weapons against self-propelled mortar trucks, tanks, transport trucks, and infantry fighting vehicles.[478] They reportedly played an important role in the Ukrainian defense of Bakhmut.[479] Ukrainian drone operators admit that the kamikaze drones do not have as high of a success rate as more expensive antitank weapons, but they argue that because the drones are inexpensive and still hit their target half of the time, mass could compensate for FPVs' inferior performance.[480] Russia relied heavily on FPV kamikaze drones to blunt Ukraine's summer 2023 counteroffensive, striking Ukrainian moving vehicles. Videos show Russian FPVs ramming into Leopard tanks, Mine-Resistant Ambush Protected vehicles (MRAPs), Humvees, armored personnel carriers, and Bradleys.[481]

FPVs often operate in groups or with a mix of other types of uncrewed systems in a "drone stack." A drone stack includes multiple drones operating in the same vicinity but at different altitudes.[482] In this formation, unarmed drones—either commercial or military—with better endurance hover over the battlespace and watch for enemy targets to appear. A more persistent higher-altitude drone may cue another surveillance drone to verify that something is a valid target and to obtain precise coordinates. Then, an FPV kamikaze is launched and catches and overtakes the target. Ideally, the drone commanders are also linked up with nearby artillery units that might then be called on to finish off a target that has been disabled but not destroyed by a kamikaze drone.[483] Unlike the ideal of an autonomous swarm, the drone stack still requires human operators to control the drones and coordinate their actions.

Compared with other drones, DIY kamikaze racing drones are difficult to counter. Because of their speed and size, traditional gunfire is not particularly effective against them, but flak defenses may prove more effective. These drones do not rely on GPS, so they are not affected

by navigational jamming.[484] They do, however, need radio communications to connect with the pilot. If those signals are jammed, the drone may fall to the ground.[485] Because Russia makes extensive use of jamming, Ukraine is developing software that locks the FPV drone onto a predesignated target, such that if the communications link breaks, the drone can autonomously reach its target.[486] This would make the FPV a semiautonomous weapon, where the human selects the target and then the weapon automatically guides itself to the identified target. Fire-and-forget terminal guidance is tightly bound in time and space and common in other fielded weapons today. If the Ukrainians can develop this type of software cheaply using commercially available systems, it would be another major step in the democratization of precision strike, but not a fully autonomous killer robot.

Beyond the battlefield, Ukraine and Russia have used kamikaze drones for strategic strikes against deep targets. These kamikaze drones used for strategic attacks are more akin to long-range cruise missiles than autonomous loitering munitions. For instance, most of Russia's Shaheds fly to preprogrammed fixed targets instead of searching a wide area and selecting a target. Ukraine began launching drone attacks into Russia in summer 2022 but dramatically increased these attacks in spring 2023.[487] Ukraine developed at least four long-range drones—the Bober, UJ-22, the Mugin-5, and the Morok—for these kamikaze attacks.[488] Little is known about where the drones are launched from, the tactics used, or how these drones have penetrated deep into heavily defended Russian airspace.

Shaheds have played three primary roles in Russia's strategic strikes: *interceptor sponges*, *pathfinders*, and *complements*.

More is known about Russia's Shahed kamikaze drone strikes on Ukraine. Russia's strategic kamikaze drone attacks should not be examined alone, but in the context of its ongoing strategic strike campaign. Russia acquired Shaheds to supplement decreasing stocks of precision-guided missiles and has employed them as an integral part of air and missile attacks. Over time, the Russian missile and Shahed attacks have become increasingly sophisticated as Russia has experimented with different tactics and learned.[489]

Shaheds have played three primary roles in Russia's strategic strikes: *interceptor sponges*, *pathfinders*, and *complements*. These roles are not mutually exclusive as the Shaheds may perform multiple functions simultaneously. Shaheds are cheap and easy to manufacture, fly slowly, and have a loud acoustic signature, meaning they are disposable and easy to intercept, which makes them well suited to these three roles.[490] In their role as interceptor sponges, the Shahed kamikaze drones are launched with long-range fires and act as decoys that distract defensive fires from the primary weapons and exhaust Ukrainian air defense interceptors.[491] Conserving Ukraine's SAMs for more advanced Russian missiles and aircraft has become increasingly important over time as Ukraine's ground-based air defenses are the primary weapon preventing the Russian air force from gaining air superiority over the entire country.[492] Ukrainian air defenders have attempted to conserve SAMs and use antiaircraft guns such as Gepard 2 against the kamikaze drones, but some number of Shaheds have been shot down by SAMs.[493] In their pathfinder role, a group of Shaheds is fired at targets to reveal important information on the posture of Ukrainian SAMs and to help identify air corridors for follow-on missile salvos.[494] Finally, as complements, the Shaheds serve as penetration aids that increase the chance that other missiles in complex massed attacks reach their targets by confusing and distracting defenders.

The Ukrainian forces have gotten better at intercepting Shaheds and missiles. One key innovation that has enabled this improvement is a crowdsourced smartphone application that allows users to geotag incoming air threats, providing early warning for drone and missile strikes.[495] This type of application is particularly useful because ground-based radars have a limited line of sight for low-flying objects. It is also likely that Western nations have supplemented Ukraine's early warning with their own intelligence assets.[496] Ukrainian forces have improved how they allocate their air defense weapons, preserving the more expensive SAMs for cruise and ballistic missiles and relying more heavily on guns and MANPADs to destroy less sophisticated threats.

Maritime Drone Boats

Along with the many breakthroughs in uncrewed weapons, the war in Ukraine has also seen the first significant use of uncrewed kamikaze surface vehicles or maritime drone boats. Without a large navy, Ukraine has relied on antiship missiles, crewed and uncrewed aircraft attacks, and these maritime drones to attack Russian naval forces and bolster the security of Ukrainian port cities.[497] In the spring and summer of 2023, Ukraine's maritime kamikaze drone boat attacks escalated and enabled Kyiv to contest Russian control over the Black

Sea.[498] In the summer of 2023, Ukrainian maritime drones supported attacks on the Kerch Bridge, a Russian oil tanker, and a Russian landing ship in Novorossiysk.[499] Maritime drones are one of the few areas where Russia has not tried to copy Ukraine's ingenious use of uncrewed and commercial technology.

Lessons Learned from the War in Ukraine

Russia's 2022 invasion of Ukraine initiated a conventional war of a scale and intensity that many thought would never be seen again, incorporating commercial technology beyond what once could have been imagined. Drones have changed and continue to change the way Russian and Ukrainian forces fight. It is inconceivable now that ground forces would maneuver or launch an assault without employing at least a small commercial drone as a scout.

Lessons learned from the first 20 months of the war in Ukraine include:

Drones operating in stacks and connected to artillery create resilient kill chains. In Ukraine, drones have operated in stacks rather than swarms. The drone stacks in the war have been coordinated through multiple drone operators using software-based battle networks or traditional means of communication. In the drone stack, different drones are responsible for each step in the kill chain, which provides redundancy, puts the cheapest drones at the greatest risk, and makes attacks difficult to defend against.

Long-range kamikaze drones can support penetrating strikes to complement or substitute for strategic missile strikes. Ukrainian forces would not have a capability to strike deep targets inside Russia and Crimea without long-range kamikaze drones. Russian forces have used kamikaze drones to complement their more expensive long-range cruise and ballistic missiles by soaking up Ukrainian SAM interceptors, identifying the location of air defenses, and creating complex heterogeneous attacks.

Drones and their operators are vulnerable to counterdrone operations, ranging from sophisticated EW to simple nets. EW is the most effective way to stop drones, but Ukrainian and Russian forces are trying counters that range from simple barriers such as wire nets to drone dogfighting. A key part of the drone-counterdrone competition has been finding and attacking drone operators using drone tracking software such as AeroScope and WindtalkerX. Because commercial and FPV kamikaze drone operators must remain near the drone's operating area, they are vulnerable to attack.

Surveillance and targeting missions remain more important than drone strikes. In Ukraine, ground forces at all echelons are employing different types of drones to improve their situational awareness, planning, and operations. When drones are attached to artillery units, they have replaced human spotters and help to acquire targets, find their precise locations, track them, and then conduct battle damage assessment. By providing this support, drones have helped both sides conserve shells, which are in short supply, by making strikes more precise and thus effective.

Drones make it more difficult to concentrate forces, achieve surprise, and conduct offensive operations. In Ukraine, drones have provided greater visibility into enemy troop movements beyond the front lines, making it difficult for the Ukrainian and Russian militaries to mass forces. Dispersion and concealment mitigate this vulnerability, but it is challenging for dispersed forces to launch large-scale offensive operations and break through heavily defended front lines. Intelligence collected from satellites also increases the transparency of the battlefield, but drones have enabled a more rapid tactical response.

Kamikaze FPV drones offer cheap precision strike capabilities but are tactical beyond-line-of-sight weapons that primarily extend the reach of ground forces. Ukrainian forces first experimented with using FPV drones in kamikaze attacks, but because these drones proved effective at hitting exposed and mobile targets, the Russians quickly also adopted them. FPV drones are essentially very cheap antitank weapons, but their range is roughly six times that of the most advanced antitank weapon. Nevertheless, they are still tactical weapons. Their biggest drawbacks are their small payload capacity, which limits their destructive power, and the fact that FPV drones, unlike modern antitank weapons, are not automated fire-and-forget systems. Instead, FPV drone pilots require training and must be very skilled to effectively steer the fast drones and crash them into vulnerable parts of an armored target. If Ukraine were to develop autonomous terminal guidance for FPV drones, this advancement could allow them to become more effective and their use to scale because they would be less reliant on pilot skill.

Even large numbers of small drones cannot match the potency of artillery fire. Reusable military and commercial drones may be armed for ground attack, and kamikaze drones' primary mission is to conduct surface strikes. The war in Ukraine has shown that, collectively, drone strikes supplement indirect-fire weapons, but they are not substitutes for howitzers. Common artillery shells pack a bigger explosive punch and can be fired rapidly in large salvos. Thus, artillery barrages far outstrip the volume of fire that even many small drones can collectively deliver. Moreover, drones must be individually piloted and their actions manually coordinated, which currently limits the size of offensive drone group attacks.

Drones provide affordable airpower, but they have not replaced traditional air forces or been able to obtain air superiority. A core mission of most air forces is obtaining and maintaining air superiority—that is, the freedom to conduct operations in the air, which includes protecting against enemy aerial attacks and conducting offensive air-to-ground operations. Obtaining air superiority typically entails destroying an opponent's air force through air-to-air engagements or attacks against air bases and suppressing or destroying ground-based air defenses. There have been a few instances of drone dogfighting and kamikaze drone strikes against Russian bomber air bases, but these missions have been few and far between. Russian troops have effectively used hunter-killer teams of ISR and kamikaze drones for SEAD operations near the front lines but have not been able to destroy Ukraine's air defenses, especially its longer-range systems in rear areas. Early in the war, Ukraine used TB2s for interdiction strikes, but since Russian forces activated their air defenses, MALE drone air-to-ground strikes have largely ceased. Because neither side has obtained air superiority, they have both relied on standoff attacks instead of direct attacks against deep targets.

Drones do not have to be survivable if they are cheap and plentiful because one can have resiliency through reconstitution. In Ukraine, thousands of commercial and DIY drones are lost each month to EW and small-arms fire. Instead of hardening commercial drones against electronic attacks, which would notably raise the costs, both parties have opted to instead buy greater numbers of cheap drones. The logic of resiliency through reconstitution also applies to military drones. Russia, for example, has bolstered production of its Orlan-10 and Lancet-3 drones to replenish systems lost or expended during the conflict.

Case Comparison: Trends in Recent Drone Use

While the three cases from 2019 to 2023 involve the use of drones, one can see how rapidly tactics and the technologies have changed in this short time. The three cases pitted very different adversaries against each other, and the technology and employment evolved between and (in the case of Ukraine) during the conflicts. The first case, the battle for Tripoli in the Libyan civil war, was a yearlong campaign in a proxy war fought by two nonstate actors. The two factions involved primarily used two large military drone models and employed them as one would crewed aircraft for intelligence, surveillance, reconnaissance, air-to-ground strikes, and battle damage assessment. These drones were not well integrated with ground force operations, but instead focused on opportunistic interdiction strikes and were only effective when a combatant also had control of the skies with ground-based air defenses. The second case, the war over Nagorno-Karabakh, was a sharp, quick war between two small nations in which one side employed different types of drones, often together, to great effect. Azerbaijani forces refrained from employing their crewed aircraft and instead used military drones and kamikaze drones to disable Armenia's air defenses and to secure air superiority. Azerbaijani forces also integrated drones into their ground-based fires units to improve their accuracy and help SOF infiltration operations. The third case, the ongoing war in Ukraine, has pitted two modern militaries against each other, each boasting various advantages in drone warfare that have evolved over time as each player quickly innovated and adapted, countering and often imitating the other. This war has seen continued roles for military and kamikaze drones and a massive boom in commercial drone capabilities and employment. In Ukraine, drones are deeply integrated into ground force operations, especially artillery units, and connected through battle networks that enable them to rapidly share information. The most critical roles for drones have been surveillance and artillery spotting, although the rise of FPV kamikaze drones has increased the importance of strike. Together the density of small military, commercial, and FPV drones has made it risky for either party to mass forces near the front lines, which in turn has decreased the ability to launch surprise attacks.

In the case studies, drone warfare rapidly evolved and yielded the following findings:

While drones provided critical capabilities in all three cases, their importance to battlefield outcomes has

been exaggerated. Drones have not made tanks obsolete. In a high-intensity war, all weapons are vulnerable, and their utility depends on how they are employed. Armenian tanks were vulnerable to drone strikes because of the lack of adequate air defenses and failure to use passive defenses to enhance their survivability. In Ukraine, FPV drones have increased the risk to tanks and other vehicles, but armored vehicles continue to offer protection to ground forces, especially because many of these drones carry small payloads and are vulnerable to jamming.

Drones alone did not determine who won or lost in any of these cases. It was robust Turkish military support—rather than solely Turkish drones—that helped the GNA to win the battle for Tripoli in 2019 and Azerbaijan to decisively defeat Armenia in 2020. In Libya, Turkish air defenses, drones, and mercenaries contributed to the defeat of the LNA; in Nagorno-Karabakh, Turkish planning, mercenaries, and training of Azerbaijani troops, especially SOF, proved critical. In Ukraine, the proliferation of short-range commercial and military drones and kamikaze drones has not decisively advantaged either side, but instead pushed both parties to disperse their forces.

Across the three case studies, there was a decreasing emphasis on large military drones and increasing use of small military and commercial drones and kamikaze drones. While both parties in Libya used commercial quadcopters, these were not weaponized or as significant as Wing Loong and TB2 drones. Nevertheless, older Turkish air defenses in Libya kept the LNA's Wing Loong drones at bay. In Nagorno-Karabakh, Armenian air defenses were antiquated, sparse, and remained stationary. Once Azerbaijani forces launched a concerted SEAD/DEAD campaign, Armenian SAMs were quickly targeted and largely eliminated, providing Azerbaijan with air superiority. Azerbaijani forces were able to use the TB2 as a strike platform throughout the conflict because they dismantled Armenia's weak air defenses, but kamikaze drones were equally critical to this SEAD. Because neither party in Ukraine has air superiority, large military drones have been eliminated or held in reserve. TB2s received a lot of coverage in the first days of the war, but once Russian air defenses began operating, Ukrainian military drone losses started piling up and Ukrainian forces began employing them more sparingly. Russia has also withheld its larger military drones. Ukrainian and Russian forces have instead relied heavily on smaller military and commercial drones to saturate the front lines. Kamikaze drones—both military-grade systems such as the Lancet-3 and DIY FPV—provide both sides with alternate strike weapons as other types of ammunition run low.

There are many ways to counter all types of drones, but a layered system of defenses is needed to protect against the full spectrum of threats. As discussed, when operated by capable personnel, modern integrated air defenses can hold at risk most military drones. Yet it often is not economical or wise to waste expensive SAM interceptor missiles on cheap drones. Self-propelled antiaircraft guns offer a more cost-effective way of shooting down smaller low-flying drones. Electronic warfare has accounted for major drone casualties in Ukraine. In addition to larger truck-based EW weapons, handheld jammers and smaller systems appended to vehicles provide useful tactical defenses. Ukraine has also experimented with drone dogfighting, and Russian and Ukrainian troops have made extensive use of cages and nets to stop kamikaze drones from reaching their targets. The drone-counterdrone fight often comes down to a cost competition as defenders need to find economical ways of defeating cheap drones.

Drones can be useful to ground, air, and maritime forces and are needed at all echelons. In Libya, military drones were employed like an air force and were not under the control of ground forces, who only had commercial drones. In Nagorno-Karabakh, Azerbaijani drone operations were more coordinated and integrated with ground force operations, and SOF made extensive use of smaller drones, including kamikaze drones. In Ukraine, the integration of drones into ground force operations has deepened. The larger reusable drones controlled by the Russian and Ukrainian air forces have played a less prominent role, but long-range kamikaze drones continue to be used for strategic strikes. Drone boats have played a smaller role in these largely air and land wars, but there are hints that they could be useful. Ukraine, for instance, has developed drone boats to deny Russia's Black Sea fleet the ability to operate near its shores. In Ukraine, the growing role for small drones has meant that drones are not just employed by highly skilled pilots in specialized drone units, but instead have become a critical part of operations at each echelon.

Drones enable riskier missions and seem particularly well suited for SEAD/DEAD operations. Parties in all three cases sent drones on risky missions with low probabilities of success that they may not have undertaken with crewed aircraft. One of the most risky and challenging operations is suppressing or destroying the enemy's air defense systems. The GNA used TB2s supported by EW to attack LNA SAMs in Libya. Azerbaijani forces employed more sophisticated tactics that added kamikaze drones to the approach used in Libya and were quite successful.

Similarly, Russian forces paired their ISR drones with kamikaze drones, such as the Lancet-3, to attrite Ukrainian air defenses. Drones may not be necessarily better than skilled fighters armed with antiradiation weapons and jammers, but they do not put at risk any operators and they offer a cheaper way of conducting a critical mission.

Because most drones are not survivable, large drone fleets are required and the ability to rapidly produce additional drones is critical in a protracted fight. In Libya, when Turkey provided the GNA with several TB2s early in the battle for Tripoli, these were ineffective. Similarly, Armenia's small fleet of drones was quickly eliminated. In Ukraine, Russia lost most of the military drones that it entered the war with, but it has been able to scale production of key systems. These cases drive home the vulnerability of all of today's drones to a variety of countermeasures. However, resiliency can be achieved through reconstitution. This requires having a large and diverse drone fleet and the ability to quickly replenish drones that are lost.

Drones are more effective when used in pairs or groups, but these tactics are not true swarms. Over the time covered by the cases, drone tactics have progressed, and it has become increasingly common for drones to operate together. Libya did not yield examples of this teaming. As a part of their SEAD operations, Azerbaijani forces used an improvised drone made from an old crewed aircraft as bait and a kamikaze or military drone to then kill the Armenian air defenses that took the bait. Azerbaijani forces also frequently employed TB2s with military kamikaze drones to hit Armenian forces. In Ukraine, there has been a further evolution to drone tactics with hunter-killer drone pairs and stacks of drones operating over the front lines. Troops on both sides are also using multiple FPV kamikaze units to support assaults and defenses. But there are limits in terms of coordinating drone operations, the vast majority of which remain remotely piloted rather than autonomous. Electronic interference also limits how many FPV drones can currently operate in the same airspace. Drones with more autonomy will be needed to achieve true swarming tactics.

Drones have removed people from some of the most dangerous ground and air force missions, such as spotting or SEAD/DEAD, but many human drone operators are still needed. Drones are being used as substitutes for particularly dangerous missions, but because they are remotely piloted, they still require operators, and the pilots of short-range drones are still at risk. Often, multiple people are needed to operate each drone. Current drones, therefore, do not reduce personnel requirements, but do put fewer operators at risk. Until greater autonomy is realized, drone operations will be constrained by the number of operators available. On the positive side, these operators can become extremely skilled, because even when a platform is lost, the operator usually survives and learns.

The drones used in these wars were remotely piloted and had little autonomy. None of these conflicts involved many, if any, fully autonomous drones. The majority of drones employed in all three cases were remotely piloted. There were some limited forms of autonomy, such as automatic takeoff and landing and collision avoidance systems, but drones did not independently find, select, and engage targets. Ukraine is working to develop semiautonomous FPV drones with terminal guidance, but these systems still require a human to select the target and make the decision to engage. Autonomous navigation and object recognition could guide the FPV into its desired aimpoint but would not make the FPV a fully autonomous weapon.

Drones complement other weapons and can partially offset capability gaps, but they have not replaced crewed aircraft, artillery units, or missiles. Drones can provide affordable aerial surveillance and strike, but alone they were only able to attain air superiority in the Second Nagorno-Karabakh War. One should exercise caution in generalizing from this single case because the outcome was influenced by Armenian forces' inept tactics and weak air defenses, and the fact that neither side was willing to employ its crewed air forces. Had Armenia employed its traditional aircraft, it might have been able to eliminate Azerbaijan's MALE drones. Similarly, drones cannot substitute for howitzers or advanced missiles. Because drones are slow-moving, many if not most of the long-range kamikaze drones used for strategic strikes in Ukraine are intercepted and thus not as effective as cruise or ballistic missiles. Similarly, even large numbers of drones cannot match the potency or volume of artillery fire. Moreover, the size of FPV drone attacks is currently limited by radio interference and the need to manually coordinate operations.

Looking across the three cases provides important findings that should inform U.S. concept development for drone operations against the PLA in the Indo-Pacific. It is critical to note the differences between the recent wars and a potential future war with China in order to distinguish between the lessons that do and do not apply. Drawing on the insights from these cases, while considering the differences, the next chapter discusses how drones could be used in a U.S. war with China to defend Taiwan.

CHAPTER 4

Drones in an Indo-Pacific Fight

The DoD considers a Chinese invasion of Taiwan the most challenging and important scenario for U.S. force planning.[500] For some time, the DoD has sought new technologies and operational concepts to offset China's growing military, and the DoD sees drones as an enduring American military strength and an important part of the solution. The Pentagon already plans to buy thousands of attritable drones, which likely means one-way or very cheap, to counter the Chinese military's numerical advantage. Similarly, Taiwan seeks to boost its production of uncrewed systems so drones can play a more prominent role in the island's defense. China is also watching and learning from the war in Ukraine and has prioritized building and fielding a range of uncrewed systems that the United States and Taiwan would need to counter in a war.[501] This raises a number of questions: What roles could all these drones play in such a war? Would the same drone types, tactics, and counters employed in recent wars be useful in the Indo-Pacific context? Could drones tip the balance in favor of the United States and its partners, as many hope?

To explore these questions, the authors conducted a concept development tabletop exercise (TTX) focused on the Taiwan scenario. The TTX included three teams: one that played the United States, one that played China, and one that played Taiwan. Because the aim was concept development, the scenario was not set in a specific year, and instead players were instructed to consider what could be done with current and emerging uncrewed technologies. The TTX was not a rigorous test of the drone operational concepts, but the teams did point out strengths, weaknesses, and counters for ideas presented. This TTX reinforced two key challenges facing the United States in this scenario: geographic asymmetry and the necessity of attritable mass. It also yielded a variety of possible operational concepts for the different belligerents, which the authors expanded on and added to in subsequent research, drawing selectively on findings from the historical case studies detailed in the previous chapter. The following chapter details these challenges and operational concepts for China, Taiwan, and the United States.

The Geographic Challenge: the Tyranny of Distance in the Indo-Pacific Theater

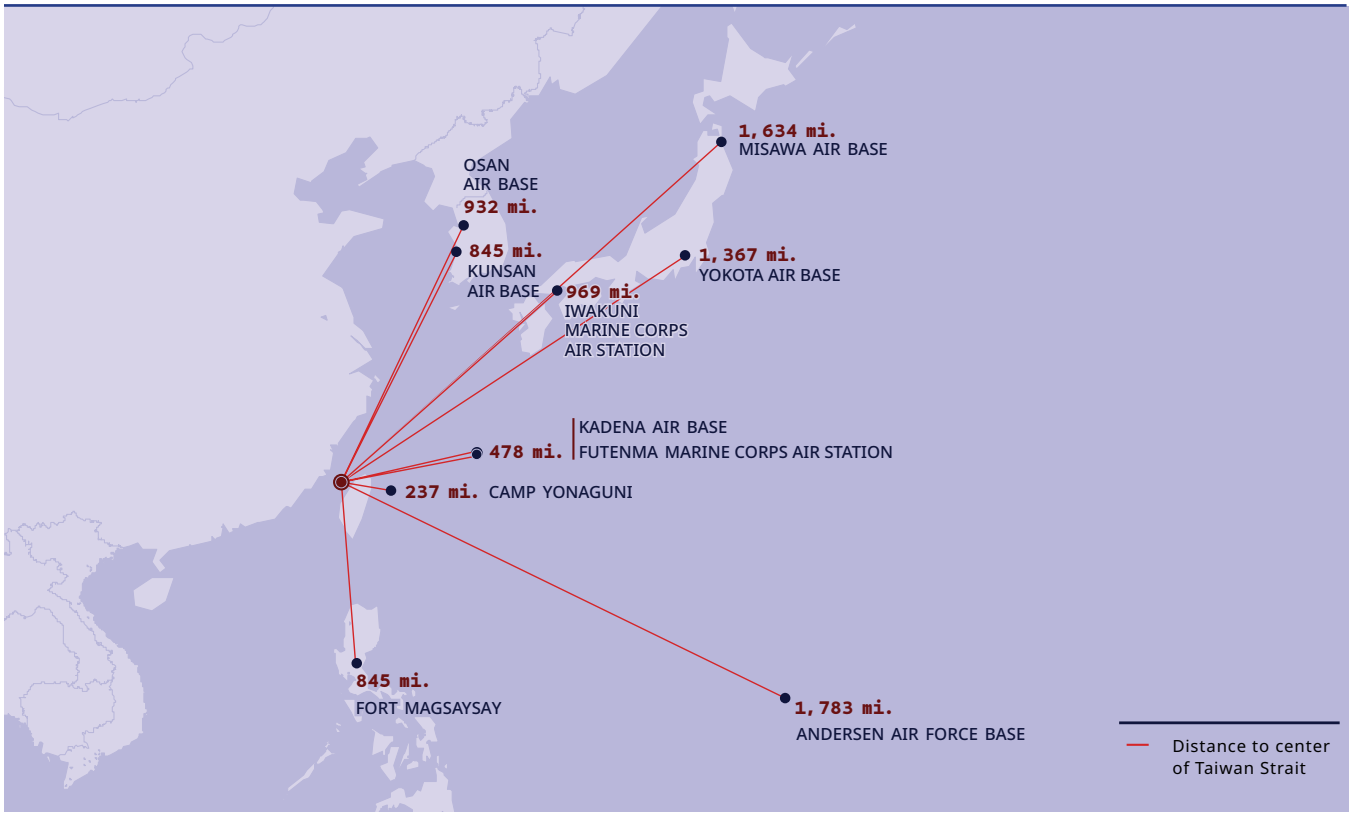
The geography of the Indo-Pacific impacts the types of drones that could be useful for different actors in a Taiwan invasion scenario. It differs vastly from that of Libya, Nagorno-Karabakh, and Ukraine. Those conflicts were primarily ground and air wars, and consequently, most of the combat occurred in close contact with the enemy and at tactical ranges of at most 15 to 20 miles.[502] In contrast, the Indo-Pacific is primarily an air and maritime theater and most American and Chinese forces would be operating from air and sea bases that are hundreds if not thousands of miles apart. Wargames and analysis suggest that the first few days and weeks of a U.S.-China war would center on a long-range shoot-out.[503] In part, this is because both sides emphasize quick and decisive action against enemy forces and have operational concepts that rely heavily on long-range precision-guided missiles.[504] But it is also due to the challenge that the geography creates for the United States in this scenario. China is very close to Taiwan, while the United States is very far away. This means that Beijing and Washington would need to utilize different classes of drones in their operations.

Chinese forces must cross the 110 miles of the Taiwan Strait to land on the island. While contested amphibious assaults are incredibly complex and challenging, this is a relatively short distance for China to project power, enabling it to use many different types of drones. Moreover, this is a home game for Chinese PLA forces that can operate from their large network of hardened military bases on the mainland. For instance, China has more than three dozen military air bases within 500 miles of Taiwan.[505] Currently, PLA Navy (PLAN) and PLA Air Force (PLAAF) high- and medium-altitude military drones, such as BZK-005, Wing Loong I, and Wing Loong II, could easily range Taiwan and beyond from any of these mainland Chinese bases. But China could also make use of shorter-range PLA and PLA Rocket Force (PLARF) drones, such as ASN-06 and ASN-07, launched from its own shore.[506] Even the shorter-range Harpy or ASN-301 kamikaze drone, which China purchased in 1994, fired from the Chinese coast could reach and loiter over Taiwan's beaches for hours.[507]

In contrast, the United States must overcome the tyranny of distance and conduct offensive operations more than 6,000 miles from the continental United States.[508] The DoD has a network of bases in the Indo-Pacific region that provide its military with forward operating locations, but all are hundreds of miles from Taiwan.[509] The nearest American air bases are on Okinawa, which is 478 miles from the center of the Taiwan Strait.[510] Guam, the closest U.S. territory, is more than 2,000 miles from the center of the Taiwan Strait. Most bases in Japan and the Philippines are more than 1,000 miles away.[511] In the early days of a fight, U.S. Navy warships are likely to operate outside the range of most

Figure 15 | U.S. Bases in the Western Pacific

To bring the full might of the U.S. military to bear in a war to defend Taiwan, U.S. forces would have to traverse hundreds of miles from even the U.S. bases closest to the straits, constraining the capabilities applicable to a fight and requiring novel operational concepts.



Source: Google Earth, Center for a New American Security analysis

of the PLA's antiship missiles, which can reach the Second Island Chain. Thus, sea-based American drones would also need significant range and endurance to reach the Taiwan Strait, the main area of operations. High- and medium-altitude MQ-9 Reaper and RQ-4 Global Hawk drones, which can stay aloft for more than a day and fly long distances, can operate from theater air bases, but there are limited numbers of these drones and they are always in high demand across the globe.[512] For instance, the United States could not field enough drones to meet the requirements during the peak of Operation Inherent Resolve, the fight against ISIS in Syria and Iraq.[513] Moreover, the war in Ukraine has demonstrated that MALE and HALE drones are not survivable in this type of contested airspace. The DoD currently has few other drones it could employ from within the Indo-Pacific theater given the distance between bases and likely operating areas.

Comparing U.S. range requirements in a Taiwan fight to the range requirements of the wars in Libya, Nagorno-Karabakh, or Ukraine, it is obvious that the United States needs to develop a much larger, different class of drone than has been commonly employed. Commercial quad-copters will only be valuable to troops in close combat, and it is unlikely that American ground forces would deploy to Taiwan. One of the larger military drones used in many of the recent conflicts, the Bayraktar TB2, has a maximum range of 186 miles, while the Forpost and Orion, Russia's longest-range drones, at most can fly 155 miles.[514] Maximum range, however, differs from combat radius for reusable drones, such as the TB2 or Forpost. Reusable drones must be able to fly out to the operating area, remain on station long enough to complete their mission (e.g., surveil an area, find enemy targets, or engage a target), and then fly back to a base or landing area to be recovered. To illustrate these requirements, a 2020 RAND report developed a concept in which truck-launched reusable drones find targeting tracks for Chinese ships during an invasion scenario and pass this information to incoming long-range missiles. The study concluded that the smallest of these drones, called the kitten, would need to have an over 3,800-mile range and be based within 1,150 miles of the Taiwan Strait to acquire targeting tracks on Chinese ships.[515]

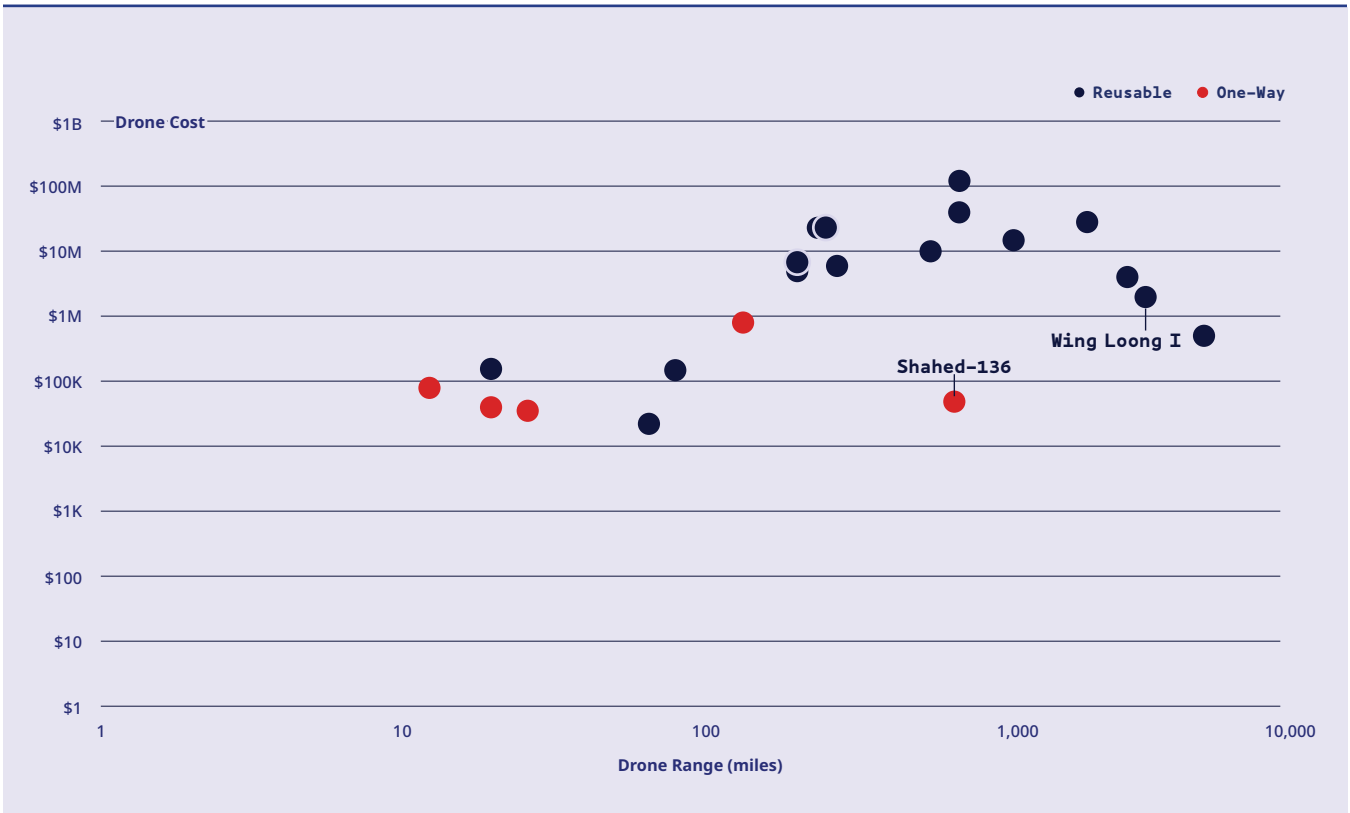
The Challenge of Affordable Long-Range Mass

The case studies revealed that no existing drones are truly survivable and that large and diverse drone fleets are needed to significantly affect the battlefield. In Libya, the GNA's first small TB2 fleet was quickly eliminated, and similarly Armenia's small inventory of short-range drones had no appreciable effect on outcomes in the 2020 Nagorno-Karabakh War. The war in Ukraine has further driven home that numbers matter and that being able to mass firepower against enemy forces is important. The number of missiles and artillery shells expended and drones lost by both sides is staggering.[516] Thus, whether the drones are reusable military systems or one-way kamikaze drones, the United States needs thousands if not tens of thousands of drones. For instance, the drone targeting mesh concept proposed in a 2020 RAND report calls for 3,000 unarmed truck-launched drones because it anticipates losing more than 1,500 drones in a conflict.[517]

Most of the drone losses in the case studies were made more tolerable by the fact that the majority of the drones employed were relatively inexpensive. Because the drones were uncrewed and affordable, they were sent on missions where losses were expected to be high. The operational concept used by Turkey in Syria and then refined in Libya and Azerbaijan was premised on sending multiple TB2s on SEAD missions supported by EW to overwhelm air defenses. TB2 losses were anticipated but acceptable because they destroyed high-value enemy assets. Over time, this tactic was improved by adding in Harop kamikaze drones, which helped saturate the airspace and destroy SAM radars. Similarly, Russia has employed Orlan-10 and Orlan-30 ISR drones and Lancet-3 kamikaze drones to hunt for Ukrainian SAMs and has lost a considerable number of the drones in doing so. Yet it is important to note that neither the TB2s, Orlan-10s, Orlan-30s, Harops, nor Lancets are sufficiently long range to be employed by the United States in a Taiwan fight.

Range and cost often go hand in hand, although this is not a linear relationship. The drone's airframe is only one of the many factors that drive cost and often not the most important one. Additionally, the drone's mission systems that enable communications,

Figure 16 | Common Military and Kamikaze Drones by Range and Cost[518]
For the most common drones used in the Libyan civil war, the Second Nagorno-Karabakh War, and the ongoing war in Ukraine, as well as some Chinese and American drones, range is correlated with cost.[519]



navigation, and an ability to sense and affect the environment tend to be as expensive as the aircraft itself, if not more so. Figure 16 plots the estimated range and cost of some of the drones employed in the case studies as well as some American drones and illustrates the relationship.

Several of the plotted drones stand out as outliers that break the cost curve and have long ranges but remain relatively inexpensive. For the most part, these are Chinese and Iranian drones. Chinese Wing Loong MALE drones closely resemble American drone models and cost a fraction of the price but are also less capable and reliable than their American counterparts.[520] The Wing Loong I is intended to be reused, but to keep costs low, at approximately $1 million to $2 million, it sacrifices performance.[521] The durability or sophistication of a drone's materials and components also drives cost. A kamikaze drone such as the long-range Iranian Shahed-136, which costs $50,000 and has been used extensively by Russian forces against Ukraine, only needs to make one trip. For this reason, the Shahed-136 is constructed from inexpensive materials, such as carbon fiber honeycomb fabric and mass-produced commercial electronic components, making it much cheaper than reusable military-grade drones.[522] Iran has economized this capability, developing a drone that is just good enough to complete the mission.

To afford the thousands of drones likely needed for a war against China, the United States would need to develop cheaper drones with sufficient range for the theater. Kamikaze drones could be an important part of the solution and appear to be what the DoD is producing with its replicator initiative.[523] The trick is developing a cheap enough kamikaze drone that is suited to the challenges of the Indo-Pacific theater. Unlike most of the kamikaze drones used by Russia that can only strike fixed targets, American kamikaze drones would need better sensors and a seeker capable of finding mobile targets. The more sophisticated Israeli Harop kamikaze, with these sensors and seeker, can only fly about 124 miles, but costs approximately $800,000 each.

Kamikaze drones alone, however, are not the answer. As seen in Nagorno-Karabakh and Ukraine, a diverse stack of drones is preferable for many reasons. A heterogeneous drone mix provides resilience and imposes dilemmas on adversaries.[524] In addition to a robust fleet of kamikaze drones, the United States should invest in cheap, reusable long-range drones, which would likely carry single-mission payloads (e.g., ISR or jamming). These cheaper reusable drones could help to target kamikaze drones as well as long-range cruise missiles but need to move toward the price point of a $5 million TB2 so that the DoD can afford to buy thousands of them. More capable and expensive drones may provide overwatch at higher altitudes and from standoff ranges until Chinese air defenses are weakened. Additionally, higher-performance reusable drones, such as those envisioned by the U.S. Air Force's CCA program, could be used in air-to-air missions. While there should be differences in cost between kamikaze and reusable drones, all of the drones need to be inexpensive yet capable enough that the United States will be willing to send them on risky missions.

Notably, this approach of buying smaller, cheaper, and "just good enough" contradicts the DoD's tendency to procure multimission weapons that are large, expensive, exquisite—and relatively few in number.[525] The 2020 RAND report estimated that its proposed kitten drone would cost roughly $500,000 for each airframe, which would bend the cost curve in the right direction. While this number includes its launch vehicle, it does not include the sensors or mission systems, which will inevitably drive up costs.[526] It could, however, fill the role of the single-mission reusable drone.

The DoD needs to acquire drones with the range to perform useful missions in this theater that can be purchased in sufficient quantities to make up for the many that will inevitably be lost in combat. To do so, the United States needs to invest in a robust drone production capacity so that it can achieve resilience through reconstitution, as Russia has done in Ukraine.[527] The ability to quickly scale up drone production has been an important factor in the Ukraine war and to a lesser extent the Libyan civil war. In the latter conflict, Turkish industry was able to rapidly deliver additional batches of TB2s, but in relatively small numbers. In the protracted Ukraine war, production has proved to be critically important. While Ukraine has consistently out-innovated Russia in drone development, Moscow's ability to mass-produce military drones and FPV kamikaze drones is providing it with an edge on the battlefield. It is not clear that the U.S. defense industrial base, which has struggled to produce munitions in sufficient quantities, is currently capable of producing the quantities of drones needed for a war with China.[528] However, just as important as figuring out how the United States will manufacture these drones is the development of appropriate operational concepts for their use in a war to defend Taiwan, and thinking about how adversaries and partners might employ drones.

Chinese Operational Concepts

As the United States develops and refines its own plans to use drones, it must also plan to respond to China's efforts to do the same. In an invasion scenario, Chinese forces must first and foremost rapidly establish a lodgment on Taiwan and then seize the capital. To achieve this overarching goal, China must also find, fix, track, and neutralize Taiwanese fires units and air defenses and defeat incoming American and Taiwanese attacks on its ships. China has already invested significantly in drones and could use drones of different types and with different ranges to help it realize these goals.

China has a large and growing fleet of aerial drones.[529] It could employ its long-range systems such as the Soaring Dragons, BZK-005, TB-001, or Wing Loong IIs to hunt for American and Taiwanese ships, high-value aircraft, and missile batteries.[530] If these targets were found, armed drones, such as the Wing Loongs, could engage them directly or pass targeting information to PLARF missile batteries, PLAN ships, or kamikaze drones. Long-range military drones could provide initial targets that would then be engaged by truck-launched kamikaze drones, such as the Harpy or CH-901, that can engage Taiwanese air defense radars and can range much of Taiwan from mainland China. If the PLA landed forces on the island armed with kamikaze drones, they could be used to search for any remaining air defenses or other high-value targets such as rocket launchers and artillery guns that had survived the PLA's opening joint firepower strike operations.

Many of the PLA's long-range drones would certainly be shot down by American and Taiwanese air defenses. The inventory numbers of the PLA's drones are not known, but the PLA likely has enough to absorb significant losses in order to take out high-value targets. Alternatively, the PLA might focus the opening missile salvos of its joint firepower campaign on suppressing Taiwan's ground-based air defenses and American missile defense ships, which could thin them out and make it easier for follow-on long-range PLA drone attacks.

Especially after destroying Taiwan's air defenses, PLA medium- and even some short-range drones could be used to find targets on Taiwan, which could then be engaged from the mainland by China's WS-2 multiple launch rocket systems.[531] Given that American aircraft would operate from distant bases, Chinese forces would likely have advance warning of U.S. sorties and could time drone operations to avoid American fighter sweeps. China also is developing several very high-end drones for long-range operations in defended airspace, such as the supersonic WZ-8 and the stealthy GJ-11, which may be used to find high-value mobile targets, such as Army hypersonic missile batteries or aircraft carriers.[532]

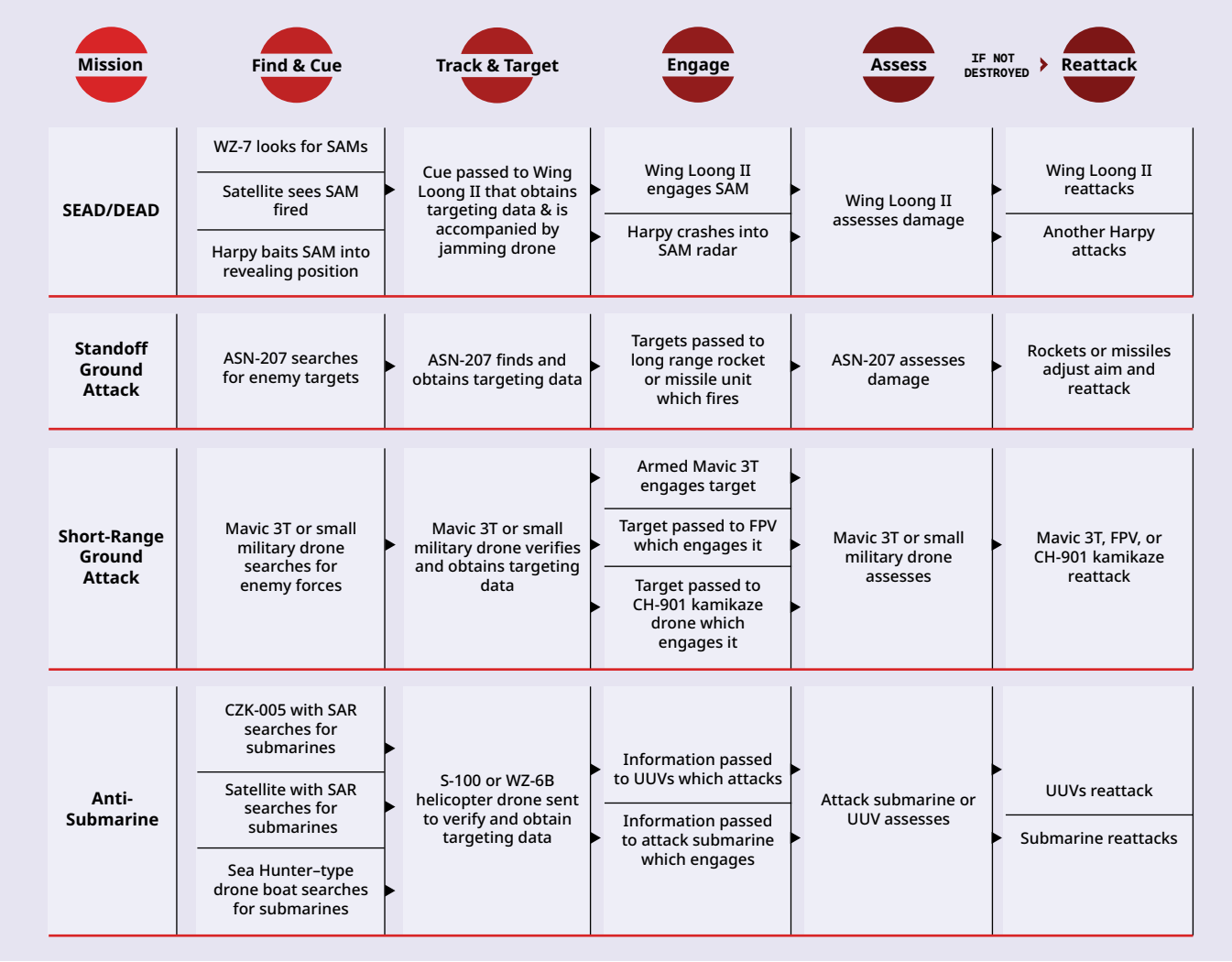
The PLAN could also use fixed- and rotary-wing drones for maritime surveillance and antisubmarine warfare (ASW) along with drone boats and undersea drones. Since American submarines pose one of the greatest threats to China's amphibious assault, this would be a priority mission. The PLA's ground-based BZK-005 and WZ-7 long-range drones could support crewed maritime patrol aircraft, such as the KQ-200, searching for American submarines and warships.[533] A growing number of Chinese frigates and destroyers also have drone helicopters, such as the UZ-6B, which could be used for surveillance and ASW.[534] The PLA's autonomous drone carrier—the *Zhu Hai Yun*—could be used to deploy undersea drones, such as the large HSU-001, in waters where American submarines have been detected by maritime patrol drones.[535] Alternatively, undersea drones could be pre-positioned in locations where American submarines are likely to transit. Finally, China could have drone boats, akin to the Sea Hunter, that search for American submarines by lurking near their likely stations in the Taiwan Strait or near other key maritime chokepoints that U.S. attack submarines are likely to have to transit through as they cycle in and out of the strait.[536] The Sea Hunters could then cue PLA undersea drones or attack submarines that would find and engage the U.S. vessels. Undersea drone attacks may not actually sink an American submarine, but the combined hunt for submarines by drones in the air, drone boats, and undersea drones could force American submarines to spend more time trying to survive than sinking PLAN ships. In other words, even if they do not sink the submarines, PLA pursuit could divert American attack submarines from their primary mission and therefore cause "virtual attrition."[537]

The PLA could arm its landing troops with small commercial or military drones that would provide situational awareness and a tactical strike capability and help Chinese forces to find weak spots in Taiwan's defenses so that the forces can get off the beaches and into better-defended positions. Inevitably, many of these commercial, presumably DJI drones would be lost, but China could harness its robust domestic drone production to provide replacements. In addition to providing these troops with some military-grade kamikaze drones to hunt high-value targets, the PLA could field tens of thousands of FPV kamikaze drones to increase the lethality of its forces in the tactical fight on the ground.

Since China has deep inventories of ballistic and cruise missiles, it may choose to use drones as decoys or to perform supporting missions instead of strikes. PLA drones thus could be decoys, interceptor sponges, or bait that tricks air defenders into revealing their location. This would be similar to how Russia has employed the Shahed kamikaze drones. Should the PLA develop fully autonomous drones, this could create further novel operational concepts. For example, PLA rocket launchers could deploy swarms of very small drones into Taiwan's airspace that would operate as a collaborative autonomous swarm. In this concept, some of the drones would emulate Chinese crewed fighters, similar to the Strategic Capabilities Office's Perdix swarm concept, while kamikaze drones would target SAM radars.[538] These Chinese drone swarms would help locate Taiwan's air defenses and force Taiwan to waste SAM interceptors on small drone decoys. Drone boat decoys could be used to flood the strait and make it difficult for American missiles and submarines to distinguish between high-value ships and worthless uncrewed commercial vessels. China could develop a kit that it attached to commercial ships to transform them into large drone decoys. This would involve remote controls for the drone ships as well as emitters that mimic the radio frequency and acoustic signature of a PLAN warship. China would hope the disguise fooled U.S. submarines and bombers so they would waste their heavyweight torpedoes and antiship cruise missiles (ASCMs) by firing at the drone ships.

Autonomous long-endurance drones, such as balloons, equipped with multiple different passive sensors to collect intelligence could also be employed to bolster China's kill chain. These balloons could also serve as communications relays and be armed with air-to-air

Figure 17 | Kill Chains for the People's Republic of China in a Taiwan War



missiles to shoot down enemy drones. These balloon drones would certainly be shot down but would require devoting fighters to the mission and could still serve their purpose by providing redundancy during the key opening phases of the war. To counter American and Taiwanese drones, China could also turn old propeller-driven aircraft armed with guns into drone killers that would clear the airspace of American and Taiwanese medium-altitude drones.[539] Finally, China could use semisubmersible surface drones that are improved versions of narco-submarines to supply the Chinese forces on Taiwan.[540]

Taiwanese Operational Concepts

Like China, Taiwan can easily make use of drones of all ranges as a part of its defenses. In the invasion scenario, Taiwanese forces would primarily focus on finding, fixing, tracking, and neutralizing China's ships to halt as much of the invasion force as possible before it hit the beaches, and then defeating any Chinese troops that do manage to land. Taiwan, therefore, is in a position to adopt an asymmetric defense strategy akin to the one that Ukraine has used and one that many analysts have urged Taipei to embrace for decades.[541] This so-called "porcupine strategy" accepts that Taiwan cannot match Chinese conventional forces one-for-one, but instead must rely on many smaller and easier-to-conceal weapons that make the costs of conquering the island so high that Beijing gives up.[542] Drones, especially large numbers of smaller systems, would anchor this approach.

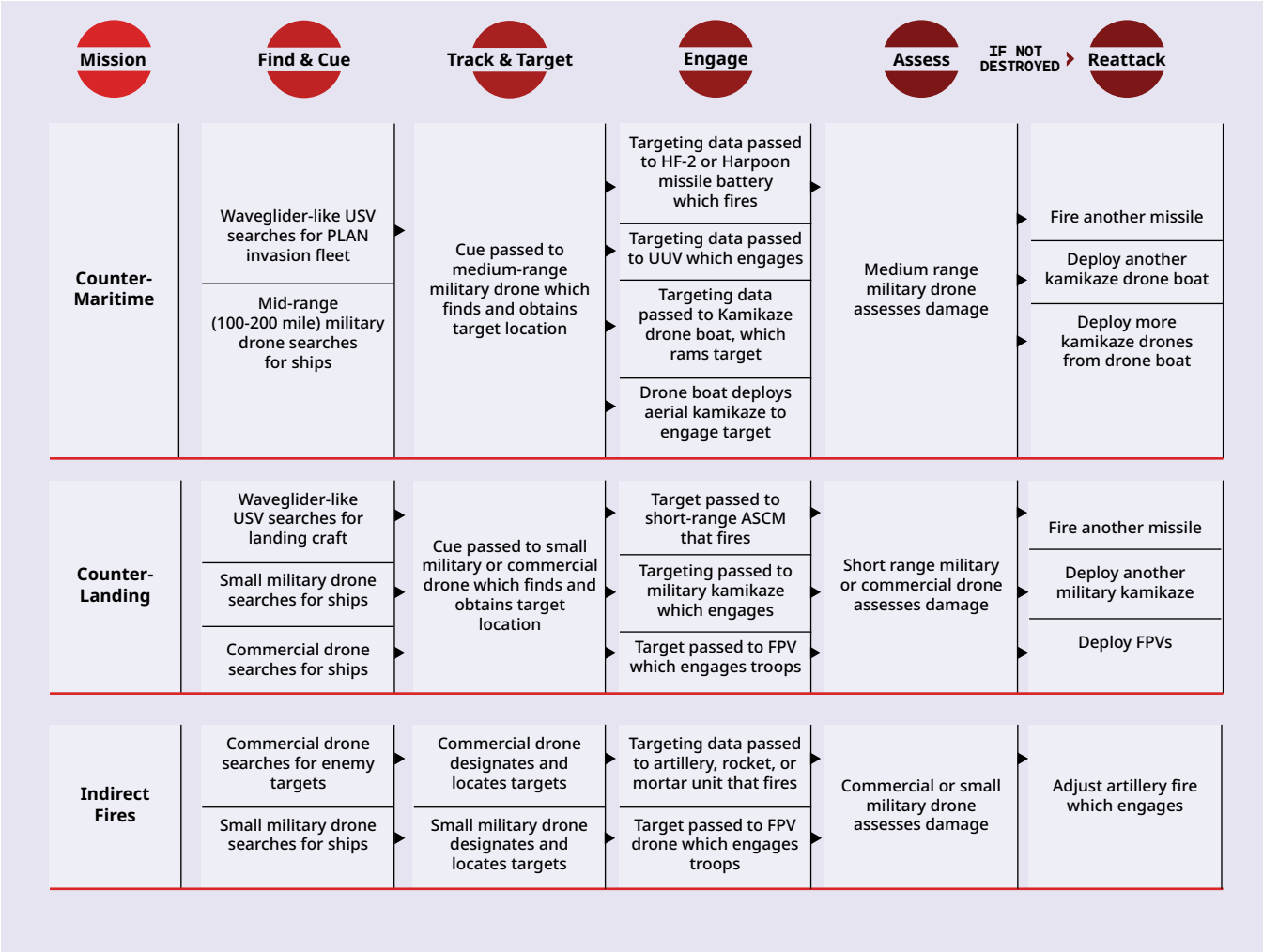
The porcupine strategy could benefit from surface, undersea, and aerial drones that together would delay and disrupt the strait crossing and provide enough time for Taiwanese and American antiship missiles and U.S. submarines to disable or destroy invading ships. To sink Chinese ships, Taiwan could couple small mobile antiship missile launchers with aerial drones that provide targeting. The ASCM batteries may be armed with longer-range Hsiung Feng II or III missiles or the U.S.-produced Harpoons, which have a range of 75 to 370 miles.[543] A 2009 RAND report concluded that antiship cruise missile attacks even without over-the-horizon targeting could significantly thin out China's invasion fleet.[544] Hundreds of Taiwanese medium-range drones assisting with targeting would significantly boost the accuracy of these attacks and disable a larger number of ships. Many of these drones would inevitably be shot down by the PLAN's air defenses and PLAAF aircraft, but if Taiwan can send large heterogeneous drone packages on raids with mostly ISR drones, but also some kamikaze drones, it would force the ships or aircraft to expend expensive missiles. Drone raids consisting of 20 aircraft or more may be able to overwhelm the defenses and acquire targeting coordinates that would then be passed to the missile launchers. So even when multiple drones are lost, these drones may be able to complete the mission if the missile launcher can rapidly close the kill chain. Additionally, Taiwan could deploy swarms of drone boats, similar to the Jet Ski variants used by Ukraine, which carry several-hundred-pound payloads and have proved capable of damaging large warships.[545] These attacks by small groups of drone boats could be cued by aerial reconnaissance drones or other drone boats collecting intelligence.

To hit ships that survive this first protective layer and are making their final approach to the shore, Taiwan could use short-range (5- to 10-mile range) ASCMs guided by short-range drones.[546] Presumably Taiwan could afford to buy large quantities of these tactical drones and missiles. Alternatively, armed short-range drones could engage the ships directly and also guide kamikaze drones or drone boats toward the transports. Unlike dedicated surface combatants, landing craft have few defenses and exposed troops could be terrorized from the air by short-range armed drones and FPV kamikaze drones.

One of the biggest hurdles to Taiwan emulating Ukraine is the dearth of commercially available drone options that are not produced by Chinese companies.

Additionally, Taiwan could deploy wave-, glide-, or solar-powered small surface drones to provide intelligence and early warning about when the first ships embark and updates on their progress, distinguishing between the high-value troop transports and decoy ships. Taiwan also could deploy large underwater drones armed with small torpedoes to attack Chinese submarines or ships directly.[547] Larger underwater drones could lay traditional shallow-water mines off the likely landing beaches to slow the Chinese advances toward the shore, making the final approach of the landing craft all the more perilous.[548] Mines could also disrupt coordination among Chinese ships and channelize maritime traffic along certain paths, making ships easier to find and engage with air and missile strikes.[549]

Figure 18 | Kill Chains for Taiwan in a Taiwan War



Taiwan would also have to defeat any of the Chinese forces that make it ashore. Drones could significantly bolster Taiwan's defenses in a close fight on its beaches, as in Ukraine. Short-range drones, probably operating in hunter-killer pairs or groups, could be used to find and target Chinese troops and then to engage them directly. Alternatively, an ISR drone could share the targeting information with a kamikaze or armed drone that performs the attack. Small drones have proved to be very effective antipersonnel weapons in Ukraine and could cause considerable damage on landing beaches, where Chinese forces will likely be disorganized, concentrated, and exposed with few places to hide.[550] FPV kamikaze drones that can be guided to targets beyond the line of sight could particularly cause physical damage and have a psychological effect if they are harassing and steadily picking off troops as they land. Drones could also be used to target artillery fire on the assembling Chinese forces. Ultimately, a variety of short-range drones and indirect-fire weapons could make it extremely difficult for Chinese troops to assemble, organize, and move off the beaches. They would also complicate Chinese efforts to resupply its landing force by interdicting supplies delivered by ships. Underwater drones and drone boats could also be used to interdict supply ships that were trying to support the Chinese lodgment.

A variety of air, sea, and undersea drones could enhance Taiwan's porcupine defense strategy and help Taipei fend off a Chinese invasion by making the costs so high that Beijing eventually gives up. Taiwan has an indigenous military drone industry that has produced a variety of military drones, but it is doubtful that Taiwan has the number of drones needed for this fight.[551] Taiwan certainly needs more very-short-, short-, and medium-range aerial drones, and kamikaze FPVs, as well as maritime and undersea drones, to conduct the sustained defense

operations outlined above. Even if non-Chinese commercial drones are available, supplying the island of Taiwan once a war has begun will be extremely difficult and is one of the key factors differentiating this conflict from the war in Ukraine. One of the biggest hurdles to Taiwan emulating Ukraine is the dearth of commercially available drones that are not produced by Chinese companies. Ukrainian forces have been able to secure a consistent supply of DJI drones despite China's prohibition of their sale to combatants. Taiwan could not rely on systems that are produced by Beijing and there are few commercial drone suppliers that can match the scale, performance, and cost of the Chinese companies. Taiwan, therefore, needs to bolster its military and commercial drone industry and build capacity to quickly assemble do-it-yourself kamikaze drones as well as employ commercial drones for short-range intelligence and targeting missions. To supplement these drones, Taiwan should prioritize acquiring large numbers of military kamikaze drones and short- and medium-range military drones that do not require runways to operate.

U.S. Operational Concepts

To support Taiwan's defense, American forces would need to conduct several key operational tasks or missions to defeat China in an invasion scenario. These include sinking the invasion fleet, providing air support to Taiwan, securing sea control or denying critical sea lines of communication, and conducting mainland strikes, each of which provides opportunities to leverage drones in different ways.[552] As discussed previously, the United States faces geographical challenges that would not affect Chinese or Taiwanese forces and, like these forces, would need to generate mass to deliver effects.

Sinking Ships

To put enough forces onto Taiwan to forcibly subjugate the island, China would need to ferry hundreds of thousands of troops across the strait via ship. The United States can try to interdict the several hundred Chinese military and commercial ships before they land on Taiwan, but because these ships would be moving, they must be found and tracked until they can be engaged. Additionally, military ships are large hard targets that may be able to withstand a hit and continue with their mission after taking some damage. In short, it is difficult to sink ships. Traditionally, there are two ways the United States would try to stop the invasion fleet: with submarines and with antiship missiles. The best way to sink a ship is with a heavyweight torpedo fired by an attack submarine.[553] Submarines are constrained by the number of torpedoes they can carry, the rate at which they can fire them, and the tight waters of the Taiwan Strait, which limit how many U.S. submarines can operate in the area.[554] To complement its undersea attacks, U.S. aircraft could fire long-range antiship missiles outside of the range of Chinese SAMs.[555] However, the United States does not have enough long-range antiship missiles, which are expensive, and it needs other capabilities to find, fix, and track the Chinese ships.[556] Furthermore, China would likely sail hundreds of decoy ships and other vessels to clutter the waters and hide its amphibious and civilian troop transport ships.[557] This increases the number of targets the United States would need to sink and creates a discrimination problem. The United States would want to preserve its most capable weapons, which it has limited inventories of, for high-priority transport ships or PLAN warships, but identifying those would be difficult.[558]

Drones in the U.S. Air Force inventory today could help target the long-range ASCMs, but doing so would require very risky missions and likely would result in the loss of many, if not all, of these relatively expensive systems. The RQ-4 Global Hawk flies at high altitudes, conducts wide area searches, and could identify high-value Chinese troop transports. This information could then be passed to legacy B-52 or B-1 bombers armed with long-range antiship cruise missiles.[559] Because subsonic cruise missiles fly at relatively slow speeds, they may be in flight for an hour or more, during which time ships could change their speed or their course unexpectedly. Standoff cruise missiles will be more likely to hit their target if they receive in-flight tracking updates. An ISR drone could remain on station for the duration of the cruise missile's flight to guide it to its target.

MQ-9B SeaGuardian drones could also perform this mission, but because they fly at lower altitudes, their search area would be more constrained and more drones would be needed to provide the same coverage as an RQ-4. There are, however, more MQ-9s in the U.S. Air Force inventory than RQ-4s, so these drones could perform the same finding, fixing, and tracking mission. Unlike the RQ-4, the MQ-9s can be armed with 500-pound laser-guided bombs and 100-pound Hellfire missiles that could be directly fired at ships once they are identified.[560] An armed MQ-9 could be employed solo on hunter-killer missions, or MQ-9s could work in pairs, where one searches for targets and uses its laser designator, while another fires on the target.

Many of the large, slow-flying RQ-4 and MQ-9 drones would inevitably be lost during these missions, which

would require them to penetrate and remain in contested airspace. Chinese airborne, sea-, and ground-based radars will be able to detect the medium- and high-altitude drones, which cannot out-maneuver fast-moving missiles or fighter aircraft.[561] In addition to fighters that could shoot drones down, Chinese forces would also likely employ extensive jamming over the strait, degrading GPS and satellite communications and preventing U.S. aircraft from accurately navigating, receiving direction from remote pilots, or passing targeting information. Finally, Chinese warships, including destroyers, cruisers, and frigates that have layered and sophisticated air defenses, could fire at the drones and intercept incoming missile strikes.[562]

A 2020 RAND report found that the weakest parts of existing American warfighting concepts for stopping the invasion fleet are the first few steps in the kill chain—that is, finding, fixing, targeting, and tracking a target.[563] Because of China's advanced air defenses, the United States would not have air superiority early in a fight and thus crewed ISR aircraft could not loiter searching for potential targets, providing targeting quality data, and following the targets as they moved. The RAND report proposed using 500 drones networked together to find, fix, target, and track Chinese ships that would be engaged by antiship missiles launched from standoff ranges. These drones would be truck-launched and recoverable. They would fly to a designated location, and because they would be networked together, they would collectively provide coverage over a larger area. The drones would constantly exchange information to create a resilient "targeting mesh." Even when China inevitably shot down many of these drones, enough would remain to guide the slow-flying missiles to their targets. The drone targeting mesh is not a swarm, but it is a relatively simple form of coordination in which the drones simply keep a certain distance from each other.[564]

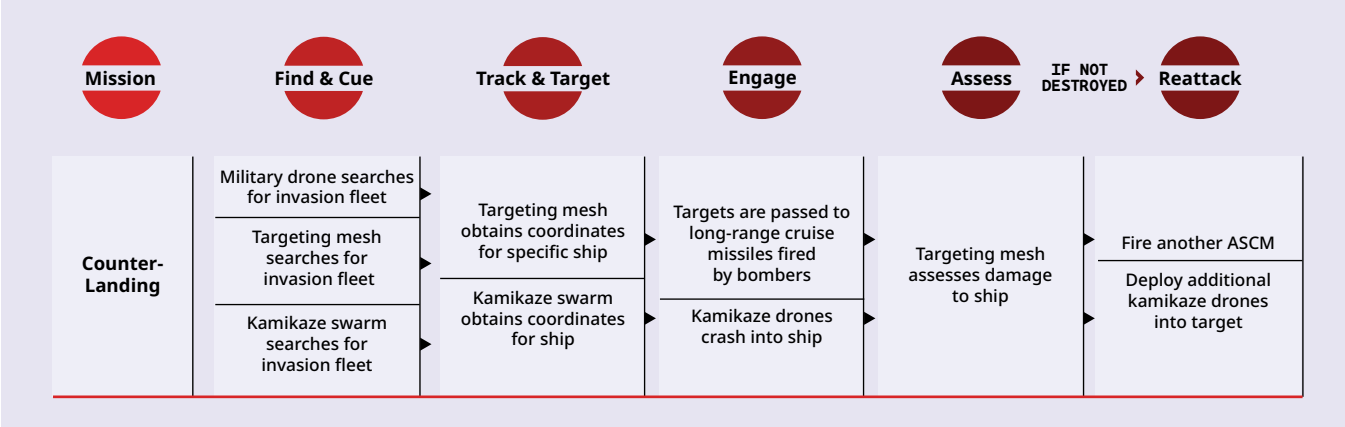
If the United States had thousands of fully autonomous long-range kamikaze drones that could home in on ships, it could take a different approach. Instead of trying to discriminate between high-value and low-value targets, U.S. forces could flood the airspace with thousands of autonomous long-range kamikaze drones that would strike any ship that they encountered within a certain geographic area. One of the strengths of this concept is that kamikaze drones complete the entire kill chain themselves, eliminating the problem of coordinating with an incoming missile and reducing the need for long-range communications in a disrupted electronic environment.

U.S. forces could flood the airspace with thousands of autonomous long-range kamikaze drones that would strike any ship that they encountered within a certain geographic area.

While more resilient in the face of electronic warfare, kamikaze drones would remain vulnerable to the same kinetic countermeasures as crewed aircraft and incoming missiles. However, if they were cheap, they could be a cost-effective way of depleting China's inventory of advanced air-to-air and surface-to-air missiles.[565] There are also questions about whether these types of attacks could critically damage large warships. As established, sinking a ship is hard. In all likelihood, long-range drones would carry a 500-pound payload and could not engage in high-speed maneuvers that penetrate ship defenses and increase the efficacy of an attack.[566] They might be able to saturate seaborne air defenses, allowing follow-on kamikaze drones to get through or paving the way for more capable missiles to reach the target. The United States would also need enough of these kamikaze drones to form many salvos of large drone swarms. It is unclear how large each attack would need to be to be effective and how many kamikaze drones would be needed in each swarm.

Advanced forms of autonomy and swarming behavior would likely increase the efficacy of these kamikaze attacks, but antiship kamikaze swarms could rely on simpler forms of autonomy that already have been proven.[567] Swarming or cooperative autonomy could enable groups of drones to fight "with greater mass, coordination, intelligence and speed than today's networked forces."[568] Sophisticated forms of autonomy, however, remain nascent today. Yet less sophisticated forms of autonomy already exist in weapons such as the United Kingdom's Brimstone missile and could be sufficient for the antiship mission. Salvos of Brimstone missiles operating autonomously can self-sort by following some simple rules that enable them to coordinate their behavior. For instance, their target selection can be determined by their firing order, where, for example, the first three missiles strike the first target and approach from the left, while the second three missiles converge on the second target that they see from the right.[569] These relatively simple rules or scripts can enable coordination between fully autonomous drones and prevent overkill but do not rely on active communications or more advanced forms of collaboration. Moreover, target or object recognition, which is also a quickly maturing

Figure 19 | Kill Chains for the United States in a Taiwan War—Sinking Ship



technology, should be easier in the relatively uncluttered surface of the ocean than on the ground.

Rather than technology, the bigger hurdle may be a policy one. The United States does not currently field any fully autonomous lethal weapons, although Department of Defense Directive (DoDD) 3000.09 permits their development as long as there is "appropriate human judgment over the use of force" (vice control).[570] Moreover, any American lethal autonomous weapon must go through a rigorous testing and evaluation and senior review process to ensure that it is safe and reliable. Currently, this testing and evaluation process for artificial intelligence is established but has not actually been applied. Ultimately, the United States needs to decide to acquire a fully autonomous weapon and then to work through the testing process so that it is trusted.

Other ideas involve using thousands of small drones delivered by a mother ship, a large aircraft, to attack the invasion fleet because the drones would be too small to carry enough explosives to damage a ship and would not have the endurance to effectively provide targeting for other weapons. Additionally, concepts to deploy smaller drones into the Indo-Pacific theater likely require tying up scarce airlift and sealift assets to transport the small drones and would require careful orchestration to ensure that the small drones were on target when needed. Alternatively, the United States could pre-position smaller drones or kamikaze antiship drones in their launchers on the island of Taiwan. Although American ground forces are unlikely to be on the front lines attacking the PLA lodgment, several hundred U.S. advisors including SOF are currently in Taiwan.[571] This detachment may be expanded in the event of a crisis to enable air-to-ground coordination and could also employ pre-positioned drones.

Drone boats and small underwater drones could similarly be pre-positioned on the island and employed in ways described in the Taiwanese Operational Concepts section. Barring that, some small solar-, wave-, or wind-powered surface vehicles could potentially self-deploy, albeit it very slowly, requiring ample warning of the invasion to reach the strait in a relevant time frame.[572] Alternatively, a commercial vessel could carry and drop the small maritime drones in nearby waters, or bombers or cargo aircraft could airdrop them. Larger underwater drones could either bolster the U.S. submarine force, serve as decoys, or deploy smaller drones akin to loitering torpedoes or mines.[573]

Fighting an Air Battle over Taiwan

If China launched a massive invasion of Taiwan and the United States came to Taipei's defense, U.S. forces would want to be able to provide air support to Taiwanese forces. Doing so would involve fighting off Chinese aircraft in Taiwan's airspace and dropping bombs on Chinese ground forces that make it ashore. The U.S. Air Force typically prefers to gain air superiority before undertaking air-to-ground attacks, but in this situation, it would not have enough time to sequentially achieve these goals. Instead, it would need to contest the airspace over Taiwan while simultaneously attacking Chinese ground forces.

Contesting the airspace over Taiwan would necessitate shooting down Chinese aircraft armed with very long-range air-to-air missiles and suppressing or destroying China's maritime air defenses that would extend over the island. To do this, U.S. forces could flood the airspace with small kamikaze drones to serve as a loitering airfield and attack Chinese aircraft. These kamikaze drones would need to be delivered by a larger aircraft and their

arrival would need to be closely timed with Chinese aircraft sweeps because of their limited endurance. This is particularly difficult given the proximity of PLAAF air bases to Taiwan and the relative distance of air bases hosting U.S. delivery aircraft (e.g., cargo aircraft, bombers, or larger mother-ship drones). Chinese forces could counter this tactic by simply waiting to send their strike packages until the kamikaze drones' life spans were exhausted. To destroy air defenses, a mixed small-drone swarm that included drones with jamming pods and drones carrying explosive payloads could be used to bait Chinese SAMs into turning on their radars or firing so they could be located and engaged in kamikaze strikes.

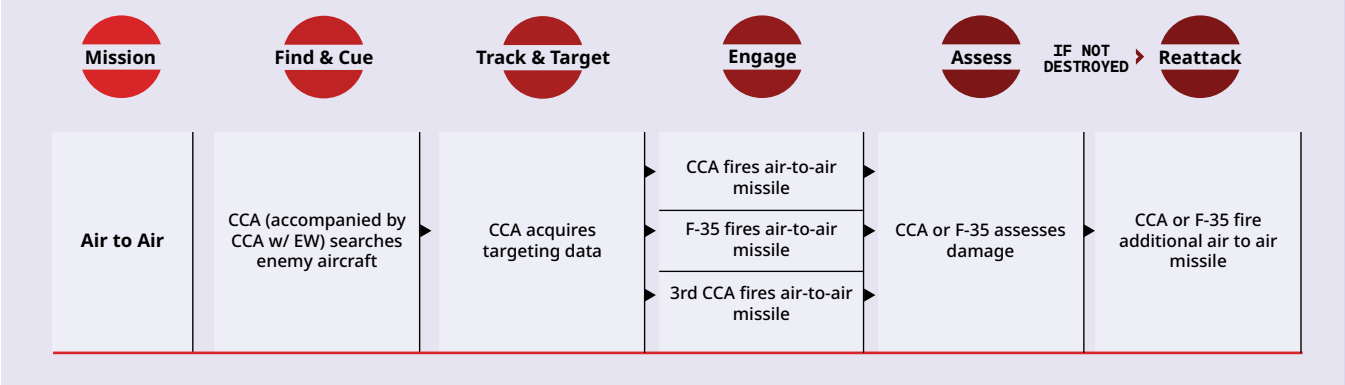
One to five of these stealth drones could be tied to a crewed fighter who acts like the quarterback and calls the plays for the drones.

Alternatively, the United States could develop more advanced jet-powered and stealth drones to accompany or replace crewed fighter aircraft, along the lines of the U.S. Air Force and Navy CCA program. One to five of these stealth drones could be tied to a crewed fighter who acts like the quarterback and calls the plays for the drones.[574] The simplest idea is to have one drone acting as a loyal wingman to the crewed fighter, possibly flying ahead of the crewed jet, extending the range of its sensors and providing extra munitions.[575] Since the F-35—the most common fighter in the U.S. inventory—is a multimission aircraft, there are multiple ways this team could operate. The F-35 could carry only air-to-air weapons, with the drone armed with ground attack or antiradiation weapons. The drone could operate farther forward into the most highly contested airspace, extending the range of the F-35's sensors and helping to target enemy aircraft. At the same time, the drone could drop air-to-ground weapons on Chinese troops on Taiwan while allowing the crewed jet to remain in the rear. Alternatively, both the jet and the loyal wingman could be armed with mixed loads or focus on air-to-air combat.

Another variant involves the crewed fighter teaming up with several loyal wingman drones that may have different capabilities.[576] By having one drone with air-to-air sensors and weapons, two with air-to-ground munitions, one armed with electronic warfare systems, and one tanker, the combined team of drones and the crewed fighter replicate a traditional strike package, but with fewer people. It thus is a self-contained unit that can conduct air-to-air, SEAD, and air-to-ground operations. This approach limits the autonomy of the drones, with the fighter pilot ultimately supervising their actions and providing them with overarching guidance on their mission and how to achieve it. Moreover, if the loyal wingman drones have a similar signature to the crewed aircraft, such as the F-35, they can also serve as decoys and force China to expend its high-end air-to-air and surface-to-air missiles on the uncrewed systems, hopefully eventually exhausting those missile supplies.[577] This approach seems very promising but may not fully leverage the potential of autonomous uncrewed systems. Tying the drones to crewed systems is inherently conservative and perpetuates the traditional way of operating.[578] It is also unclear whether the cost of the loyal wingman drones can be driven down enough that the United States can afford to buy thousands and will be willing to risk losing them in combat.[579]

A third approach for winning a future air battle over Taiwan is to use fully autonomous swarms of stealthy drones that are not tethered to crewed aircraft.[580] Many

Figure 20 | Kill Chains for the United States in a Taiwan War—Air Battle over Taiwan



networked stealthy drones sharing information from their different sensors in real time and searching the airspace from multiple angles could collectively quickly detect Chinese aircraft, obtain a track on the aircraft, and assign one drone to fire a missile and down the enemy.[581] The swarm, with its capabilities distributed across dozens of different drones acting together, could be more effective than a multimission aircraft because it can act more quickly, cover a wider area, and leverage different types of sensors looking from multiple angles. This would, however, require a more advanced form of autonomous behavior than currently exists and two-way radio communications between the drones.

Sea Denial/Control Operations

Finally, U.S. forces operating from Japan or the Philippines may want to control key sea lines of communication to keep the PLAN from getting outside of the First Island Chain. While the invasion of Taiwan may be ongoing, this is a peripheral but important mission for U.S. forces based on Japan or the Philippines, such as Marine Littoral Regiments (MLR) or Army multidomain task forces (MDTF). U.S. forces need to find, fix, track, and neutralize China's maritime militia and naval ships, clear the water of PLAN submarines, and ultimately, by doing so, keep the straits open for U.S. submarines transiting to and from the Taiwan Strait.

The more constrained geography of this mission and its proximity to American bases in Japan and the Philippines means U.S. forces could employ drones with many different ranges effectively. In these operations, U.S. and allied forces would likely have air superiority and PLA aircraft would have to fight their way in. In this environment with fewer PLA SAMs, medium- and high-altitude American and Japanese drones, if they survived Chinese attacks on U.S. air bases, could provide persistent overwatch and detect Chinese ships. The MDTF would likely be operating from the island of Kyushu and thus would need medium-range drones to target its missile batteries. The MLR operating from Okinawa could employ short- and medium-range drones launched from the shore to conduct maritime surveillance. Additionally, it could deploy swarms of wave-powered surface drones to search the area and provide persistent surveillance and faster jet-powered surface drones, such as the ones Ukraine has created from Jet Skis, to launch swarming attacks against relatively nearby targets. Similarly, the MLR could deploy underwater drones to form smart loitering minefields. One could also imagine a "quadcopter aircraft carrier" that consisted of a balloon that could be tethered to a platform with several operators who controlled the quadcopters for persistent surveillance and strike in the critical waters. This would find a way to make quadcopters useful, but the balloon would be a tempting target.

Mainland Strikes

Penetrating strikes onto mainland China would require a very long-range stealthy military drone that could carry large weapons because many of the targets on the mainland are sizable facilities, such as air bases or hardened installations. One could imagine a loyal wingman concept for the B-21 bomber in which the drone provides extra magazine capacity. But it is not clear that this would be more cost-effective than simply buying more stealthy bombers that can carry larger payloads. Stealthy long-range drones could also be used to escort the bombers to ensure that they reach their target. The experience of Russian and Ukrainian forces offers an alternative: try to reach deep targets using cheap long-range kamikaze drones, many of which will be intercepted. Both Russia and Ukraine have launched long-range kamikaze drone attacks because they lacked better options. Similarly, were the United States to employ this concept against mainland targets it would likely be as much to exhaust PLA missile interceptors and identify the location of air defenses because even if the kamikaze drones got through the air defenses, they would probably not do much damage to hardened targets. Nevertheless, since air defenses are such a high-demand and low-density asset, this could be a worthwhile use if the drones are cheap enough.

Drones in the Indo-Pacific Today and Tomorrow

Drones could play many different roles in a Taiwan invasion scenario. Lessons learned from drone use in Libya, Nagorno-Karabakh, and Ukraine suggest that the most important missions for drones would be intelligence, targeting, and strike. Drones are important sensors that help to surveil the battlespace and target other weapons and can be employed on dangerous missions because there are no humans at risk. They also can directly attack enemy forces and serve as decoys. Other important missions in this scenario are maritime strike and ASW. This nonexhaustive discussion of potential roles and operating concepts highlights how important drones could be to all the primary belligerents.

Although the types of drones and many of the tactics employed in the case studies will be useful for Taiwan and Chinese forces, the United States will have difficulty

usefully employing smaller drones because of the long distances from which its forces will be operating. American forces can deploy smaller drones of all types into the theater, but this requires some sort of larger air or sea transport, which could be attacked by PLA forces. Moreover, the most likely options are transport aircraft, such as the C-130 or C-17, and bombers, both of which are in high demand and likely already overtaxed. Additionally, timing the delivery of smaller drones, which have relatively little stamina, would be difficult, and Chinese forces, which are operating from closer bases, could adopt a strategy of avoidance by simply waiting for these smaller systems to exhaust their endurance before undertaking offensive operations. Smaller drones only seem like a viable option for the United States if they are pre-positioned in Taiwan.

China is overall best poised to take advantage of drones in this scenario with existing technologies.

Thus, the United States primarily needs longer-range, more capable drones, which are likely to be more expensive than many of the drones that Chinese and Taiwanese forces could use. There is a question about whether the United States can develop drones that are long-range and capable enough to complete the mission, but cheap enough to be purchased in large numbers. It is simply more difficult to achieve affordable mass when operating from long ranges. It is worth noting that China would face a similar challenge employing drones against U.S. bases in the region to complement or substitute its long-range missiles when they are depleted.

Determining who would win this war is difficult because it depends on if and when autonomous technologies and counterdrone systems, such as directed energy, mature and are adopted by each party. It also depends on the numbers of drones and counterdrone systems that each side has, the overall balance of capabilities, the operational concepts employed, and the proficiency of each country's military personnel. It seems likely that drones will be a necessary capability for all combatants, but that they alone will not be sufficient to win the war.

Although drones could be useful for China, Taiwan, and the United States, China is overall best poised to take advantage of drones in this scenario with existing technologies. China already has fielded a diverse fleet of drones within its army, navy, air force, and rocket force, and nearly all these systems could be usefully employed in this scenario. Taiwan and the United States have drone fleets, but they are smaller than China's and consist of more expensive platforms that they may be unwilling to put at risk. China also has invested heavily in long-range artillery and rocket force units and has integrated drones into their targeting operations, which could enhance the lethality of their long-range fires. An additional Chinese strength is its dominance of the commercial drone market. Chinese forces would have access to the expansive production capabilities of DJI and Autel, while Taiwan would have to build its own quadcopters or find other sources, which likely lack the production capacity of the Chinese companies. American commercial drone companies do not begin to match the scale of their Chinese competitors and thus could not easily fill the gap, especially at the same price.

As the United States looks into the future, there is a lot of uncertainty about who this drone competition favors. Most of the American operating concepts involve autonomous drones that the United States does not currently have, whether for swarms of kamikaze drones or stealthy loyal wingman drones. Thus, the United States needs to actually field drones with greater autonomy. Relatively simple autonomous kamikaze drones may be the most resilient way of closing long-range kill chains in the near term. In the meantime, the United States should develop concepts for integrating types of drones that exist today into its warfighting concepts. Although these systems may not be highly survivable, that will be true of many capabilities in a large-scale war with a great power. The United States should reconsider how it might usefully employ existing drone technologies, while keeping costs down, to achieve core missions. Finally, the United States and Taiwan need to rapidly expand their industrial bases to build the drones that could complete some of the missions identified above.

CONCLUSIONS AND RECOMMENDATIONS

Drones would undoubtedly play a role in a war to defend Taiwan, as they have in all recent conflicts. The performance of drones on battlefields has fueled their proliferation, and in particular, kamikaze drones are becoming increasingly sought after. All parties have observed what has happened in the wars in Ukraine, Nagorno-Karabakh, and Libya and seek to better integrate drones into their operations. Today, China has more drones than the United States and Taiwan combined and could use them in a variety of roles to help its forces to rapidly close kill chains and destroy Taiwanese and American forces.[582] In contrast, the United States and Taiwan do not have enough drones nor the right types of drones to help mount a successful defense. Washington and Taipei must rapidly procure existing drones to close this current gap, while simultaneously working to develop more sophisticated autonomous drones for the future.

The needs of the two partners, however, differ. Taiwan urgently needs to acquire short- and medium-range military and commercial drones from third parties to support its porcupine strategy. Additionally, Taiwan should invest heavily in kamikaze drone boats and underwater drones that could help prevent Chinese ships from reaching the shore. At the same time, Taipei should build an indigenous military and commercial drone industrial base to ensure that it can replace the many drones that would inevitably be lost in a war. Taiwan's military also must revise its operational concepts and doctrine to incorporate drone operations. Finally, Taiwan must implement a large-scale training program to provide a large percentage of its forces with the skills to employ drones for reconnaissance and strike and to ensure that they are integrated with ground-based antiship and antisurface fires.

In contrast, the United States needs to develop longer-range drones that can operate from distant bases and ships, including many that are affordable and thus can be sent on risky missions. Many of these should be kamikaze drones with relatively simple autonomy, but the United States also needs cheaper reusable drones that can provide more persistent surveillance. As the Pentagon moves toward implementing its warfighting concept of all-domain operations, it will need to develop more advanced concepts of teaming between crewed systems and drones. Ultimately, the United States needs a diverse fleet of long-range drones for a fight in the Pacific.

Determining whether drones would decisively advantage one side or the other in this conflict is difficult because it depends on if and when autonomous technologies and counterdrone systems mature and are adopted by each party. It also depends on the numbers of drones and counterdrone systems each side can field, as well as the overall balance of capabilities, operational concepts, and proficiency of each country's military personnel. Thus far, China appears to have an edge. It has already fielded a diverse fleet across its services and has integrated drones into its long-range artillery and rocket force units' targeting operations. It dominates the commercial market, which the Chinese military will have access to while U.S. and Taiwanese forces will not. To tip the balance, the United States and Taiwan will need to act quickly.

Recommendations: Preparing for the Pacing Scenario

The findings from this analysis yielded the following recommendations for the United States and Taiwan.

For the United States

The U.S. Department of Defense needs to acquire more "good enough" longer-range drones for this fight in the Pacific.

The United States' current slate of drones does not suit a fight with China. The DoD must develop and procure drones with the range to perform useful missions in this theater that can be purchased in sufficient quantities to make up for the many that will inevitably be lost in combat. It may also explore options to deploy smaller drones in theater without tying up scarce air- and sealift assets.

The United States needs a diverse fleet of aerial drones that includes a mix of higher-end and cheaper systems.

In addition to acquiring "good enough" long-range drones for target acquisition and strike, the United States should have a smaller number of stealthy drones that can conduct surveillance in highly contested airspace and provide targeting information for standoff missile strikes. If the United States had multiple ways of closing long-range kill chains and engaging mobile targets, such as ships, American kill chains would be more resilient and more difficult for China to counter. More sophisticated drones will also likely be needed as a part of the collaborative combat aircraft program.

The United States should invest in autonomous kamikaze drones for attacking ships.

Affordable kamikaze drones with relatively simple autonomy could overwhelm the Chinese navy's air defenses and damage or destroy the invasion fleet. Kamikaze drone attacks that do not rely on long-range communications are less vulnerable to jamming and can close kill chains on their own.

The United States should consider pre-positioning short- and medium-range drones on Taiwan.

Smaller drones face a time-distance problem and will be difficult to put in place once a war has begun. Doing so would require tying up in-demand transport assets and deployment missions would be quite risky once the shooting began. If the United States wants to make use of shorter-range aerial drones, drone boats, or small undersea drones, it will need to pre-position them on Taiwan. A decision to pre-position assets on Taiwan would obviously be a sensitive one that would likely provoke Beijing's ire, so the operational benefit must be carefully weighed against the risk.

The DoD must develop and refine operational concepts and tactics, techniques, and procedures for drone employment specific to U.S. challenges in a fight in the Indo-Pacific, such as those outlined in this report, and pick the most effective concepts to incorporate into warfighting plans and doctrine.

This includes considering how U.S. forces will get drones into the theater before a conflict or quickly after one begins, and different ways to team drones with crewed platforms. It also includes defensive counter-counter-drone measures to make "good enough" drones more survivable where possible. These concepts should include drone technology that the United States has today and what it is developing for the future.

The United States needs to invest in training drone pilots so that they are skilled and also can operate closely with crewed systems.

Since most of the drones that the United States develops are likely to be remotely piloted or semiautonomous, the DoD needs to invest in training large numbers of drone pilots. Additionally, the DoD needs to develop a rigorous program of testing and training them to operate alongside crewed platforms across all domains.

The U.S. Department of Defense urgently needs to invest in a range of counterdrone capabilities, including air defenses and EW systems.

In a fight for Taiwan, China would certainly employ its large fleet of drones, so the United States needs to prepare to counter them. The DoD established the Joint Counter-small Unmanned Aircraft Systems Office to focus on this problem in 2019, but it has not invested enough resources into this effort and thus the JCO has not moved quickly enough. There is no one solution that will protect American forces from drones because there are many different types of drone threats. Moreover, because drones have become so accessible, the U.S. military needs to be prepared to counter large, diverse adversary drone fleets. These counters include layered, high-capacity air defenses and electronic warfare capabilities focused on the drone threat. To deal with the drone threat that already exists today and the threat that will exist tomorrow, the DoD needs to invest in cheaper, proven technologies that offer affordable defenses against drones, as well as higher-end future technologies, such as high-powered microwaves and directed energy, that could offer very effective defenses against swarms of drones. The DoD should explore efforts to repurpose existing technologies, such as the Vampire system created for Ukraine, and find gun- or cannon-based systems that can be fielded quickly and are much cheaper than missile interceptors.

The DoD and Congress in partnership with U.S. industry need to build both the commercial and military drone industrial base so that it can scale production and have surge capacity.

The DoD needs to rapidly acquire a large number of drones using proven technologies, while developing more sophisticated future systems. To do so, it needs a more robust drone industrial base. Moreover, drones, like all other platforms in a Pacific fight, will not be survivable. The DoD needs to make the necessary moves to bolster resilience by reconstitution, which requires maintaining an ability to rapidly produce drones during a conflict.

The United States should advocate for changes to the MTCR and look at alternatives for stemming drone proliferation.

The MTCR has failed to stop drone proliferation to authoritarian states and has allowed other nations to

dominate the military drone market. The United States should continue to advocate for changes to the MTCR controls on Category I drones to ensure its allies have the types of drones needed for operations in the Indo-Pacific. Although the United States unilaterally changed its drone export policy in 2020, some allies and partners continue to be hampered by the outdated and ineffective MTCR controls. This regime should be revised so American allies and partners are not disadvantaged compared with states outside of the regime, which often pose a threat to U.S. interests.

The DoD should work with Congress, the State Department, and the National Security Council to reform its export control and foreign military sales process so that it can more quickly deliver capabilities to allies and partners.

As a core part of its integrated deterrence strategy, the United States must be able to provide its allies and partners with drone and counterdrone technologies in a timely and predictable manner. This will require reforming the outdated and ineffective process that exists today.

The DoD and Congress should consider whether the United States and its allies and partners can leverage the drone industrial capabilities of allies.

The United States and its allies and partners need to find trusted and affordable non-Chinese sources for military and commercial drones. The U.S. foreign military sales process is too slow and uncertain and current U.S. drones, while very capable, are too expensive for many allies and partners. NATO ally Turkey has developed a robust military drone industry that is rapidly producing drones for export, which could be purchased by the United States and other U.S. allies.

For Taiwan

Taiwan needs to foster its commercial and military drone industrial base. Taiwan also stands to benefit from the use of drones but is not currently positioned to realize their potential.

Taiwan's indigenous drone industry has produced a variety of military drones, but not in sufficient numbers. Unlike Ukraine, Taiwan will not be able to rely on the depth of commercial options produced by Chinese companies, which no other nation can currently match in scale, performance, and cost. Taiwanese efforts should prioritize large numbers of kamikaze drones and other short- and medium-range aerial drones that do not require runways to operate, as well as drone boats and undersea drones.

Taiwan should arm its ground forces with FPV kamikaze drones to provide additional cost-effective short-range precision fires.

FPV drones have proved to be effective at striking infantry and vehicles beyond the line of sight in Ukraine. They could be used by Taiwanese defenders to terrorize PLA forces that are trying to land or have reached the island. Given their extremely low cost, Taiwan should build large numbers of these simple systems and invest in technologies that could provide autonomous terminal guidance for contested environments.

Taiwanese forces need to integrate short- and medium-range drones with their ground-based fires units and stockpile large amounts of artillery shells, mortars, rockets, and missiles.

In Nagorno-Karabakh and Ukraine, drones were most effective as a part of a ground-based fires complex and helped to turn unguided artillery into precision weapons. Taiwan should focus on building the capabilities for these drone-fires reconnaissance-strike complexes.

Taiwan should develop battle management software to integrate drones with ground-based fires units.

To rapidly close kill chains, drones need to be linked to artillery units. Taiwan should develop map-based software that will accelerate information sharing to, in turn, accelerate targeting timelines and enable highly responsive fires against emergent targets.

The Taiwanese air force and army should develop operational concepts and tactics and focus on integrating and sharing information between drones and fires units and with allies.

In addition to developing battle networks that enhance Taiwanese forces' situational awareness, Taiwan and the United States should explore ways for Taiwan to share targeting information with the United States and multinational partners while under attack. This enhanced air-to-ground coordination would be necessary to mount an effective defense against an invasion.

Taiwan should acquire kamikaze drone boats and underwater drones to bolster its defenses.

Ukrainian forces have successfully denied the Russian navy control over parts of the Black Sea through a combination of kamikaze drone boats and antiship missiles. Taiwan should use the same combination of capabilities along with underwater drones to prevent Chinese ships from reaching the shore.

Taiwanese forces need to begin training on commercial, military, and especially FPV drones.

It takes time to learn how to effectively operate drones and integrate them into operations with other types of forces. Taiwan needs to establish a robust training pipeline for its drone operators of all types so that it has a large, skilled cadre of operators.

The Taiwan military needs to invest in a robust system of counterdrone capabilities, including mobile air defenses and EW systems.

In a fight for Taiwan, China will employ its many drones and Taiwan will need to counter them. Mobile defensive systems will be much more survivable than fixed systems. These counters include layered, high-capacity air defenses and electronic warfare capabilities focused on the drone threat. In addition to long-range air defenses, Taiwan needs to bolster its short-range air defense system significantly.

Evolution, Not Revolution

The previously published companion report *Evolution Not Revolution: Drone Warfare in Russia's 2022 Invasion of Ukraine,* by Stacie Pettyjohn, found that today's drones represent an evolution rather than a revolution in military affairs. Drones enable riskier operations and extend flight duration and endurance. They provide cheap ISR and precision strike capability. As demonstrated in Ukraine, they can enhance the efficacy of missile strikes or an air force by acting as decoys or soaking up SAM interceptors and exhausting inventories. However, drones have not replaced fighter aircraft or antiaircraft guns and missiles in defensive air combat roles. They also cannot generate the potency and volume of fire that artillery units can produce. Furthermore, like crewed aircraft, they have proved to be vulnerable to electronic warfare and air defenses, and against a fully capable air force, drones would face the threat of strikes on air bases and being shot out of the air. In Ukraine, the first full-scale drone war, large numbers of drones were lost. Even when they have been effective, they have needed to be replenished regularly. Looking forward, advances in autonomy may lead to a true revolution in military affairs, a shift that produces a durable military advantage and makes past ways of fighting obsolete. But a revolution requires more than simply an advancement in military technology. Militaries must reshape their force structure and organization and develop new warfighting concepts that leverage drones.

The United States is betting that it can out-innovate China and use drones to defeat a PLA invasion of Taiwan. Here, the United States should view Ukraine as a cautionary tale. Ukraine consistently has pioneered new approaches to drone warfare, but Russia has rapidly adapted and scaled drone production in a way that Ukraine cannot match. Technological and tactical innovations are necessary but not sufficient. Mass production of an affordable mix of drones is also needed to support a large and likely protracted conflict. Today China is positioned to take advantage of its large fleet of drones, which could provide it with an edge in a war over Taiwan. The United States and Taiwan need to rapidly close this gap and to develop a layered system of counterdrone defenses or risk being on the losing side of a war. Washington must also find a way to supply allies and partners, such as Taiwan, with military and commercial drones. And the Pentagon must consider how these diverse technologies enable new operational concepts and doctrine. Ultimately the United States must recognize that while drones alone would not win a war against China to defend Taiwan, they have become a key part of the competition, and the United States cannot afford to remain behind.

APPENDIX

Proliferation Dataset Methodology

The authors created an original dataset that tracks military-grade aerial drone transfers from 1995 to September 1, 2023. This appendix offers a more in-depth explanation of the methods used to identify, organize, and code the proliferation dataset. Entries in the proliferation dataset include the following categories of information: transfer status; seeker, seeker region, supplier; weapons system, type; year of interest, year of order, year of first delivery; and year of identification, completion, or cancellation.

Transfer Status

The dataset distinguishes between two types of proliferation: drone transfers and drone pursuit. It is critical to note that this dataset does not track indigenous drone development and acquisition and focuses solely on international transfers and pursuit. The drone transfer variable captures completed and ongoing foreign military sales, direct commercial sales, leases, and gifts of military-grade drone systems between January 1995 and September 2023. The Defense Security Cooperation Agency (DSCA) defines foreign military sales as "the U.S. Government's program for transferring defense articles, services, and training to international partners and international organizations," using the "DoD's acquisition system to procure defense articles and services on behalf of its partners."[583] DSCA defines direct commercial sales as those in which "U.S. companies obtain commercial export licenses from the Department of State, allowing them to negotiate with, and sell directly to partners."[584] Suppliers such as Israel commonly make lease agreements in place of sales, as leasing outsources operations at a reduced cost to customers.[585] Therefore, as not all the transactions captured were formal sales, researchers use the term "transfer" rather than "sale."

The status variable, which is detailed in Figure A1, indicates whether a recipient country is interested in acquiring drones, has successfully obtained military drones or is waiting for the final execution of an agreement, or was unable to obtain drones. The status variable, therefore, provides a better understanding of drone pursuit by including instances of expressed interest in drone acquisition as well as attempts at drone acquisition that never resulted in the transfer of a weapons system. This distinction helps to establish the timelines in which a country pursued drones and how they may have approached different potential suppliers. The "no" status includes formal requests for purchase of military drones that were rejected by the supplying nation and signed agreements that were terminated or canceled.

Seeker, Supplier, and Region

The data include the seeking nation (termed seeker) and the supplying nation (termed supplier). The seeking nation is the requestor and/or recipient of exogenously produced drones. The supplying nation is the nation providing, though not necessarily producing, the drones. There are a few instances of secondhand proliferation and resale, such as Jordan's sale of its six Chinese CH-4Bs to the Libyan National Army (LNA).

The authors were also interested in identifying the global regions where drone proliferation was highest. To do so, seeking nations were broken down regionally. Given that regional affiliations can be difficult to determine in some areas, the authors opted to use the United States' regional combatant command delineations, which can be seen in Figure A2.[586]

Weapons System and Type

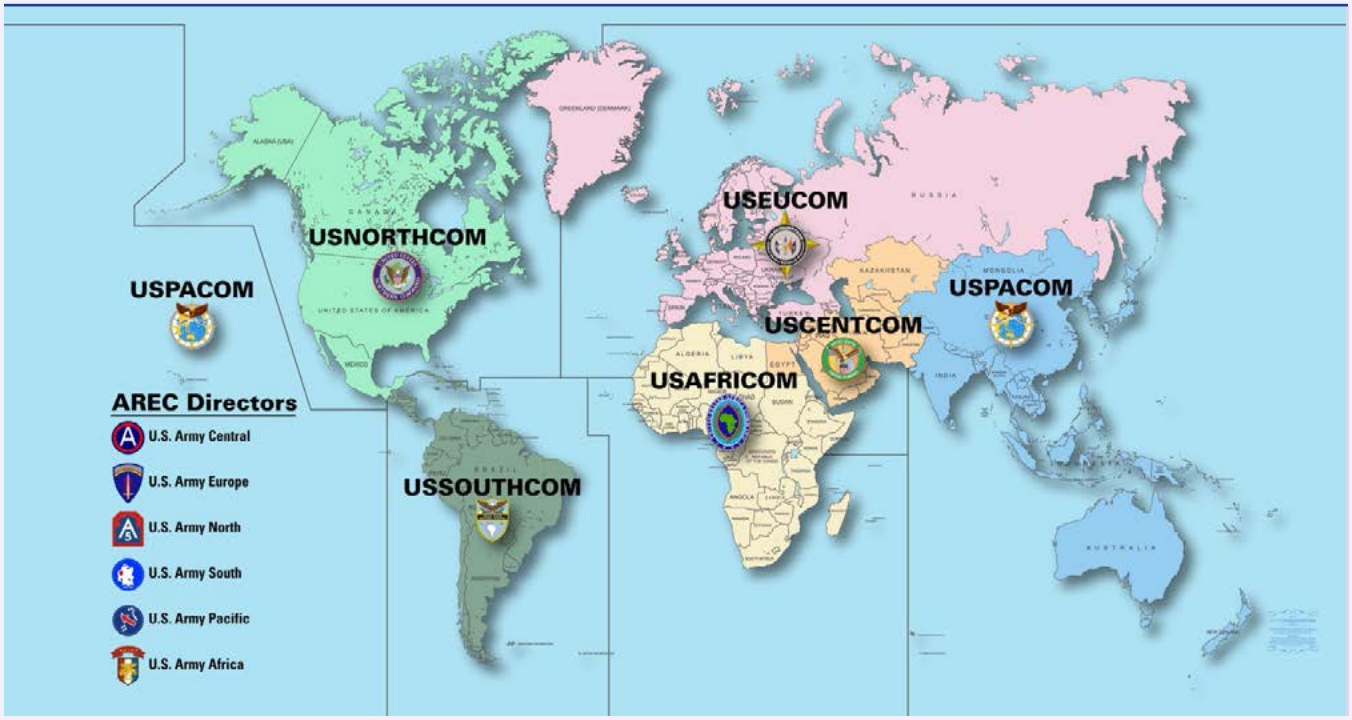
Weapons system in the database refers to the specific model of military drone (e.g., MQ-9B SeaGuardian), while the type categorizes drones by whether they are reusable armed drones, reusable unarmed drones, or one-way kamikaze drones. The data include only military-grade aerial drones, and not commercial off-the-shelf or do-it-yourself technology. Military drones are built specifically for professional military personnel use in a combat setting. Nonaerial uncrewed systems, such as ships or ground vehicles, are not tracked in this dataset. Weapons system designation is derived from the manufacturer and is based on the most specific model information available.

Figure A1 | Drone Transfer Status Definitions

Status	Definition
Yes	The full deal is confirmed, and delivery of the systems has begun. The seeking nation has taken possession of the drone system.
Pending	An entry determined as "pending" meets either of the following conditions: ▪ A deal has been signed but delivery has not yet begun. ▪ A deal has been signed and the date of projected completion has passed, but the ultimate status of the order is unclear.
Interest	A legitimate representative of a nation and its government makes a credible action, legal attempt, or verbal indication of intention to acquire a specific weapons system. General comments expressing interest in purchasing a drone capability without reference to a specific system or supplying nation were not included. An entry was only marked "interest" if no subsequent orders, successful or unsuccessful, were made.
No	An entry determined as "no" includes: ▪ A formal request for purchase of military drones that was rejected by the supplying nation. ▪ Ongoing agreement discussions that were terminated. ▪ Signed agreements that were terminated or canceled.

Figure A2 | Map of United States Combatant Commands

This map shows the delineations of each region according to the U.S. combatant commands. The authors used the same categories to compare drone transfers in different regions.



Timothy Hale, "ARECs Ensure US Army Reserve is Engaged on the World Stage," U.S. Army Reserve, February 1, 2016, https://www.usar.army.mil/News/Images/igphoto/2001339846/.

Whenever possible, the authors distinguish between different configurations of drone models, such as purchased MQ-9A Predators from the MQ-9B SeaGuardian maritime configuration. Some agreements included the transfer of multiple weapons systems. In these instances, a new data entry was made for each weapons system with a comment explaining the context.

Type is based on the overall capability of the drone, as well as the specific configuration of the acquired system. The authors used three broad-based type categorizations: unarmed drone, armed drone, and loitering munition. Other datasets, such as that by Matthew Fuhrmann and Michael Horowitz in 2017, are not as inclusive of weapon type and instead focused on particular medium-altitude long-endurance (MALE) systems that met the 20-hour/16,000-foot elevation and endurance capabilities of the Chinese Wing Loong.[587] As has been seen in Ukraine, smaller drones can still have a notable impact and therefore it is worth tracking such transfers.

In this database, a weapons system is classified as unarmed when the acquired system was not configured to carry a lethal payload. Both armed drones and loitering munitions carry a lethal payload and have many similarities, but loitering munitions are those that are intended to fly single one-way missions and crash into the target. Many, if not most, MALE systems can be optionally armed. Though the authors considered categorizing all systems that had the capability to be armed as armed drones, the final dataset reflects the actual configuration acquired. In its transfer lists, the Stockholm International Peace Research Institute (SIPRI) includes in the weapon description whether it was armed or unarmed. However, there is room for error in the armed-unarmed typology, as instances identified through open-source blogs, news reports, and social media often document weapons systems in the most general sense, leaving an incomplete picture of the true type. However, there is only one instance of type uncertainty in the dataset, in the case of Pakistan's 2019 purchase of Chinese CH-4 drones. SIPRI reported it to be the unarmed CH-4A, while other sources report sightings of the armed CH-4B within Pakistan.[588]

Additionally, target drones are not included in the dataset. While the United States has used target drones for decades and they can be converted into kamikaze drones, the authors found their inclusion was tangential to the research question and had the potential to skew the final data analysis.

Years

The dataset covers the period from January 1995 to September 2023 and is the most up-to-date of its kind.[589] While there are a few documented sales of early drone systems in the 1980s, they are outliers to the trend of modern proliferation tracked in this dataset. The dataset captures four time stamps: year of interest; year of order; year of first delivery; and year of identification, completion, or cancellation. Figure A4 defines each of these terms. To the extent possible, the dataset includes, at minimum, both the year of order and year of completion for each transfer.

Figure A3 | Drone Type Definitions

Type	Definition
Unarmed drone	Any military drone that is not currently configured to carry a lethal payload. This includes multirotor quadcopters.
Armed drone	Medium-altitude long-endurance (MALE) drones that are purchased in an armed configuration. This was only applied when a nation specifically purchased an armed version. Unarmed configurations of weapons-capable systems, such as the MQ-9, are categorized as unarmed.
Loitering munition/ kamikaze drone	Armed drone designed for single, one-way use.

When available, the year of first delivery is also included, as many orders are fulfilled over a period of years. Many entries lack year of order, as some transfers only become public upon completion, and the year of the initial agreement is not publicized. Furthermore, some transfers, especially those to certain isolated regimes or terrorist organizations, go largely unpublicized. Those entries may lack a year of order and year of completion. In these cases, the dataset records the year of identification—that is, the year in which it was publicly identified that a seeker possessed a particular nonindigenous weapons system. For entries in which no year could be ascertained, the transfer is labeled "NA." To facilitate data analysis, year of identification, completion, and cancellation are grouped together, as all represent the end point of a transfer.

Figure A4 | Order Year Definitions

Year	Definition
Interest	The earliest known year that a seeking nation made a credible action, legal attempt, or verbal indication of intention to acquire a specific drone system.
Order	The year the specific agreement was signed.
First delivery	The first year the seeking nation was in possession of the acquired drone system.
Identification, completion, or cancellation	▪ Identification: The year it was publicly identified that a nation was in possession of a particular drone system. ▪ Completion: The year the specific agreement was completed, and all systems have been delivered to the seeker. ▪ Cancellation: The year of cancellation.

Sources

Existing literature on drone proliferation and open-source databases regarding international arms transfer provided the basis for data collection. Key unclassified datasets included:

- Michael Horowitz, Joshua A. Schwartz, and Matthew Fuhrmann, "Who's Prone to Drone? A Global Time-Series Analysis of Armed Uninhabited Aerial Vehicle Proliferation," *Conflict Management and Peace Science* 39, no. 2 (March 2022): 119–142, https://doi.org/10.1177/0738894220966572.
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Limitations

Limited available information on certain nations imposes constraints on these datasets. Nonstate actors and authoritarian regimes have significant motivation to keep details of their international arms transfers secret, which results in ambiguous data. For this reason, it can be assumed that sales and acquisitions by countries such as Russia, Iran, and North Korea are much higher than documented. Additionally, information on unsuccessful military drone transfers is difficult to identify for military drone suppliers other than the United States.

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159. S/2019/914, 35, 38, 286.

160. "In the Libyan Sky, Battle between Turkish and Emirati Drones."

161. Delalande, "How Libya's Skies Became Battleground for UAE-Turkey Proxy War"; S/2019/914, 33, 35.`

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171. S/2019/914, 38-39; Franz-Stefan Gady, "Useful, but Not Decisive: UAVs in Libya's Civil War," International Institute for Strategic Studies, November 22, 2019, https://www.iiss.org/online-analysis/online-analysis//2019/11/mide-uavs-in-libyas-civil-war.

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239. Kofman and Nersisyan, "The Second Nagorno-Karabakh War, Two Weeks In." The Azerbaijani air force included a squadron of Soviet MiG-29s fighters, MiG-25 interceptor and reconnaissance aircraft, a regiment of Su-24 and Su-25 attack aircraft, and a regiment of attack/transport helicopters. International Institute for Strategic Studies, *The Military Balance 2020*, 185–186; Antal, *7 Seconds to Die: A Military Analysis of the Second Nagorno-Karabakh War and the Future of Warfighting*.

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September 30, 2020, https://caspiannews.com/news-detail/armenia-threatens-azerbaijan-with-use-of-ballistic-missiles-2020-9-28-45/; The Iskander-E ("E" denoting the export variant) has different specifications, "9k720 Iskander (SS-26)," CSIS Missile Defense Project, August 2, 2021, https://missilethreat.csis.org/missile/ss-26-2/. Turkish F-16s at Azerbaijan's Ganja airport: Christiaan Triebert, (@trbrtc), "There are at least two F-16s at Ganja International Airport in Azerbaijan, our analysis of an Oct. 3 @planetlabs satellite image shows. The fighter jets are likely operated by the Turkish Air Force, alongside a possible CN-235 cargo aircraft. Here's a short thread why." X (formerly Twitter), October 7, 2020, https://twitter.com/trbrtc/status/1313903827435892737?fbclid=IwAR3osaiw-4ShjjHQpqVytt8azU4bCohmrLyG1eJvsvKq5N-oirK2xd-dV89ww; The Drive as cited by CRS: Joseph Trevithick, "Turkey's Forward Deployed F-16s in Azerbaijan Have Moved to a New Base," The War Zone, October 26, 2020, https://www.thedrive.com/the-war-zone/37278/turkeys-forward-deployed-f-16s-in-azerbaijan-have-moved-to-a-different-airport. Armenia's threat: "Армения назвала условие применения "Искандеров" в Карабахе,[Armenia named the conditions for the use of Iskander missiles in Karabakh]," RIA, September 28, 2020, https://ria.ru/20200928/iskandery-1577909939.html. Turkey accused of downing jet in Armenian airspace: "Armenia, Azerbaijan Conflict Escalates; Turkey Calls Allegation of Downing Jet 'Absolutely Untrue,'" The Associated Press via *USA Today*, as cited by CRS, September 29, 2020, https://www.usatoday.com/story/news/world/2020/09/29/armenia-says-turkey-azerbaijan-downed-jet-nagorna-karabakh-dispute/3574360001/; Video of first attack using LORA, October 2, 2020: Joseph Trevithick, "Video Points to Azerbaijan's First Use of Israeli-Made Ballistic Missile against Armenia," The War Zone, October 2, 2020, https://www.thedrive.com/the-war-zone/36877/video-points-to-azerbaijans-first-use-of-israeli-made-ballistic-missile-against-armenia. Azerbaijan received up to 50 LORA missiles with truck-mounted launchers, between 2017 and 2018. These weapons are very precise, more destructive than Azerbaijan's military drones or kamikaze drones. Armenian strikes on Ganja: Nurlan Mustafayev, "The Legality of Use of Ballistic Missiles on Cities: The Case of Armenia-Azerbaijan Armed Conflict," EJIL:Talk! (blog), February 8, 2022, https://www.ejiltalk.org/the-legality-of-use-of-ballistic-missiles-on-cities-the-case-of-armenia-azerbaijan-armed-conflict/; and "Nagorno-Karabakh Conflict: Major Cities Hit as Heavy Fighting Continues," BBC, October 4, 2020, https://www.bbc.com/news/world-europe-54407436.

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nian forces but present at Russian 102nd base in Gyumri." X, (formerly Twitter), November 4, 2020, https://twitter.com/Zinvor/status/1324073095490142209.

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