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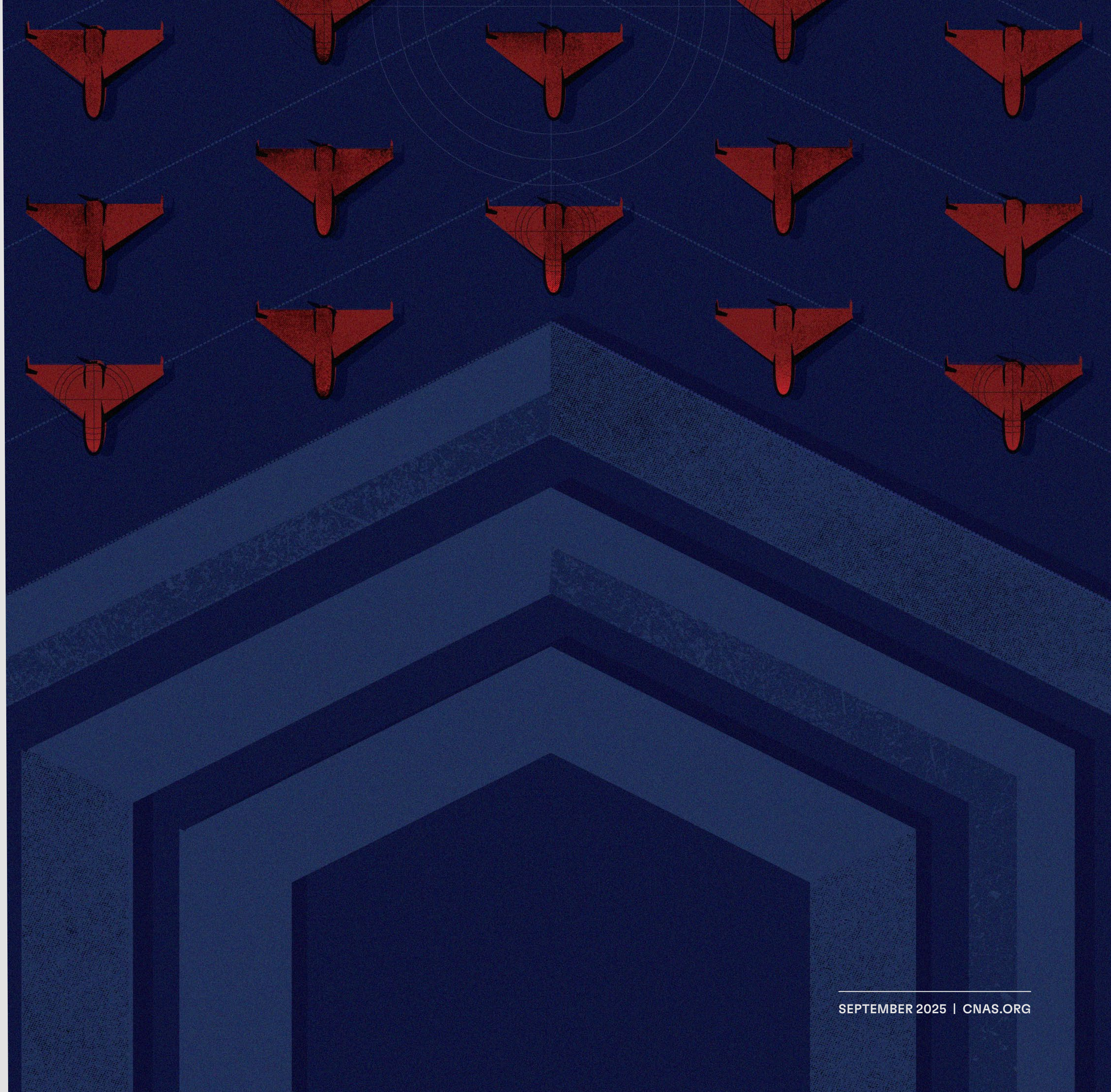
COUNTERING THE SWARM

Protecting the Joint Force in the Drone Age

Stacie Pettyjohn and Molly Campbell



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EXECUTIVE SUMMARY

AFTER DECADES OF AIR DOMINANCE and a near monopoly on precision strike, the United States now faces a dramatically different, more hostile world as the proliferation of cheap drones has democratized mass precision fires. It is likely that in any future conflict, drones will pose an unavoidable threat to American forces.

As this report's analysis of U.S. defense spending reveals, the Department of Defense (DoD) has invested in both legacy and emerging counter–uncrewed aerial systems (C-UAS) capabilities for nearly a decade. However, these efforts have been hindered by insufficient scale and urgency. Despite the Pentagon's shortfalls in procuring purpose-built C-UAS capabilities, U.S. counter-drone operations in the Middle East have been notable.

The United States views China as its foremost strategic threat, and the People's Liberation Army (PLA) is rapidly advancing its drone capabilities by developing more autonomous systems and acquiring them at scale. Without deep magazines of substantially enhanced counter-drone capabilities, the United States risks having its distributed warfighting strategies overwhelmed by massed Chinese drone attacks, and the United States could lose a war over Taiwan. This is a complex challenge with no silver bullet solution. The DoD must act swiftly. The stakes are not theoretical—without adequate defenses, even the most advanced systems and tactics will be rendered irrelevant in the face of overwhelming drone attacks.

Overall Recommendations for the Department of Defense

Prioritize counter-drone defense and extend capabilities beyond the air defense community. Drone defense cannot be siloed to dedicated air defense units. Every unit will need the ability to defend itself against small uncrewed aerial systems (UAS).

Expand counter-drone training across the Joint Force. The Pentagon needs to develop and share best tactics, techniques, and procedures and ensure that all forces are trained in drone self-protection.

Improve the rigor and realism of counter-drone prototype testing. The current test and evaluation process fosters a false sense of confidence in prototype counter-UAS, as they are often assessed using unrealistic facsimiles of enemy drones and low-fidelity tests of electromagnetic weapons.

To Be Prepared for Today's Drone Threat, the DoD Must Invest in Proven Capabilities

Build resilient defenses with layered active defenses and passive countermeasures. U.S. forces must be operationally resilient, meaning they have the ability to defeat or absorb drone attacks while continuing with their other missions. Resilience requires layered active defensive systems with multiple different types of sensors and effectors.

Given that no air defense system can provide complete protection at all times, integrating passive defense measures is essential to achieving operational resilience.

Strengthen mobile counter-drone capabilities and tactics for maneuvering forces. The United States has not developed appropriate mobile defense for maneuver formations, nor has it fielded sufficient handheld capabilities for dismounted infantry.

Procure large stockpiles of high-volume, short-range kinetic interceptors. High-volume air defense solutions incorporate emerging technologies such as high-power microwaves (HPM) and directed energy systems, which do not rely on interceptors. However, expanded use of immediately available gun-based systems and low-cost rocket interceptors, such as the Advanced Precision Kill Weapon System, is also needed.

To Be Prepared for the Future Drone Threat, the DoD Must Also Invest in Emerging Capabilities

Invest in AI-enabled processing of sensors and AI command and control to speed up C-UAS kill chains. Integrating the command and control of diverse counter-drone systems and leveraging artificial intelligence (AI) to accelerate threat identification and engagement is essential for improving defense effectiveness while also advancing the Pentagon's vision of Joint All-Domain Command and Control (JADC2).

Transition promising rapidly emerging technologies, especially high-power microwaves, to programs of record. HPM is the technology most capable of defeating swarms and high-volume attacks.

Invest in high-resolution passive sensors. Long-range, high-resolution passive sensors offer a survivable alternative to active radars for finding drones and have the potential to enhance the defender's advantage.

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INTRODUCTION

ON OCTOBER 17, 2023, IRANIAN-BACKED MILITIAS launched two one-way attack drones—better known as kamikaze drones—at al-Asad Airbase in western Iraq. U.S. forces swiftly shot down one drone; the other, though damaged, slipped through defenses and injured several American troops.[1] At the same time, Harir Air Base in northern Iraq was targeted by a militant drone, but U.S. forces intercepted it before it could do harm.[2] The next day, U.S. personnel at Syria's al-Tanf Garrison stopped one incoming drone, but another evaded defenses and made impact, inflicting minor injuries.[3] On October 19, Yemeni Houthi rebels launched drone attacks on Israel, thrusting the USS *Carney* (DDG-64) into a 10-hour battle that would become "the most intense combat engagement by a U.S. Navy warship" since World War II.[4] These drone strikes surprised American forces, and marked the beginning of what one expert described as a new type of guerrilla warfare.[5]

In each instance, the individual attacks were unremarkable—only one or two drones or missiles—and most were defeated by skilled American operators employing sophisticated air defenses. However, the frequency and scale of the drone strikes that began in October 2023 was not something U.S. troops had previously experienced. Although U.S. forces performed incredibly well under fire, the cumulative impact of these sustained attacks has been significant: injuring U.S. personnel, depleting U.S. air defense interceptor stockpiles, and degrading readiness.

Since 2004, the proliferation of Iranian drones to Tehran-backed proxy forces has made these attacks possible and has profoundly transformed the Middle Eastern battlefield.[6] Iranian systems are cheap enough to be bought in large quantities, yet capable enough to hit their targets from hundreds of miles away. While proxies traditionally have relied on inaccurate missiles, rockets, and mortars, Iran's drones are precision weapons that can be acquired en masse. These "precise mass" cheap drones have put U.S. forces at risk, eroding the longstanding U.S. precision strike advantage and enabling adversaries to impose disproportionate costs on the United States.[7]

As a result of the widespread availability and proven effectiveness of drones, enemies of the United States—be they states, terrorists, or criminals—will use drones to precisely attack U.S. forces.[8] Drone warfare is rapidly evolving, and the drone threat will intensify. It spans the entire globe, including the U.S. homeland, as evidenced by the notable increase in drone incursions over domestic American military bases.[9] In the Ukraine war, Russian and Ukrainian forces continue to use drones in innovative ways, and they have become essential weapons on the front lines and an important tool for deep strikes.[10] As America's adversaries become more adept at mission planning, salvo sizes will increase and attacks will become more complex, making them harder to defeat. At the same time, artificial intelligence (AI) is rapidly developing, and before long truly autonomous drone swarms will be a reality. Drone defenses are in high demand and short supply, evidenced by the fact that in June 2025 the United States diverted a shipment of rockets used to intercept drones intended for Ukraine to U.S. forces in the Middle East.[11]

To make the drone problem tractable, the analysis in this report is focused exclusively on overseas operations where U.S. forces can use a variety of means to disrupt or destroy hostile drones. Counter-drone operations in the U.S. homeland present different policy challenges, given the number of agencies involved and the various authorities restricting how drones can be engaged in U.S. airspace. Additionally, this report only considers drones, or uncrewed aerial systems (UAS), that fall into U.S. Groups 1 through 3.[12] These are the smaller drones that have proliferated the most and pose a novel challenge to traditional air defenses.[13]

This report seeks to answer three core questions: Is the Pentagon acquiring enough of the right types of counter-drone capabilities? What lessons should be learned from recent counter-drone operations in the Middle East? Is the United States prepared for the future threat posed by drones, especially from China?

To answer these questions, the authors evaluated the strengths and weaknesses of different types of counter-drone defenses, assessed the weapons that the Pentagon has bought to defeat drones, analyzed two cases studies, and ran a tabletop exercise (TTX) exploring how China might use drones in a war over Taiwan.

This report concludes that there is no silver bullet capability that can defeat all drones. Instead, U.S. forces need a layered system of active defenses. When integrated, multiple different types of sensors and effectors can compensate for the weaknesses of any one system, and collectively find, track, identify, and defeat drones. The Pentagon has begun to buy some defenses designed specifically to counter small drones, but it is not nearly enough. More of these systems are needed to defend priority fixed sites, as well as large stockpiles of cost-effective interceptors. Moreover, to prepare for the future drone threat, the United States must also incorporate emerging technologies into its layered defenses. In a war with China, the People's Liberation Army (PLA) is likely to launch large, heterogeneous salvos of drones and missiles and autonomous drone swarms at American forces who will need AI-enabled battle management and high-power microwaves (HPM) to counter them.

Drones are ubiquitous on the modern battlefield; not even the U.S. military will be able to shoot down every single one. While destruction or disruption of hostile drones remains key to counter-drone defenses, a more holistic approach centered on operational resilience is required. Resiliency is achieved not only through taking offensive actions against drones, such as shooting them down or jamming their navigation systems, but also with robust layers of passive defenses that limit the effectiveness of drone attacks.[14] Resilient forces can weather an attack, adjust their operations, and complete their core missions.[15] To achieve resilience, all U.S. forces must be able to protect themselves against small drones and be proficient in defensive tactics.[16] Thus, the counter-drone mission entails much more than simply air defense and cannot be relegated to traditional, isolated air defense formations.

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This report is divided into six chapters. The first provides an overview of counter-drone operations and describes the various capabilities that can be used to defeat drones. The second evaluates U.S. Department of Defense (DoD) investments in counter-drone technologies. Chapters three and four present case studies of U.S. Army operations in the Middle East and of U.S. Navy and Air Force operations in the Battle of the Red Sea. The fifth chapter provides insights from the TTX about defeating Chinese drones in the context of a protracted conflict. The final chapter analyzes the investments, case studies, and TTX insights to offer conclusions and recommendations.

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CHAPTER 1

CLOSING THE COUNTER-DRONE KILL CHAIN

THE U.S. MILITARY HAS LONG HAD the capability to shoot down fighter aircraft and missiles, which raises the question: Why do drones present a challenge? The Group 1 through 3 drones that are the focus of this report are generally slower and smaller than piloted aircraft, making them hard to detect with existing air defense radars optimized to identify fast, high-flying jets.[17] Furthermore, because drones tend to be cheap, they are plentiful. Adversaries can employ multiple drones simultaneously or send pulsed waves of attacks to overwhelm defenses. Finally, the multifaceted nature of the drone threat means U.S. forces must be prepared to defeat different types of drones, that all may require different countermeasures, at scale.

To shoot down a drone, defenders must complete a series of steps to close a kill chain under extreme time pressure. Drones can be defeated in multiple ways, but first the defenders need sensors to detect the drone incursion. Once alerted to the presence of a potentially hostile UAS, defenders must locate, track, and identify it. If confirmed as a threat, troops must then decide what weapon to use, attack the hostile drone, assess whether the target was successfully destroyed or disrupted, and determine whether a reattack is necessary.[18] All of these decisions are usually made in a matter of minutes. The steps to find, fix, identify, track, defeat, and assess the drone threat require different capabilities to sense and defeat the drone at different stages. There is no single capability that enables defenders to confidently defeat all drones. Each defensive technology has strengths and weaknesses and is therefore most effective when deployed in an integrated, layered fashion to minimize an individual technology's limitations. To create a resilient and robust drone defense, the United States needs a layered system consisting of multimode sensors, layered active defenses, and protective measures or passive defenses.

Sensors to Find, Fix, Identify, Track, and Assess

The cornerstone of a counter-UAS (C-UAS) defensive system, and often the most difficult step in the kill chain, is detection. There are various types of sensors that can help find drones, which can be generally characterized as either active or passive. Active sensors, such as many radar, sonar, and light detection and ranging systems, transmit energy and detect the reflection of the signal that they emit. In contrast, passive sensors, such as optical cameras, microphones, and infrared sensors, simply detect the naturally occurring energy that objects emit. Active sensors tend to provide higher-resolution data on a target's location but are conspicuous and vulnerable to attack. Passive sensors are more discreet due to their lack of emissions but tend to provide lower resolution or less accurate location data. Both types of sensors can be ground, maritime, or air defense–based, though sensors on aircraft have longer detection ranges and can see in all directions because they are not obstructed by terrain features.[19] Ideally, sensors identify an incoming drone from as far away as possible to ensure there is sufficient time to engage countermeasures while troops take shelter. Ultimately, a combination of multidomain active and passive sensors should be operated in tandem to find, fix, identify, and track drones.

Radar is the most important active sensor for countering drones. Active radars are used for air defense and fire control systems due to their ability to accurately track multiple targets simultaneously and at long range and pass that data to an interceptor.[20] Active radars emit radio signals, however, which reveal their location and thus make them vulnerable to enemy attack.[21] Active radars also tend to be expensive, limiting the number that can be acquired. Passive radars compare the energy reflected from background electronic emissions with previously conducted electromagnetic surveys to identify targets, but they require significant computer processing and tend to offer lower-resolution returns.[22]

Most passive sensors tend to be less complicated, less expensive, and more proliferated forms of detection. For example, Ukraine uses an extensive network of microphones attached to cell phone towers to listen for the distinctive sound made by Iranian Shahed one-way attack drones, track them, and direct

TABLE 1 | STRENGTHS AND WEAKNESSES OF DRONE DETECTING SENSORS[23]

Detection Method	Sensor Type	Strengths	Weaknesses	Example System
Early Warning Radars Scan a wide area and identify potential targets	Passive	Long-range detection and fire-cuing Difficult to identify radar location	Require prior electromagnetic spectrum surveys Require sufficient background emissions activity	Army Long-Range Persistent Surveillance (ALPS)
Fire Control Radars Emit radio waves for target detection and tracking	Active	Accurate Multitarget tracking All-weather, 24/7 operation Robust against counters	Limited mobility due to size, weight, and power requirements Poor detection of low, slow, and small objects like drones Smaller threats only detected at short range Confused by clutter leading to false positives	AN/TPS-80 Ground/Air Task-Oriented Radar (G/ATOR)
Acoustic Microphones that detect sound created by uncrewed aerial systems (UAS) motors	Passive	Inexpensive Low power requirement Difficult to detect Provide two-dimensional bearing tracking from multistatic triangulation	Short range Low quality, susceptible to sound pollution Require library of acoustic signatures	Doscoviar G2
Radio Frequency Antennas that identify wireless control signals	Passive	Difficult to detect Can triangulate location of drone and operator Track multiple targets at once	Ineffective against nontransmitting (autonomous) systems	Tsukorok X-MADIS
Optical Cameras, including visible, infrared, and thermal radiation	Passive	Difficult to detect Low power requirement Ranging capability Visual target identification Can provide fire control	Short range Line-of-sight detection Reduced effectiveness in low light and adverse weather Require computer processing to eliminate false positives	Night Hawk HD

mobile counter-drone teams to shoot them down.[24] Passive sensors can detect without emitting signals and therefore are easier to conceal. For instance, radio frequency (RF) analyzers use antennas to home in on the radio signals connecting the operator and the drone being piloted.[25] Most Ukrainian and Russian soldiers carry commercially made RF analyzers for drone detection. The cheap, lightweight systems are preferred because they do not interfere with friendly operations, nor do they increase exposure to attack by emitting detectable signals.[26] RF analyzers, however, are not effective against preprogrammed or autonomous drones, such as Shaheds, and often fail to provide accurate location and tracking information. While a simple RF analyzer signals that a drone is nearby, more sophisticated systems employ software to processes the radio signals and pinpoint the drone and its operator—but this requires access to the latest drone databases that include drone RF signatures.[27]

Positively identifying an incoming drone as a threat, known as identification friend or foe (IFF), is another crucial step in the kill chain that is reliant on sensors. Before a suspected drone can be engaged, defenders must first verify it is hostile.[28] Optical sensors, or cameras, use visible light, infrared, and thermal imaging to produce pictures and can be particularly helpful for specifying a drone's model. Visual sensors, however, are impacted by bad weather, particularly fog, rain, and clouds.[29] In addition to visual identification by cameras, radars can be used to identify the bearing, altitude, range, and speed of incoming targets, which can be compared against known drone signatures.

Any type of sensor can be used to develop a catalog of drone signatures to help identify friend from foe. However, IFF can be particularly acute if both sides are flying commercially available systems, as in Ukraine. Some advanced counter-drone systems use AI-enabled computer vision software to evaluate, synthesize, and compare data from multiple sensors and rapidly identify targets.[30] The identification process is one key step in the kill chain that could be accelerated by incorporating AI.

Ultimately, the most effective drone defenses employ a mix of passive and active sensors in tandem. For example, a lower-resolution passive acoustic or RF sensor identifies an object of interest, then cues a sensor with a high-resolution camera and laser rangefinder or active radar to verify that the object is indeed a hostile drone and to obtain target quality tracks so that it can be defeated.[31] Incorporating data from multiple different types of sensors helps limit blind spots and ensure that drones are found, fixed, tracked, and identified. After these steps occur, the people targeted by the attacking drone have two choices: They can actively try to defeat the incoming drone, or they can take cover and rely on shelters and other forms of passive defenses to limit any damage if the drone hits.

Active Defenses to Destroy and Disrupt

How does a defender stop an incoming drone once it has been detected and identified as a threat? Detection, fixing, tracking, and identification are critical first steps, but do not prevent a drone from achieving its mission. Unarmed drones may be spying or passing targeting information to other units, while armed drones can pose a physical threat to personnel, equipment, and facilities. Thus, destroying the drone or, at a minimum, preventing it from achieving its mission, is necessary. There are many ways to actively counter UAS, and determining the most effective approach often depends on the specific situation and the characteristics of the attacking drone. Cost also needs to be factored into the defeat equation—particularly against cheap drones—as oftentimes the most prudent way of defeating a drone involves using an expensive long-range interceptor. While this course of action may make sense when protecting personnel or a large, hard-to-replace asset—like a ship or aircraft—it is not a sustainable approach, particularly if an adversary has many cheap drones or in the context of a large high-intensity conflict. More affordable defeat mechanisms are needed to avoid exhausting high-end missile stockpiles and to conserve the most capable air defenses for more sophisticated threats, such as ballistic or cruise missiles.

Kinetic defenses, such as guns, rockets, and missiles, have different ranges that are directly associated with cost. Guns are relatively short range, but they are plentiful, have a high rate of fire, and use relatively cheap ammunition, making them an accessible and potent option for defeating drones.[32]

When paired with laser rangefinders or fire control radars for targeting, and enhanced with proximity fused fragmentation ammunition that increases the likelihood of damaging a small and maneuverable drone, guns can be an effective and affordable short-range defense.

Rockets are projectiles that carry onboard fuel (e.g., rocket motor) and thus have greater range than bullets but are therefore more expensive. Still, at less than $20,000 per munition, rockets are a small fraction of the cost of a short-range air-to-air or surface-to-air missile (SAM), which run between $450,000 to $1 million.[33] Palletized rockets paired with laser range finders can be mounted onto many different vehicles, creating a self-contained, mobile short-range defensive system. Mobility enables the defensive system to be easily relocated to avoid counterbattery fire, to cover a changing list of priority assets, and to defend maneuver units. Therefore, maneuverability is an important component, given that the need for defensive systems usually outstrips the supply.

Missiles are rocket propelled, have the greatest range, and carry sophisticated sensors to enable the precise accuracy needed to hit an incoming aerial threat.[34] However, they are the most expensive option for active drone defense. Long-range SAMs—whether a standard missile (SM-2, SM-3, or SM-6) fired by a destroyer, or a Terminal High-Altitude Area Defense (THAAD) interceptor fired by a ground-based launcher—can interdict a drone hundreds of miles from the target. Heat-seeking missiles, which are common on man-portable air defense systems (MANPADS), are generally less effective, since many UAS, particularly smaller ones, have electric engines that produce significantly less heat than a rocket motor or jet engine.

Because projectiles can be based on ground vehicles, ships, and aircraft, one method of extending interception range is by forward deploying a platform carrying interceptors to interdict inbound drones. Typically, fighter aircraft and guided missile destroyers are armed with several types of projectiles and form the outermost layer of counter-drone defense. If conducting combat air patrols, fighters can surge forward to pick off drones using their guns, rockets, or air-to-air missiles hundreds of miles away from the intended target.[35] Similarly, guided missile destroyers are outfitted with multiple different classes of SAMs, 5-inch guns, and a short-range, gun-based close-in weapon system (CIWS).

One means of counter-drone defense that does not fit neatly into the category of kinetic defeat mechanisms is friendly UAS. The primary advantage of counter-drone drones is that they can be deployed in anticipation of a threat and loiter overhead, ready to ram into any incoming enemy drones. However, these systems need to be faster than the drones they are intercepting and require endurance to remain on patrol. They tend to cost more than simple rockets but less than most missiles. Ukrainian forces have used first-person view (FPV) drones to ram into larger Russian surveillance drones and have developed at least five purpose-based drone interceptors.[36]

Non-kinetic counter-drone weapons do not rely on energetics to propel a projectile, providing a lower cost per shot, but are more expensive to develop and purchase. For instance, directed energy (DE) weapons—namely high-energy lasers (HELs) and high-power microwaves—use beams of light and electromagnetic energy to destroy or damage drones.[37] Because DE weapons do not need inventories of expensive interceptors, they potentially have a limitless magazine of shots, making them more difficult to overwhelm with mass or saturation attacks and eliminating the need to resupply ammunition. Even with an infinite magazine, lasers are limited to engaging one threat at a time. HELs are less capable against swarms and large salvos due to "dwell time," the length of time the laser beam must remain precisely pointed at a target to destroy it, and the amount of time it takes to redirect the laser toward a new target. Despite their promise, transforming HELs into an operationally fielded capability has proven challenging, as laser beams are degraded by bad weather and atmospheric conditions like dust and humidity. Moreover, while HELs do not need interceptor stockpiles, they do require large amounts of power and cooling, which limits mobility.[38] Lasers can also be used to blind or temporarily dazzle a hostile drone's sensors, preventing it from surveilling the environment and conducting accurate attacks. Dazzling is a less demanding mission and can be successfully completed by less powerful lasers, but it still requires maintaining the laser beam precisely pointed at the sensor.[39]

In contrast, high-power microwave weapons appear to be the only counter-drone technology that can neutralize large swarms of Group 1 and 2 drones simultaneously, using energy pulses that destroy or disable the electronics of incoming UAS. HPM, however, is a short-range system akin to a final force field that can drop nearby drones en masse.[40] Because its range is only a few kilometers, HPM is a last line

TABLE 2 | STRENGTHS AND WEAKNESSES OF ACTIVE DRONE DEFENSES[41]

Mission	Domain	Defeat Mechanism	Modality	Strengths	Weaknesses
Disrupt	Ground Air Sea	Jamming—radio signals	Electronic warfare	Causes drone to return to station or fall out of sky Software-defined consumer systems can be used tactically	Risk of collateral damage Vulnerable to direction finding Defeated by radio frequency hopping
		Jamming or spoofing—GPS	Electronic warfare	Makes uncrewed aerial systems (UAS) fly off target	Only target one form of navigation
		Dazzle optics	Laser	Defeat intelligence, surveillance, and reconnaissance (ISR) drones Lower power requirement than destructive lasers	Require sufficient power to permanently damage drone camera, otherwise just temporarily blinded
Destroy	Ground Air Sea	Guns	Kinetic	Inexpensive and plentiful munitions High rate of fire High volume of fire	Short range Limited kinetic effect High rate of ammunition consumption
		Missiles & rockets	Kinetic	Precise Large payload Effective against Group 3+ UAS	Expensive Limited stockpiles Heat-seeking capabilities less effective against electric UAS with low heat signatures
		High-energy laser	Directed energy	Infinite magazine Low cost per shot	Expensive upfront Power intensive Limited mobility Short range
		High-power microwave	Directed energy	Capable of defeating large salvos and drone swarms Infinite magazine	Expensive upfront Short range Risk of collateral damage
	Air	Counter-drone drones	Kinetic/ electronic warfare	Can be deployed in anticipation of threat Long endurance Potentially reusable	Expensive Slower than missiles Relatively short range
		Fighter aircraft	Kinetic/ electronic warfare	Can intercept incoming systems hundreds of miles away from the intended target Carry multiple weapons Fast	Expensive May be withheld for higher-priority missions

of defense that can be used to defeat the "leaker" drones that slip through previous defensive layers, and multiple HPM systems would be needed to defend the entirety of a large facility such as an airbase. Moreover, it is risky to rely on HPM alone. Should it fail, the drones are so close that there is no other opportunity to defeat them. HPM also carries a high risk of unintentional damage to friendly electronics.

One of the most effective ways of countering commercial drones is through electronic attack, which neutralizes a drone but does not destroy it.[42] Most of today's drones are remotely piloted by an operator, which is a vulnerability to be exploited. Jammers interfere with the radio signal used to control the drone, forcing it to return to its home station or fall out of the sky. However, jammers are short range, as well as emitting, making them vulnerable to enemy identification. To evade jamming, Russian and Ukrainian forces are using fiber-optic cables to pilot kamikaze drones on the front lines. However, fiber-optic drones are short-range weapons, and the cables can get tangled in vegetation or other obstacles and thus are a useful countermeasure in a limited number of circumstances.[43] Moreover, jamming can be overcome by UAS with autonomous terminal guidance, or by using more sophisticated radios capable of hopping frequencies, a capability often found on military drones.

Defenders also can jam navigational signals to push a drone off course and away from the intended target. In Ukraine, most American-made drones were unable to operate effectively due to Russian Global Positioning System (GPS) jamming.[44] More sophisticated spoofing attacks can send a false GPS signal to a drone, directing it to the wrong location, though these attacks are less common. If a drone has redundant forms of navigation (such as inertial navigation or terrain mapping), it may be able to effectively navigate to its target in a GPS-denied environment. This drives up cost, however, making jamming a part of an effective counter against the most common types of drones.

Passive Defenses to Conceal and Protect

Simultaneous to taking offensive action to disrupt or destroy a drone, passive defenses should be employed to conceal targets and mitigate damage.[45] Unlike active defensive systems, which launch some form of attack, passive defenses offer protection and do not intercept or otherwise harm the hostile system. Most passive defenses are helpful against any form of air attack and rocket, artillery, or mortar fire, but they can be particularly useful in defending against Group 1 and 2 drones with small payloads.

One form of passive defense focuses on camouflaging or concealing targets from enemy attack, which can range from the cheap and simple like a smoke grenade to temporarily obscure sensors, to the sophisticated and expensive like multispectral camouflage nets and paints that mask visual, heat, and radar signatures.[46] Basic camouflage techniques such as situating forces under trees or using colored netting to blend into the background make it more difficult for drones with basic optical sensors to identify targets, and such techniques have proven effective in Ukraine.[47] Camouflage also may confuse more sophisticated drones reliant on AI-enabled computer vision algorithms for target identification.

Camouflage, concealment, and deception are not foolproof, making it essential to defend against the weapons drones carry as well. Defensive structures—made from steel, wood, rock, soil, concrete, or brick—can offer varying degrees of protection (depending on their hardness) and can serve as fighting positions for soldiers or shelters for valuable equipment. Barricades and revetments can help shield against shrapnel, blasts, or secondary explosions, but overhead protection is critical in countering drones, as it at least diminishes targeting effectiveness. Vehicles also can be modified with additional armor to survive smaller drone attacks. However, extra armor increases vehicle weight and reduces mobility, and the vehicles remain vulnerable. Russian troops have encased their tanks in sheet metal, but these so-called turtle tanks remain susceptible to drones with penetrating explosives and antitank weapons.[48] Alternatively, lighter defenses like nets and cages have been used successfully by Ukrainian and Russian

FIGURE 1 | PASSIVE DEFENSES FOR COUNTERING DRONES[49]

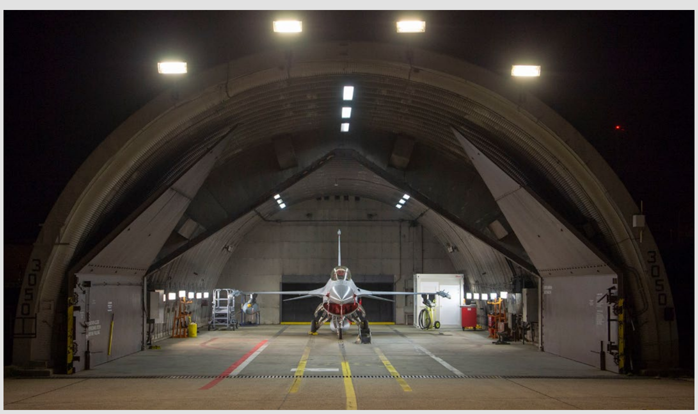
Passive defenses, such as bunkers, nets, cages, aircraft shelters, and armor, protect targets from drone attacks by making them harder to find and mitigating the damage that can be inflicted on them. (From top to bottom: Jason Scott/ U.S. Army Corps of Engineers, Florent Vergen/AFP via Getty Images, Kyle Cope/U.S. Air Force, Alina Smutko/Reuters)

BUNKERS, BLAST WALLS, AND BERMS

Fixed defenses like bunkers, blast walls, and berms protect against shrapnel and secondary blasts but require significant resources, with only bunkers providing overhead cover.

NETS AND CAGES

Lightweight and versatile, nets or cages provide overhead protection from drones and double as camouflage for mobile or fixed defenses.



HANGARS

Hangars protect equipment, supplies, and personnel against direct drone strikes and large blasts, but may fail against swarm attacks.

ARMOR

Armor provides mobile protection against small explosives but adds weight, reduces vehicle mobility, and is vulnerable to larger weapons.

forces to intercept kamikaze drones before detonation, though they offer limited protection against gravity bombs or timed-fuse weapons.[50]

Deception is another means of evading enemy drones that has been used successfully in Ukraine.[51] Decoys are fake pieces of military equipment, such as tanks, howitzers, or aircraft, that are used to provoke the enemy into expending resources, time, and effort attacking something of little value.[52] Large numbers of low-fidelity decoys can slow down enemy targeting processes and soak up limited inventories of high-end munitions. Ukrainian forces have an extensive program of wooden decoys used to increase the survivability of their forces and deplete high-end Russian munitions.[53] However, as the number and sophistication of sensors on the battlefield increases, decoys often must do more than resemble the real thing to be effective. To further disguise imitation systems, high-fidelity decoys must have heat, radar, and radio signatures, which make them more expensive and less plentiful.[54]

Employing different types of sensors and defeat mechanisms together can compensate for the limitations of any one system and makes it harder for an adversary to penetrate all the different layers.

In the absence of layered drone defenses or deception techniques, forces rely on mobility and dispersal to make themselves more difficult to target. Both of these approaches limit the tempo of offensive operations and create logistical burdens, but this may be the price of survival on a battlefield saturated with drones.[55] Artillery and SAM batteries often use "shoot and scoot" tactics: After firing, units displace to a new location to evade counterbattery fire.[56] Furthermore, dispersal involves spreading out forces to limit vulnerability and is often reliant on mobility.[57] Frequently relocating forces makes it more difficult for an adversary to find them and limits the damage that one attack can inflict.[58]

Conclusion

When comparing the wide array of counter-drone approaches presented, the importance of employing layered air defenses to mitigate the deficiencies of any one defensive measure becomes clear. No one capability is optimized to deal with every type of drone, and when operated alone each capability has strengths and weaknesses. Employing different types of sensors and defeat mechanisms together can compensate for the limitations of any one system and makes it harder for an adversary to penetrate all the different layers.

While there are many active and passive capabilities to defend against drones, not all are readily available to U.S. forces. This is due in part to uneven procurement and long timelines for the development of next generation C-UAS weapons such as HELs and HPMs. The next chapter examines C-UAS investment and acquisition by the DoD and considers what types of counter-drone capabilities are being purchased, and whether the counter-drone effort has been commensurate with the growing threat.

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CHAPTER 2

EQUIPPING THE FORCE FOR DRONE DEFENSE

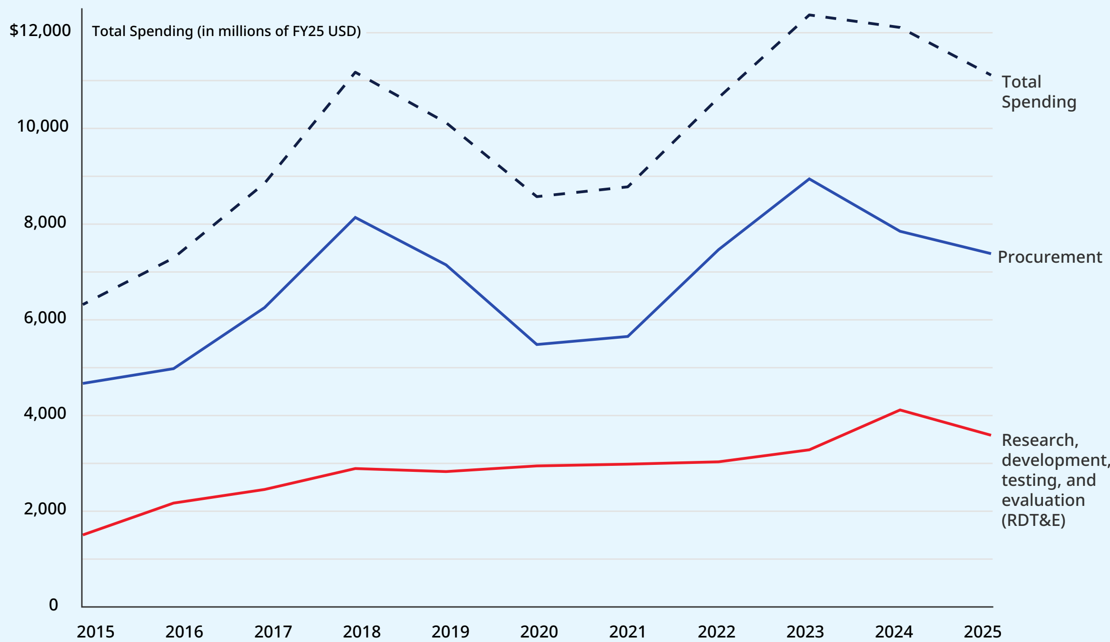
TO EFFECTIVELY COUNTER THE VARIETY of drones in Groups 1 through 3, the U.S. military needs multiple different types of sensors, layered active defenses, and passive defenses. Since the Islamic State of Iraq and Syria (ISIS) began employing drones to attack U.S. forces in 2016, the DoD has proclaimed the counter-drone mission to be a top priority. While limited numbers of C-UAS systems have been acquired in response to these urgent operational needs, few have entered into full production and been fielded at scale. Consistently, the Pentagon has lagged behind the drone threat, continuing to buy expensive, high-end air and missile defenses, as well as aging short-range air defense systems. Despite heavy investment in next-generation technologies like HELs and HPMs, few prototypes have transitioned to programs of record and been procured at the scale required to keep pace with the modern drone threat. This chapter provides an overview of the past decade of U.S. military spending on counter-defense systems. The technology included in the counter-drone mission budgetary analysis has been defined broadly, ranging from ballistic missile and long-range air defense to counter–rocket, artillery, and mortar (C-RAM) and purpose-built C-UAS platforms. The data attempts to be inclusive of the full spectrum of capabilities relevant to the counter-drone kill chain.[59]

As Figure 2 illustrates, between 2015 and 2025, the Pentagon has consistently invested in the research, development, and procurement of weapons and technology that can be used to defeat and defend against drones. Spending has been reactive, however, as the spikes in 2018 and 2023 were both in response to the unexpected drone threats that emerged during Operation Inherent Resolve and the war in Ukraine, respectively. In 2015, the Joint Force spent an estimated $4.8 billion on procuring capabilities that could be used against drones, composed primarily of established air and missile defense technology like Patriot and legacy fire control radars.[60] A decade later, spending has more than doubled, as the Pentagon plans to spend roughly $7.4 billion on C-UAS in 2025.[61]

Pentagon Counter-Drone Spending, 2015–2025

The first surge in U.S. counter-drone capability investment was spurred by ISIS's use of commercial quadcopters against U.S. troops during Operation Inherent Resolve.[62] At the DoD's request, $20 million was reprogrammed in June 2016 for the Joint Improvised Explosive Device (IED) Defeat Organization, or JIEDDO, to fill "unanticipated critical capability gaps" in detection and defeat of small and tactical drones in response to U.S. Central Command (CENTCOM) submitting a joint urgent operational need.[63] While ISIS had been experimenting with DJI quadcopters for several years, the first large-scale employment came during the battle to liberate Mosul, Iraq, from ISIS's control in October 2016, when the group launched more than 120 drone attacks in two days.[64] In addition to drone bombers,

Figure 2 | Joint Counter-Drone Spending, 2015–2025[65]



U.S. spending on counter-drone systems spiked during Operation Inherent Resolve and after the 2022 Russian invasion of Ukraine.

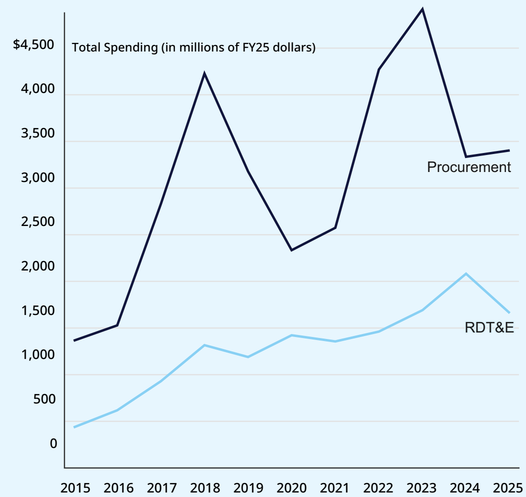
ISIS used drones for intelligence and target identification, as well as to direct mortar fire and guide vehicle-borne improvised IEDs toward targets.[66] Testifying before the Senate Armed Services Committee in March 2017, former CENTCOM commander General Joseph L. Votel stated that the U.S. military needed effective defenses "that can defeat all classes of UAS" and that this was a "top priority" for the combatant command.[67] By 2018, C-UAS spending had surged to over $11 billion, $8.2 billion going toward procurement and $3 billion toward research and development, or R&D (see Figure 2).[68]

The 2018 spike in counter-drone spending was driven by U.S. Army and Navy procurement spending on high-end air and missile defenses. The Army spent $4.2 billion while the Navy spent $3.2 billion, together accounting for over 65 percent of total 2018 C-UAS spending.[69] For the Army, $2 billion of the 2018 procurement went toward the MIM-104 Patriot and accompanying PAC-3 interceptors.[70] Similarly, the Navy spent $1.3 billion procuring SM-3 missiles, an interceptor part of the ship-based Aegis Ballistic Missile Defense System.[71]

However, the U.S. Army also surged funding to procure readily available legacy air defense systems with some operational relevance to the counter-drone fight. For instance, between 2016 and 2017, the Army doubled spending on the Land-Based Phalanx Weapon System (LPWS) and AN/TPQ-50 counter-fire radar.[72] Both systems were designed to intercept rockets, artillery, and mortars, but also were capable of countering small drones.[73] Similarly, the Army had planned to wind down investment in legacy short-range air defense such as the AN/TWQ-1 Avenger system and FIM-92 Stinger missile but allocated more funds toward the programs from 2017 to 2018.[74]

At the same time, the Army began developing purpose-built counter-drone defenses. In July 2017, it awarded its first contract for $16 million to develop the Low, Slow, Small UAS Integrated Defeat System, or LIDS, which has become the service's primary counter-drone system.[76] The same year, the Army used $57.8 million in supplemental Overseas Contingency Operations funds to develop and procure the Coyote interceptor, the kinetic-kill option for LIDS that has been deployed

Figure 3 | U.S. Army Air and Drone Defense Spending, 2015–2025[75]



U.S. Army spending on research and development for counter-drone technologies has increased steadily, but procurement has been more variable.

in the Middle East since 2017.[77] However, Coyotes have been procured in relatively small quantities as Figure 4 shows, even after the Ukraine-related spike in C-UAS spending.

The counter-drone mission is a component of the broader mission of short-range air defense (SHORAD), which includes defeating short-range threats such as rockets, mortars, artillery, and Group 1 drones, as well as point defenses for long-range threats like cruise missiles and Group 2 and 3 drones. In the early 2000s the Army divested from SHORAD capabilities, and today, investment in new technology to reconstitute Army SHORAD has consumed a significant proportion of the service's C-UAS spending.[78] However, the chosen SHORAD programs have not been designed with the drone threat in mind, despite the overlapping missions. In 2018, the Army began developing its mobile (M)-SHORAD Increment 1 system: a modified M-1126 Stryker combat vehicle armed with Longbow Hellfire and Stinger missiles, a 30mm Bushmaster cannon, a 7.62mm machine gun, onboard IFF, software-defined radar, and electro-optical/infrared sensing.[79] While M-SHORAD fills gaps in short-range air defense, it does so with weapons that are not optimized for C-UAS. For instance, the rate of fire of the 30mm cannon (200 shots per minute) is too slow to create the wall of bullets needed to take down small drones.[80] In comparison, LPWS fires 3,000 to 4,500 shots per minute.[81]

Similarly, the antiquated heat-seeking technology on Stinger missiles struggles to perform against low-signature electric drones, even with upgraded proximity fuses.[82] In addition to the M-SHORAD platform, Stingers are incorporated into the Army's Mobile LIDS (M-LIDS) and the Marine Corps' Marine Air Defense Integrated System (MADIS).[83] The Army has launched two developmental projects that are intended to eventually replace Stinger with modernized missiles, but these will not begin production until between 2028 and 2030, leaving U.S. soldiers and Marines heavily reliant on the dated Stingers as a part of their counter-drone suites of weapons.[84]

Unlike the Army, the Navy maintained robust layered air defenses, including SHORAD systems, in its surface fleet, and continued to fund existing programs while simultaneously developing next-generation technology. The Navy made respectable investments in directed energy and electronic attack systems and was able to deploy some early on, such as the Joint Counter Radio-Controlled Improvised Explosive Device Electronic Warfare (JCREW). JCREW jammers originally designed to counter IEDs in Iraq and Afghanistan were modified to disrupt the command signals of drones.[85] The Air Force made modest investments of around $80 million into sensors and directed energy systems for air base protection, while the Marine Corps began developing the MADIS C-UAS family of systems in 2018.[86]

Coyotes have been procured in relatively small quantities, even after the Ukraine-related spike in C-UAS spending.

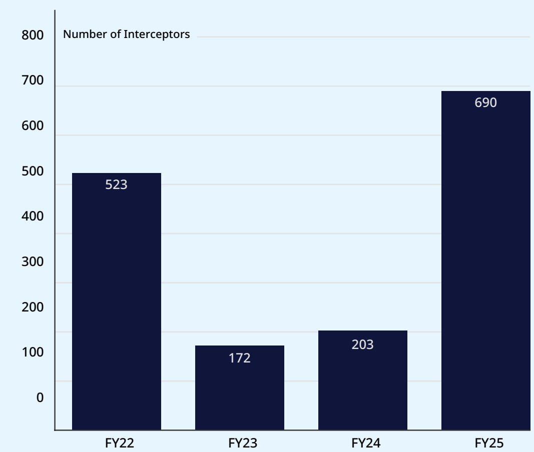
By 2019, the DoD had been worrying about the drone threat for several years, but still lacked cohesive and streamlined investment and acquisition strategies. Many C-UAS investments were duplicative and went toward systems that were not interoperable.[87] While the urgent warfighter need exposed in Operation Inherent Resolve and subsequent Middle East engagements unlocked additional funding and resources, most of this money was spent on short-term solutions, mainly legacy air defenses and prototypes that had not yet entered full-scale production. Dozens of new counter-drone technologies were developed and prototyped, but no one was systematically evaluating them or selecting the ones that should become programs of record.

In an effort to centralize the counter-drone efforts of the Joint Force, in 2019 the secretary of defense designated the U.S. Army as the executive agent of the counter-drone mission, putting it in charge of "doctrine, requirements, materiel, and training standards and capabilities" and ensuring that the systems acquired by each of the services were interoperable.[88] In February 2020, the Army established the Joint Counter-Small Unmanned Aircraft Systems Office (JCO) to further streamline efforts.[89] To eliminate redundancy and facilitate the transition from R&D to production, the JCO assessed 40 different C-UAS technologies and endorsed the best eight for acquisition.[90]

Despite the leadership the JCO provided, C-UAS spending dipped between 2020 and 2021, as the urgent need in the Middle East receded. Although drones were playing an important role in other conflicts, U.S. forces were no longer battling them daily, and other service priorities took precedence.[91] The Army spent around $70 million on procuring defenses for small drones in 2020 and 2021, down from $302 million in 2019 alone.[92] In 2022, following Russia's invasion of Ukraine, drones became one of the dominant weapons systems, and U.S. Army spending on countering small drones surged to $760 million.[93] While the Pentagon increased spending on traditional air defenses and weapons development for Ukraine, the war reenergized U.S. spending on the mission as the scale of modern drone combat came into clear relief.[95]

Additionally, by 2022 some of the C-UAS weapons the JCO selected in 2020, such as LIDS and MADIS, entered full production.[96] Nevertheless, the pace of procurement and quantities being fielded are insufficient. As Figure 4 shows, the Army reduced procurement of Coyote interceptors in 2022 and 2023 to a paltry 172 and 203, respectively, instead of maintaining 2021 levels.[97] The Navy and Air Force have been particularly lagging in procuring purpose-built layered C-UAS defenses.[98] By 2023 the Air Force had deployed 99 Negation of Improvised

Figure 4 | U.S. Army Coyote Interceptor Procurement[94]



Coyote interceptors were the most effective counter–uncrewed aerial systems (C-UAS) weapon during the attacks on U.S. bases in 2023–2024, but the U.S. Army has not been consistently procuring sufficient numbers of these weapons.

Non-State Joint Aircraft (NINJA) systems at priority air bases, but this system, which consists of sensors and nonkinetic disruptors, does not offer protection against the full range of drone threats.[99] NINJA was primarily designed to protect air bases from incursions by small and commercial off-the-shelf drones; it has limited defeat and divert capabilities against Group 3 systems, and it does not provide the layers required for effective air defense. Similarly, the Navy has invested in electronic warfare capabilities and some directed energy programs, but not kinetic interceptors designed for drones.

In 2024, the Army announced it was planning to establish nine new counter-drone batteries that reside within the Indirect Fire Protection Capability (IFPC) and division air defense battalions.[100] Each C-UAS unit will have between 15 and 20 Coyote launchers capable of holding four missiles each.[101] This is incredibly thin counter-drone protection, given a division is intended to cover nearly 20 miles of frontage.[102] Moreover, almost all of the Army's planned C-UAS launchers are for fixed locations rather than mobile.[103] These acquisitions will help to defend bases but will not help dismounted infantry troops or maneuvering U.S. forces that are on the offensive.[104]

C-UAS Weapons Cost per Shot

Perhaps most significantly, most counter-drone weapons being procured by the services have an unfavorable cost-per-shot ratio, meaning that the cost of the interceptor far outstrips that of the drone. For instance, a DJI Mavic 3 costs roughly $2,000 a unit, while an Iranian Shahed-136 is estimated to cost between $20,000 and $50,000.[105] All too often, U.S. forces use exquisite precision-guided missiles worth hundreds of thousands if not millions of dollars apiece to destroy cheap drones.[106] At about $125,000 each, the Coyote interceptor is cheaper than most other C-UAS weapons in the U.S. arsenal, but rockets and gun-based defenses drive the costs down significantly more and hold tremendous promise. Less-expensive munitions also allow for larger stockpiles in reserve and on hand. Having a depth of inexpensive interceptors allows for the conservation of expensive munitions for higher-end threats.[107] The United States needs to procure more kinetic C-UAS weapons that offer a favorable cost-per-shot exchange.

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After nearly a decade of work, the DoD has expanded the Joint Force's ability to defeat drones, though it began from an incredibly low baseline. Much remains to be done to procure appropriate layered defenses for bases, ships, and maneuver forces. For example, directed energy is one of the most promising counter-drone capabilities and has received significant R&D investment from all branches of the military. However, despite $3.3 billion in spending over 10 years, the United States has yet to have a directed energy system reach full operational deployment.[109]

TABLE 3 | COST PER ROUND OF C-UAS KINETIC INTERCEPTORS[108]

Interceptor	Unit Cost (FY25 USD)
M940 20mm	$80
30mm XM1198	$203
APKWS II	$24,900
Coyote	$126,500
AGM-114L Hellfire II Longbow	$150,000
Tamir/SkyHunter	$180,800
FIM-92 Stinger	$480,000
Roadrunner*	$500,000
IFPC 2 AIM-9X	$762,000
AMRAAM	$1,370,000
ESSM	$1,492,000
PAC-3	$4,187,000
SM-6	$5,950,000

*Estimated cost

The Unfulfilled Promise of Directed Energy Weapons

Directed energy weapons, including high-energy lasers and high-power microwaves, have been touted as the technology that will give American warfighters a decisive defensive edge against drones. DE has the potential to serve as an effective defeat capability even against drone swarms, while offering low cost-per-shot ratio and potentially endless magazines.[110] Despite this promise and significant investment in HEL and HPM, no service has transitioned any of their DE research and development programs into a fully operational capability.[111] Part of this is due to the inherent challenges with integrating DE onto existing weapons platforms. Both HEL and HPM systems require significant power supply and cooling systems, which drives up the size and weight of the vehicle that can house them.[112] Consequently, most DE systems are large and intended to defend fixed locations.

The Navy, Air Force, and Army are developing a variety of different HEL and HPM systems, and the Marine Corps is reportedly interested in the Army's HPM system.[113] In the past decade, the Navy has spent $261 million researching and developing a low-power laser to dazzle drones, which was finally transitioned to low-rate production in 2025.[114] Since 2015, the Army has spent approximately $1.7 billion in directed energy R&D, with the bulk of the money focused on lasers.[115] Furthermore, in the past two years alone, over $200 million has gone into IFPC HEL and DE M-SHORAD capabilities.[116] However, neither laser has performed well in testing. Four DE M-SHORAD 50-kilowatt lasers were deployed to CENTCOM in 2024 to defend bases, but soldiers found the weapons cumbersome and ineffective.[117] This may be due to inadequate testing prior to deployment, which is severely limited because of concerns about inadvertent damage to objects in the sky, including satellites.[118] Army leaders claim the service remains invested in the 300-kilowatt IFPC-HEL, but in its 2025 budget the Army intends to slash $4.8 billion in planned funding for the program.[119]

The Army previously funded and received four IFPC-HPM counter-drone systems, which may hold more near-term promise than the lasers currently under development.[120] High-power microwave systems are the only capabilities able to simultaneously target and engage multiple drones.[121] Yet the Army only began investing in HPM in 2022, spending about $80 million on the program as of publication. One IFPC-HPM system was tested successfully during the Balikatan exercise in the Philippines in May 2025.[122] Additional real-world tests of HPM are needed to determine whether it is ready for production; but if the system continues to perform well, the Army should consider shifting its DE portfolio from HEL to HPM.

Conclusion

The evolution of U.S. counter-drone spending reveals two major surges in investment: the immediate operational response to ISIS's use of drones in the mid-2010s, and a more recent spike driven by lessons from Ukraine's high-tempo drone warfare. These funding waves have supported the repurposing of legacy systems like LPWS, as well as the creation of purpose-built counter-drone technologies such as the Coyote interceptor and directed energy weapons. However, despite billions in investment, the DoD has prioritized fielding exquisite effectors over scalable, cost-effective solutions, often using expensive missiles to defeat cheap drones. This disparity in cost came into stark relief when U.S. forces in the Middle East came under heavy drone attacks following the outbreak of war between Israel and Hamas in October 2023.

Despite billions in investment, the DoD has prioritized fielding exquisite effectors over scalable, cost-effective solutions, often using expensive missiles to defeat cheap drones.

It is important, however, to look at counter-drone technology not only through the lens of budgetary investments but to also consider how U.S. forces have leveraged the capabilities the Pentagon has procured. An examination of how U.S. forces countered drone attacks on land and at sea in the Middle East illustrates the complexity of the C-UAS mission and demonstrates the importance of pairing the right tactics, techniques, and procedures with layered active and passive defenses.

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CHAPTER 3

THE ARMY UNDER FIRE, OCTOBER 2023–FEBRUARY 2024

FOLLOWING THE OUTBREAK of the Hamas-Israel war on October 7, 2023, U.S. ground forces across the Middle East came under sustained attack, with Iran-backed militias launching more than 170 strikes across 13 American military installations in Syria, Iraq, and Jordan—killing three U.S. service members and wounding 150.[123] The militants fired mortars, rockets, and short-range missiles, but their preferred weapon was the fixed wing one-way attack drone (see Table 4).[124] The purpose-built fixed-wing drones carrying warheads of 40 to 100 pounds and capable of flying autonomously for hundreds of miles exploited the seams in U.S. air defenses: They were too large to be reliably intercepted by man-portable systems, yet too small and cheap to warrant expensive air defense missiles.[125]

The first drone engagements on October 18, 2023, were inauspicious for U.S. forces. At al-Asad Airbase in western Iraq, one drone was destroyed, but the other was only damaged and struck an aircraft hangar.[126] The same day in southern Syria, al-Tanf Garrison also was targeted by two one-way attack drones. The Base Defense Operations Center (BDOC) responded to the first drone "slowly and indecisively," as the standard operating procedure required visual positive identification of the threat before engagement, which "took too long to establish" during the attack, allowing the drone to make impact on the base.[127] The BDOC, then acting with greater urgency, was able to successfully destroy the second drone.

Fortunately, U.S. forces quickly became more proficient at defeating drones. This was thanks in large part to one Army unit—the 2nd Brigade Combat Team, 10th Mountain Division (2/10)—which was responsible for defending more than half of the U.S. bases in the region. During its nine-month deployment, the 2/10 intercepted nearly all incoming drones; tested new technologies and tactics; and, based on what it had learned, identified areas where U.S. forces needed to improve.

TABLE 4 | MOST COMMON IRAN-MADE DRONES FIRED AT U.S. FORCES IN THE U.S. CENTRAL COMMAND AREA OF RESPONSIBILITY, 2023–2024[128]

Drone	Range (mi)	Speed (mph)	Payload (lbs)
Shahed-101/ Murad-5	870	75	18
Shahed-131	560	Unknown	20–40
Shahed-136	1,600	115	40–90
Quasef/Ababil-2/T	75–125	230	70

Transforming in Contact: The 2/10's Counter-Drone Success

Between October 18, 2023, and February 7, 2024—the most intense period of drone strikes—the 2/10 shot down 93 of approximately 115 drones fired at the eight bases under its protection, giving it an impressive 80 percent success rate.[129] Key to 2/10's success was its leadership, which took the drone threat seriously, empowered junior officers, and embraced experimentation and learning during deployment.

The 2/10 performed exceptionally, and its success is especially impressive given that the soldiers tasked with shooting down the incoming drones were not air defense specialists. Additionally, each base was equipped with nonstandard and diverse sets of counter-drone systems. While impressive, the 2/10's success came against a modest drone threat. The attacks were small, and, even when measured cumulatively, the nearly daily strikes did not threaten to exhaust U.S. defenses.

The Army unit deployed prior to the 2/10 had been targeted by only a few kamikaze drones.[130] Nevertheless, Colonel Scott Wence, the former commander of the 2/10, took proactive steps toward enhancing the unit's counter-drone capabilities early in its deployment. First, COL Wence empowered junior officers who were responsible for deciding how to respond to inbound drones and prepared them for the mission by requiring additional C-UAS training.[131] Second, he launched an effort to experiment with different counter-drone equipment and tactics, an initiative nicknamed the "Project Convergence of CENTCOM," out of al-Asad Airbase.[132] As a result of these steps, 2/10 learned in real time and was able to adapt to the threat.

It is important to note that the process of detecting a drone, identifying it as hostile, and engaging it, was fully manual and had to be completed within as little as 30 seconds and, at most, two minutes.[133] Most of the soldiers who intercepted the drones were not air defenders but had other occupational specialties, including the three noncommissioned soldiers from 2/10 who shot down a total of 28 drones, earning them "Ace" status.[134]

One of the challenges the 2/10 faced was the unique geography of each base and the variety of C-UAS equipment available at each location, which complicated the creation of identification and implementation best practices for counter-drone operations across the command. All eight bases had different mixes of counter-drone systems, including Fixed-Site Low, Slow, Small, Unmanned Aircraft Integrated Defeat System (FS-LIDS), high-energy lasers, the LPWS, and two kinetic interceptors developed in the United Kingdom (UK).[135] These defensive systems did not offer equivalent capabilities and were at different stages of development, resulting in varying levels of performance when employed.

The process of detecting a drone, identifying it as hostile, and engaging it, was fully manual and had to be completed within as little as 30 seconds and, at most, two minutes.

While the 2/10 tested different technologies, many prototypes failed to perform as expected, prompting soldiers to rely on the tried-and-true kinetic interceptors in full-scale production.

Radars were one of the biggest deficiencies, as most had ranges of only four miles, giving defenders under a minute to close the kill chain.[136] The Ku-band Radio Frequency Sensor (KuRFS) radar had three times the range of most radars and proved superior at detecting the kamikaze drones and filtering out clutter, while older radars presented dozens of false tracks.[137] As a consequence of the capability and topography disparities, some bases proved easier to defend than others. For instance, al-Asad Airbase is situated on relatively flat land and possessed KuRFS radars, making it capable of detecting drones at a range of 12 miles, which partially explains why the airbase intercepted 39 drones in a row.[138]

The modest intensity and size of the attacks also played a role in the 2/10's accomplishments. U.S. soldiers did not face complex heterogeneous salvos of drones alongside cruise and ballistic missiles. During the most intense period of drone attacks, there was a "consistent but low volume" of mainly Shahed-101 and Quasef strikes coming in groups of one or two.[139] The single largest drone attack during the 2/10's deployment comprised of five Shahed-136s coming 15 minutes apart.[140]

Lessons Learned: Improving the Army's Counter-Drone Mission

During its deployment, the 2/10 gained unprecedented expertise in U.S. counter-drone equipment and tactics, and it has since disseminated its best practices with the Joint Force.[141] Its experience also highlights areas where U.S. counter-drone defenses need to progress: improved sensing to increase warning time of drone attacks, expedited IFF processes, faster decision-making through greater automation, layered active and passive defenses, realistic prototypes testing, and plans and equipment to defend dispersed sites.

IMPROVED SENSING

Soldiers reported that the biggest obstacle to countering drones was early sensing, which highlights the Army's need for long-range sensors optimized for UAS detection.[142] Typically, the kamikaze drones were launched from sites hundreds of miles away, having flown for several hours before getting within range of the target. U.S. bases lacked sensors that could detect at such range, removing the option of striking the drones before they were launched.

Additionally, the Islamist militants skillfully planned and executed their drone strikes to evade U.S. sensors. The Iranian-made drones used inertial navigation to fly preprogrammed routes with no electronic emissions signaling their presence, making them impervious to jamming.[143] Militants identified designated U.S. air landing corridors and programmed their drones to use these routes to slip through base air defenses.[144] The drones also flew very low, sometimes less than 100 feet from the ground, well below the sightlines of most radars. Further still, militants often knew the location of U.S. radars, probably from human sources and intelligence collected with commercial quadcopters.[145] This allowed the hostile drones to exploit radar blind spots and use terrain to mask their paths.[146] A greater inventory of long-range radars would minimize exploitable gaps as well as provide additional warning time that U.S. soldiers could use to defeat drones or seek shelter.

FASTER THREAT IDENTIFICATION

To compensate for minimal warning time, soldiers in the 2/10 sought to accelerate the decision stage of the counter-drone kill chain. Initially, 2/10 BDOCs were bogged down by standard operating procedure, which required positive threat identification of an incoming drone based on its visual or electronic signature prior to kinetic or nonkinetic engagement.[147] As one soldier quipped, however, if you "wait to see" the drone on a camera, you would "see it all the way to the crash."[148] To expedite the identification process, base defenders switched from positive identification to the less-demanding standard of procedural IFF based on location, bearing, altitude, range, and speed.[149] Put simply, if an object was identified in an airspace that U.S. aircraft were not supposed to be in, flying the same speed and height as known enemy drones in the direction of the base, it was deemed hostile and could be engaged.[150] This drone "duck test" enabled quicker IFF, granting the 2/10 base defenders more time to make the decision to engage.

SPEED THROUGH AUTOMATION

The soldiers of 2/10 identified the urgent need for modernized and automated command and control (C2) systems to speed up decision cycles.[151] The Army's current air defense C2 system requires manual target identification and engagement. Base defenders found the 1990s-era radar software was unwieldy, with as many as 14 drag-down menus and clicks that had to be navigated before an interceptor could be fired.[152] Moreover, the C2 architecture for different defensive systems was federated. As a result, soldiers had to monitor multiple interfaces instead of a single pane of glass, making it harder for them to digest the information and quickly input their actions, thereby further slowing down the kill chain.[153] Moving forward, the Army should integrate its counter-drone systems under a more streamlined interface and incorporate AI to accelerate kill chains.[154] The sequential, manual, one-at-a-time process currently in use will fail against larger attacks, let alone sophisticated swarms of autonomously collaborating drones.[155]

The sequential, manual, one-at-a-time process currently in use will fail against larger attacks, let alone sophisticated swarms of autonomously collaborating drones.

RESILIENT AND LAYERED DEFENSE

The attacks against U.S. bases highlight the importance of operational resilience and layered active and passive defenses. Drones easily circumvented or evaded the thin defenses at some of the more remote bases, while bases with more robust layered defenses, such as al-Asad, were harder to penetrate.

Active defenses can be saturated and therefore are not 100 percent effective. As a result, passive defenses are needed to minimize the damage when a drone does break through. During the 2/10's Middle East deployment, soldiers could shelter in hardened bunkers when an incoming drone was spotted with sufficient warning.[156] However, many U.S. bases are not hardened against attack and may be unable to offer the same blast protection.

REAL-WORLD TESTING

Frequently, the 2/10 found that many of the prototype C-UAS systems were operating in a real battle environment for the first time and were performing poorly as a result of the Army's sanitized testing and evaluation processes. In the United States, the prototypes were tested against facsimile enemy drones, which they easily defeated. But in the Middle East, all of the prototypes failed in the real world engagements against the Iranian-made drones.[157] All of the 2/10's successful intercepts were done with established kinetic kill weapons including LPWS and the UK systems.[158] The most reliable and frequently used weapon was the kinetic Coyote Block 2+, the interceptor for the Army's primary C-UAS platform, FS-LIDS. [159] Ultimately, the Army must improve the rigor and realism of its tests to better evaluate the counter-drone systems that it is developing.[160]

PLANNING FOR DISPERSED DEFENSE

Finally, the 2/10's experience highlights the challenge of defending against drones when forces are distributed over a large area. As most C-UAS active defense systems are relatively short range, they must be present at each location that needs to be protected. Thus, each base needs layers of different types of active and passive defenses as well as robust stockpiles of interceptors. The 2/10 had to move Coyote interceptors, which were in short supply, nearly daily to ensure that all eight bases were protected.[161] This logistics approach worked because of the otherwise permissive environment and because the drone attacks occurred at a measured pace and were relatively small in scale. The Army needs to develop logistical plans to support distributed operations in highly contested environments and to sufficiently equip its dispersal locations with counter-drone defenses.

Conclusion

In the early hours of the morning on January 28, 2024, an Iranian-made Shahed-101 kamikaze drone crashed into a containerized housing unit structure at the Tower 22 military outpost on the border of Jordan and Syria. The attack on Tower 22 highlights the deadly consequences if U.S. forces are not prepared to defeat drones. The single-drone strike injured 40 and took the lives of three U.S. soldiers, making it the only fatal drone attack on U.S. forces between October 2023 and February 2024.[162] Initial military assessments shared with the media indicated the hostile drone might have been misidentified as friendly or wholly undetected, as a U.S. surveillance drone was landing at the time of the attack.[163] However, the final investigative report asserts that the Tower 22 radar detected the Shahed-101, but the BDOC crew failed "to interrogate or assess the unidentified aircraft" and dismissed the radar ping as "too far away," "moving too slowly," or "possibly birds or trash."[164]

To prevent such tragedies from occurring again, the lessons from the 2/10's operations in the Middle East need to be incorporated into Army and joint doctrine, and layered counter-drone defenses need to be widely fielded at overseas bases. Moreover, as the drone fight evolves, the Joint Force must continue to learn and transform in response to adversary adaptations.

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CHAPTER 4

THE BATTLE OF THE RED SEA, NOVEMBER 2023–MAY 2025

IN RESPONSE TO ISRAEL'S OCTOBER 2023 invasion of Gaza, Iranian-backed Houthi forces, who control parts of Yemen, began attacking Israeli-linked ships that were transiting the Red Sea—the primary maritime trade route linking Europe, the Middle East, and Asia.[165] On November 15, 2023, the USS *Thomas Hudner* (DDG-116), an Arleigh Burke–class destroyer, shot down a hostile Yemeni drone, marking the beginning of what would become an 18-month U.S. operation to protect international shipping from Houthi attacks.[166] According to data collected by the International Institute for Strategic Studies, the Houthis launched 315 attacks against ships in the Red Sea between November 15, 2023, and December 2024.[167] On May 6, 2025, the United States and the Houthis agreed to a ceasefire after the Trump administration bombed more than 1,000 Houthi targets during a seven-week air campaign called Operation Rough Rider.[168]

While U.S. naval and air forces shot down the bulk of the Houthi attacks, protecting the maritime commons has come at great cost, and the high operational tempo wore U.S. forces down.[169] The U.S. success in the Battle of the Red Sea can be attributed to its layered and integrated multidomain defenses, its forces' ability to learn and adapt in real time, and the Trump administration's decision to degrade Houthi capabilities through significant offensive action. However, the financial cost of U.S. counter-drone operations in the Red Sea makes this approach unsustainable. U.S. forces need to develop lower-cost ways of shooting down cheap drones, which may require changes to existing shot doctrine. Additionally, the Joint Force needs to adopt technologies that enable rapid information sharing if it is to defeat large, heterogeneous attacks that will soon exceed the size of those seen during this fight.

Fighting for Freedom of Navigation: U.S. Navy and Air Force Operations Against the Houthis

Between November 2023 and January 2025, U.S. naval and air forces shot down an estimated 480 Houthi drones, upholding freedom of navigation across the Red Sea.[170] As seen in Figure 5, Houthi efforts peaked in June 2024 with 50 attempted antiship attacks, followed by a precipitous decline.[171] Early in the conflict, the militants sporadically launched one or two kamikaze drones at ships. Over time, however, the salvos became larger and more complex.[172] Vice Admiral Brendan McLane, commander of the U.S. Naval Surface Force, noted that by the beginning of 2024, Houthi barrages increasingly included "antiship ballistic missiles, and roving, one-way UAVs [uncrewed aerial vehicles]" searching for targets "in pre-assigned kill boxes," demonstrating "a marked escalation in the scale and complexity of enemy techniques and capabilities."[173] Nevertheless, Houthi attacks had low rates of success, as only 18 percent caused damage, mainly to commercial ships.[174] Moreover, despite the direct targeting of U.S.

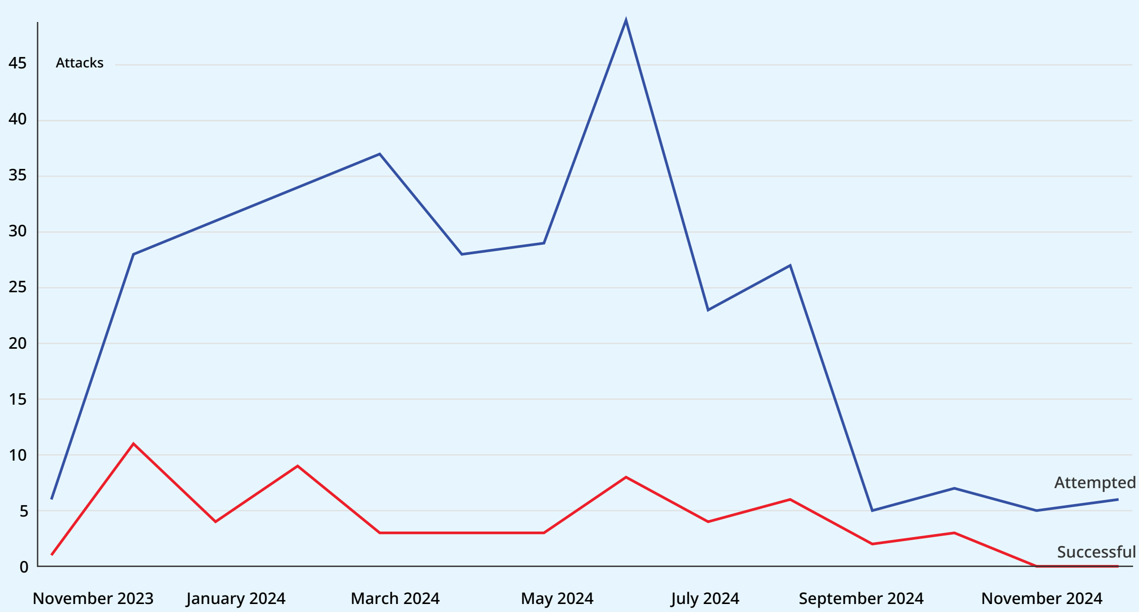
warships with ballistic missiles, cruise missiles, and kamikaze drones, U.S. losses have been minimal, and no ships were directly damaged by Houthi attacks during this period.[175]

Ultimately, the outstanding performance of U.S. forces can be credited to the surface Navy's robust layered defenses, well-coordinated joint multidomain defensive operations, and the culture of learning the Navy embraced. It also is important to acknowledge the role the offensive counter-drone operations and wide-ranging strikes against Houthi forces in Yemen had in contributing to the May 2025 ceasefire.

The layered defenses of the U.S. Navy's surface fleet have proven their worth in the Red Sea. Integrated into the Aegis combat system, naval destroyers and cruisers have long-range SAMs including the SM-3, SM-2, and SM-6, and shorter-range missiles such as the Evolved Seasparrow Missile (ESSM) and RIM-116 Rolling Airframe Missile (RAM), in addition to 5-inch guns and 20mm CIWS guns. This defense in depth provides ships with multiple opportunities to engage inbound threats in a short amount of time. Commander Jeremy Robertson of the USS *Carney* noted that "from start to finish," many of the engagements are "anywhere from 9 to 20 seconds."[177] Unsurprisingly, given the short engagement window, there is at least one instance of a Houthi antiship cruise missile penetrating the outer defensive layers of a U.S. destroyer, only to be shot down within a mile of the ship by its CIWS gun—the last line of defense.[178] While kinetic interceptors were the most common and effective drone counter, multiple ships reportedly employed their electronic warfare systems to defeat Houthi attacks.[179]

Vice Admiral Brad Cooper, deputy commander of Central Command, described the intense and harrowing experience of transiting the Red Sea on board the destroyer USS *Stockdale* (DDG-106), on a "zigzag course, lights out," in state of constant vigilance as they rapidly coordinated forces spread over hundreds of miles.[180] VADM Cooper recounted how, "with absolutely zero indications and warning," the Houthis launched four ballistic missiles toward the *Stockdale*, forcing the ship to maneuver, change speed, and fire an SM-6.[181] The destroyer intercepted three of the ballistic missiles, while the fourth went off course,

Figure 5 | Houthi Red Sea Attacks, November 2023–December 2024[176]



Houthi attacks against ships in the Red Sea peaked in June 2024, but very few of the attempted strikes were successful.

"so they let it go."[182] Eleven minutes later, the ship's radar detected a much slower moving threat, likely a cruise missile, which was intercepted by F-35Cs guided by E-2s coming from an aircraft carrier more than 500 miles away.[183] Within a few hours, a second salvo consisting mainly of drones and cruise missiles was detected, and a second destroyer guided Air Force F-16s to shoot them down.[184]

Senior Navy officials identified rapid learning and faster training as a key to their success in the Red Sea.[185] The data collected by the Aegis weapons system aided in this process. The Navy sent the digitized radar data back to the United States and dissected each engagement, identifying the best tactics and areas for improvement.[186] Initially, this process took nearly 40 days; by the end of the operation, the Navy was routinely analyzing engagements within 48 hours.[187]

In January 2024, the United States and the United Kingdom began "left of launch" strikes to destroy Houthi drones and missiles in Yemen before they could be fired. On March 15, 2025, the Trump administration significantly intensified attacks in Yemen, and within a month, CENTCOM reported a 69 percent reduction in ballistic missile launches and a 55 percent reduction in drone strikes.[188] After an intense two-month campaign that hit more than 1,000 targets in Yemen, the United States and Houthis agreed to a ceasefire.[189]

U.S. forces did not leave the Battle of the Red Sea unscathed. During the last six months of the fighting, the Navy lost three F/A-18 fighters: One was shot down by friendly fire, one slid off the deck of the USS *Harry S. Truman* (CVN-75) when the ship executed sharp maneuvers to evade Houthi drones, and the third crashed.[190] Additionally, at least a dozen MQ-9 Reaper drones collecting intelligence over Yemen were shot down by Houthi air defenses.[191]

Lessons Learned: Improving the Navy's Counter-Drone Mission

Despite the overall success in defeating Houthi attacks, the Battle of the Red Sea highlights several deficiencies and areas where the U.S. military needs to strengthen its counter-drone operations, including fielding less-expensive counter-drone weapons, expanding its stockpiles of interceptors, potentially revising its shot doctrine, and fielding C2 systems that can automatically differentiate friendly from enemy tracks and share information.

BUILDING AFFORDABLE STOCKPILES

Defensive operations against inbound weapons have been tremendously successful but highly resource intensive. The U.S. Navy has fired 120 SM-2s, 80 SM-6s, 20 ESSMs, 20 SM-3s, and 160 rounds from 5-inch guns, expending over a billion dollars in air defense interceptors and leaving stockpiles "dangerously low," according to Secretary of the Navy John Phelan.[192] Navy leaders have emphasized that the cost-exchange ratio of SAMs versus cheap drones is secondary when ships and sailors are at risk.[193] However, the Houthis employed a Fabian strategy in which they sought to exhaust and attrite U.S. forces, so that they eventually could succeed in damaging an American ship due to low interceptor stockpiles or by simply overwhelming depleted U.S. forces.[194]

During the Battle of the Red Sea, U.S. forces sought more cost-effective ways to defeat cheap Iranian-made drones instead of using multimillion-dollar missiles. An early effort to find a more plentiful and cheap interceptor originated with an enlisted sailor on board the USS *Mason* (DDG-87), who experimented with using the destroyer's 5-inch gun to shoot down Houthi drones.[195] Each destroyer carries 600 shells and fires 16–20 rounds per minute, making the 5-inch gun an effective short-range air defense system against slow-moving drones.[196] Notably, the Navy has invested in precision guidance kits and proximity fuses to increase the performance of 5-inch shells as air defense weapons.[197]

The Navy also has expanded the capacity of F/A-18E/F Super Hornets to hold nine air-to-air missiles, calling the fighters that carry this load "Murder Hornets."[198] While the F/A-18s are still firing missiles, their weapons are considerably less expensive than the standard missiles used by ships for air defense. In contrast, the Air Force has sought to reduce its dependence on air-to-air missiles, which can cost up to a million dollars, in favor of laser-guided rockets for air-to-air drone engagements.[199] The Advanced Precision Kill Weapon System II (APKWS II), a precision-guidance design conversion of the Hydra 70 rocket, costs less $40,000 and has been used effectively by F-16s to defend the U.S. fleet in the Red Sea.[200] While prudent, these efforts introduce a possible future dilemma between loading out aircraft with cheaper rockets or missiles tailored for counter-drone strikes, and carrying more sophisticated air-to-air missiles for enemy fighters.

For this reason, it seems especially important to ensure that surface vessels have cheap and plentiful options for counter-drone defense. Enhancing bullets fired by naval guns is an efficacious approach. Additionally, the Navy plans to add the Roadrunner and Coyote counter-drone interceptors used by U.S. ground forces to its destroyers in the next year.[201] The Roadrunner and Coyote jet-powered drones are considerably less expensive than naval air defense missiles and offer comparable ranges to the 5-inch guns. However, these drones can loiter overhead and automatically intercept hostile UAS, which may reduce the decisions that a weapons officer needs to make.[202]

EVOLVING SHOT DOCTRINE TO MEET RESOURCE CONSTRAINTS

In addition to integrating cheaper C-UAS weapons and building stockpiles of interceptors, the U.S. Navy should consider revising its shot doctrine so that it holds its most expensive and scarce air defense missiles in reserve for high-end threats and uses cheaper and shorter-range interceptors against drones. Doing so would fundamentally change the current concept of layered defenses. Retired Rear Admiral Fred Pyle, former director of the Navy's Surface Warfare Division, explained that, under current doctrine, "you want to engage [a threat] at the longest possible range to give yourself decision space" and to hedge against any one of those layers failing.[203] In other words, the Navy fires its longest-range weapon first and, if that fails, then moves down to its next longest-range weapon, giving the ship as many opportunities as possible to defeat an inbound threat.

This approach is effective but incredibly conservative, and it does not consider that magazine-constrained ships are disadvantaged when facing large salvos of cheap drones and missiles. At sea, a ship cannot quickly or easily reload its missile tubes. Thus, a smarter approach that selects the most appropriate defensive weapon for the level of the threat may be needed. Additionally, the Navy fires approximately two rounds per incoming missile.

> **The U.S. Navy should consider revising its shot doctrine so that it holds its most expensive and scarce air defense missiles in reserve for high-end threats.**

This hedges against the failure of one interceptor but quickly expends limited inventories of SAMs.[204] In their war against Russia, Ukrainian forces have adapted their shot doctrine out of necessity. The Ukrainians employ mobile gun trucks as the first line of defense against Russian Shahed drones and conserve long-range air defense missiles, such as Patriot missiles and advanced medium-range air-to-air missiles (AMRAAMs), as interceptors of last resort to use against incoming drones bound for critical civilian or military infrastructure, as well as to defeat Russian cruise and ballistic missiles.[205] More analysis needs to be done to consider whether the U.S. Navy should follow suit. However, given the scale of the drone and missile threat, a more risk-acceptant shot doctrine may be needed.

SPEED THROUGH AUTOMATION

Finally, the joint Navy–Air Force counter-drone operations highlight the importance of rapid sensor data processing and sharing across widely dispersed forces. The forces in the Red Sea were able to use the AI-enabled Maven Smart System (MSS) to assist in this mission. MSS collected target data from various sensors, such as the ship-based SPY phased-array radar and the E-2 airborne early warning aircraft, and synthesized them into a time-delayed common operating picture shared among CENTCOM headquarters and components.[206] However, more should be done to integrate the sensors and shooters across all domains of the Joint Force. Basic data-fusion capabilities are not widely available across the different combatant commands, nor does MSS produce a real-time common operating picture. U.S. forces must have the capacity to find, track, and assign forces to intercept multiple simultaneous threats under extreme time pressure. Sorting through false radar tracks that can appear and disappear and distinguishing friend from foe is particularly difficult and demands a lot of operators' attention and time.[207] Automated command and control systems could ease the burden on operators and improve response times.

Conclusion

While the Houthi drone campaign in the Red Sea failed to inflict major damage to the U.S. Navy, the battle revealed critical cost impositions and exposed the need for more integrated processing. Nevertheless, the U.S. Navy was able to accelerate learning cycles, embrace a positive cultural shift toward adaptation and iteration, and make concrete investments in layered, cost-effective defenses. The Battle of the Red Sea can also be seen as a forewarning for future conflicts: Successful tactical adaptation cannot fully offset the strategic strain of prolonged defensive operations against a low-cost, adaptive enemy, which is exemplified in the counter-drone fight.[208] As such, the Red Sea serves not only as a case study in counter-drone warfare, but also as a guide to the operational and institutional adaptability required for success in future large-scale combat operations.

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CHAPTER 5

THE FUTURE THREAT: DEFENDING AGAINST CHINESE DRONE ATTACKS

THE THREAT OF IRANIAN-MADE DRONES in the Middle East, while serious and deadly, is relatively small and crude in comparison with the sophisticated offensive UAS capabilities of China. The PLA has long considered drones to be essential elements of a "world-class military" and prioritizes production and integration of drones into its force.[209] In 2024, the PLA ordered one million kamikaze drones to be delivered by 2026, and it continues to research and develop autonomous drone swarms as a part of its drive toward becoming an "intelligentized" miliary force.[210] In a potential conflict over Taiwan, U.S. forces must be ready to counter not just Chinese missiles and crewed aircraft, but also a rapidly expanding fleet of drones that threaten American bases and dispersed operations. While less effective than advanced missiles, China's deep magazine of drones could be used to suppress and destroy U.S. forces in a protracted Indo-Pacific conflict.

Although the PLA has many Group 4 and 5 drones that are routinely operated around Taiwan and in the East and South China Seas, it has begun to diversify its drone fleet.[211] Like the United States, China is drawing lessons from the war in Ukraine and other recent conflicts. As a result, the PLA has intensified its pursuit of UAS, showcasing 36 different drones at the Zhuhai Airshow in November 2024, which ranged from large, exquisite systems to two-pound microdrones.[212] As kamikaze drones of various sizes have played an important role on the Ukrainian battlefield as a form of strategic and tactical firepower, the PLA is also expanding its fleet of one-way attack drones. The PLA is stressing "mass production" of "affordabl[e]" drones that can "overwhelm adversaries" through "quantity" and "innovative" tactics.[213] For instance, one PLA soldier can simultaneously control multiple microdrones capable of carrying up to three grenades, augmenting the number of weapons on the battlefield.[214] PLA units also are integrating FPV drones into their formations for antitank and antipersonnel missions.[215] Some of the FPVs are controlled via fiber-optic cables so that they are not susceptible to jamming.[216] Additionally, at least two stealthy drones are in development, the CH-7 Rainbow and GJ-11 Sharp Sword, which are intended for long-range, high-altitude surveillance and strike missions in hostile airspace.[217] In sum, the PLA is rapidly producing high- and low-end drones and may soon have the largest and most sophisticated drone fleet in the world.

As the United States grapples with the idea of a military confrontation in the Indo-Pacific, understanding how the Chinese military will leverage current and future drone technology is essential. The embrace of AI and advanced drone technology by the PLA makes it nearly certain that American forces will have to defend against sophisticated UAS attacks. If war broke out tomorrow, would the U.S. military be ready?

Simulating Chinese Drone Warfare

To explore this question, the CNAS Defense team conducted a tabletop exercise to examine how U.S. forces could defend against Chinese drone attacks during a protracted war over Taiwan. The scenario was set 42 days into a major conflict and posited that both the United States (Blue) and China (Red) had depleted their stockpiles of sophisticated long-range missiles and long-range air defense interceptors. In this scenario, China employed drones in an attempt to suppress and destroy U.S. forces operating inside of the First Island Chain.

Given the research emphasis on American counter-drone capabilities, the TTX was designed as a one-sided planning exercise. The Red attacks were scripted against three separate Blue teams representing U.S. military planners tasked with posturing their forces and developing air defense plans. The game was set in an undefined near future in which China had invested heavily in long-range military and small commercially derived kamikaze drones, while the United States had fielded a layered drone defense with limited quantities of lasers, cannons with enhanced ammunition, high-power microwaves, counter-drone drones, and jammers. The TTX aimed to understand how these systems might perform together in specific Indo-Pacific tactical vignettes and to help identify the gaps and challenges in U.S. counter-drone operations.

The Blue teams were presented with two independent tactical vignettes: (1) a U.S. Marine Littoral Regiment (MLR) carrying out expeditionary advanced base operations on the island of Yonaguni in Japan's Southern Ryukyus, and (2) U.S. Air Force fighters supported by U.S. Army air defenders conducting agile combat employment (ACE) operations across distributed airbases on the Philippine island of Mindanao.[218] The TTX presented six different Chinese drone attacks against U.S. forces. The attacks were intentionally designed to vary the level of difficulty and included both current drone technologies and future autonomous swarming capabilities. The details of the Red attacks in each vignette are presented in Tables 5 and 6.

Tabletop Exercise Vignette 1

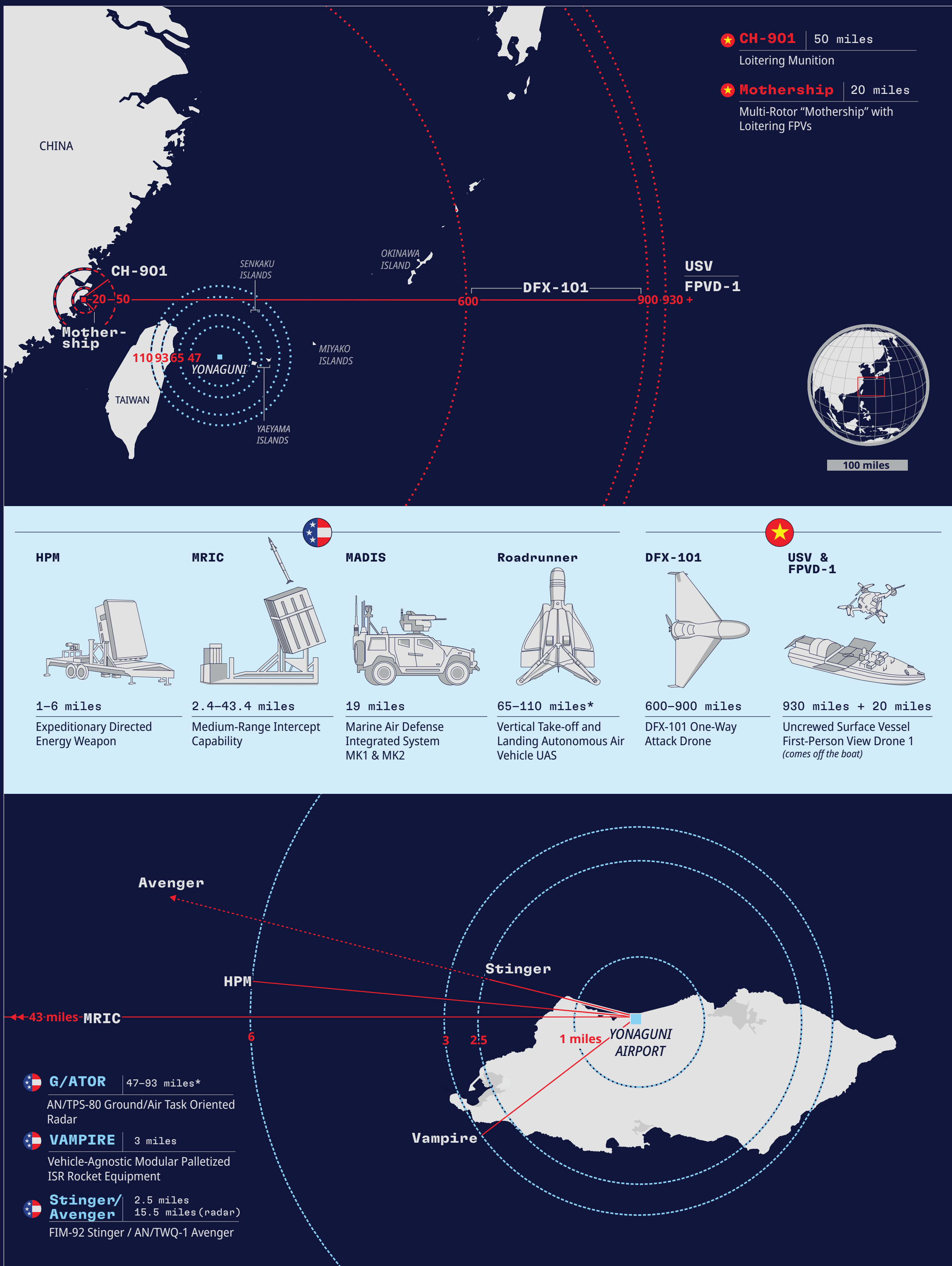
MARINE LITTORAL REGIMENT ON YONAGUNI, JAPAN

TABLE 5 | SUMMARY OF VIGNETTE 1 CHINESE DRONE ATTACKS

Red Attack	Attack Description	Launcher Modality & Location	Desired Targets
Attack 1	3 salvos of 6 long-range, propeller-driven kamikaze drones with preprogrammed flight paths, 2 minutes apart	Truck launched from Chinese mainland	Fixed fuel points Supply points Transporter erector launcher (TEL) hides
Attack 2	1 uncrewed surface vessel (USV) carrying smaller aerial drones both military-grade loitering munitions (Group 2 drones) and first-person view (FPV) kamikaze drones	USV launched from Chinese mainland	Radars and TELs with military drones FPVs hunt U.S. forces
Attack 3	An autonomous, self-healing, heterogeneous swarm of ~220 FPV drones: • 5 larger "mothership" multirotor aircraft that can carry 4 FPVs each • 200 high-speed FPV drones armed with 3lb bombs	Drone boats deploy armed FPV drones and mothership multirotor aircraft carrying FPVs	Radars and TELs

FIGURE 6 | TTX VIGNETTE 1: KEY CAPABILITIES FOR U.S. MARINE CORPS COUNTER-DRONE OPERATIONS[219]

On Yonaguni, Japan, U.S. Marines conducting expeditionary advanced base operations in the Southern Ryukyu Islands were close to Taiwan and China and vulnerable to a range of drone attacks. However, the island's small size made counter–uncrewed aerial systems (C-UAS) operations less difficult.



*Asterisk indicates range estimated by the authors. The range distances for the imagined Chinese drones employed in this tabletop exercise were estimated by the authors based on similar existing systems.

Key Findings from the Tabletop Exercise

Ultimately, the TTX clearly demonstrated the degree to which future drone threats will differ from those seen today in Middle East and on the battlefields of Ukraine. This is due not only to the scale and sophistication of the PLA's drones but also to the archipelagic nature of the Indo-Pacific and the vast distances between islands, which would stress U.S. counter-drone operations.

Chinese drones threaten to disrupt U.S. operations, overwhelm defenses, and complicate logistics.

With cheap drones, China possesses a sustained ability to attack U.S. forces inside the First Island Chain. Long-range, military-grade kamikaze drones could be used for standoff strikes, while smaller drones may be delivered by longer-range aircraft or surface vessels. Additionally, the maneuverability of FPV and kamikaze drones deployed from a "mother-ship" UAS or uncrewed surface vessel (USV) creates a 360-degree threat vector.

While most drone strikes are likely to suppress U.S. forces rather than destroy them, they would still disrupt U.S. offensive operations by compelling American forces to adopt a defensive posture. The cumulative impact of repeated drone attacks could deplete U.S. interceptor stockpiles and further limit operations, eventually leaving U.S. forces exposed as a result. Ultimately, the scale of the Chinese drone threat is going to outstrip American active defenses.

The high likelihood of widespread attrition of active counter-drone defense and interceptors means the United States must also prioritize passive defense in an Indo-Pacific drone fight. Active defenses such as jammers, missile interceptors, cannons, and high-power microwaves are necessary but insufficient to defend against the growing drone threat. The

Tabletop Exercise Vignette 2

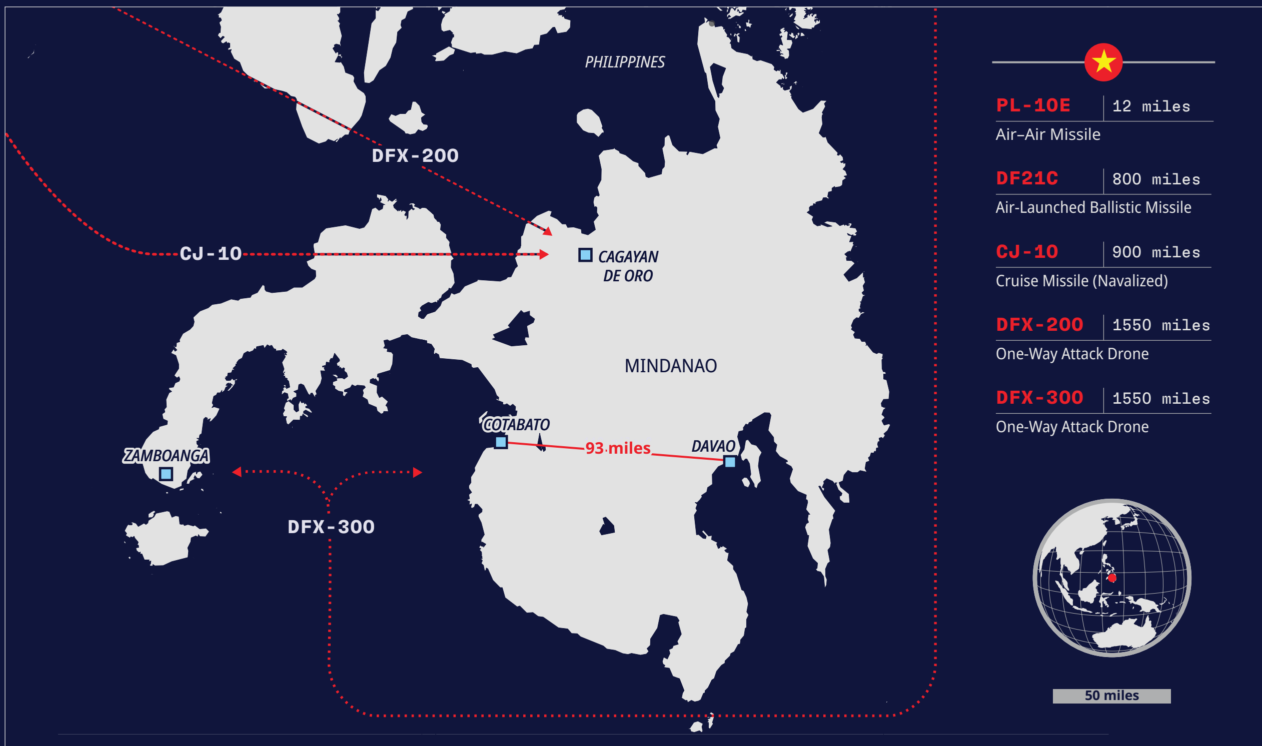
AGILE COMBAT EMPLOYMENT OPERATIONS ON MINDANAO, PHILIPPINES

TABLE 6 | SUMMARY OF VIGNETTE 2 CHINESE DRONE ATTACKS

Red Attack	Attack Description	Launcher Modality & Location	Desired Targets
Attack 1	4 salvos of 5 jet drones, 1 minute apart	Truck launched from Hainan Island	Fuel storage or runways
Attack 2	Complex attack with 35 turbofan kamikaze drones, 4 cruise missiles, and 1 air-launched ballistic missile	Truck-launched drones from Hainan Island	Preferentially targets F-35 locations
		H-6-launched ballistic missile in Chinese-controlled airspace	CJ-10 aimed at fuel storage or offload points
		Ship-fired CJ-10 cruise missiles	
Attack 3	30 autonomous turbofan kamikaze drones with self-healing mesh launched simultaneously	Truck launched from Hainan Island	F-35s

FIGURE 7 | TTX VIGNETTE 2: KEY CAPABILITIES FOR U.S. ARMY AND AIR FORCE COUNTER-DRONE OPERATIONS[220]

U.S. air bases on Mindanao in the Philippines are dispersed hundreds of miles apart, making effective counter-drone defense difficult.



AN/MPQ-64 — Sentinel A3 Radar — 47 miles

ALPS — Army Long-Range Persistent Surveillance — 310–1,550 miles

LPWS/C-RAM — Land-Based Phalanx Weapons System — 1.2 miles

DE M-SHORAD — Directed Energy Laser, Mobile — 5 miles (RADAR)

IFPC 2 — Indirect Fire Protection Capability 2 — 20–22 miles

HPM — IFPC High-Power Microwave — 1–6 miles

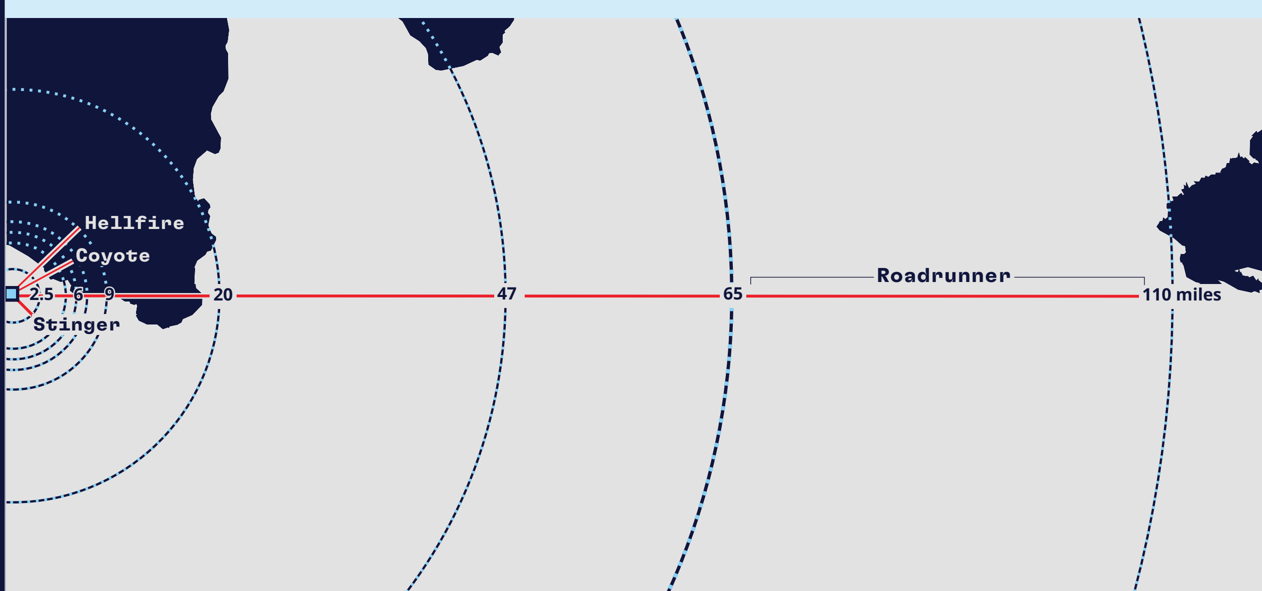
Roadrunner — VTOL Autonomous Air Vehicle UAS — 65–110 miles*

M-LIDS — Mobile Low, Slow, Small UAS Integrated Defeat System

Coyote	6–9 miles*
30mm	4,400 yards
KuRFS-M Ku-band Radio Frequency Sensor Mobile	9.9 miles (RADAR)

M-SHORAD — Mobile Short-Range Air Defense Inc. 1

Hellfire	5–7 miles
Stinger	2.5 miles
XM914 30mm	13,120 yards



* Asterisk indicates range estimated by the authors. The range distances for the imagined Chinese drones employed in this tabletop exercise were created by the authors based on similar existing systems.

ubiquity and scale of Group 1 and 2 drones means that "leakers"—drones that slip through air defenses—are inevitable. Thus, U.S. forces need to develop a robust system of passive defenses, particularly at fixed locations such as airbases, that will be useful against a range of different air threats, including drones. With active and passive defenses U.S. forces will be able to absorb and mitigate some effects of drone attacks and continue to conduct offensive operations.

The United States needs large stockpiles of proven counter-drone capabilities to protect dispersed forces from Chinese attacks.

In the Indo-Pacific, U.S. forces would be operating across multiple archipelagic nations hundreds or thousands of miles apart. Dispersing U.S. forces increases survivability but also increases demand for point defenses—short-range systems that can defend a limited area or point—if the locations are sufficiently far away. Most purpose-built C-UAS systems are short-range, and therefore every location American forces hope to defend from drone attacks will require its own set of layered and integrated sensors and effectors. It is therefore reasonable to assume that in an Indo-Pacific conflict, the demand for short-range counter-drone systems would increase significantly.

In Vignette 1, the MLR had ample defenses to counter the first two Red attacks because of the short geographic distance in the scenario. Yonaguni is a small island of less than 11 square miles, which allowed for mutual defense of dispersed positions. In contrast, the geography of Mindanao in Vignette 2 meant that there were not enough defenses to adequately cover the ACE bases, which are about 100 miles apart. American warfighting concepts for the defense of Taiwan are premised on distributed joint operations; the United States will be defeated if distributed forces cannot be protected against drone attacks.[221]

Key to protecting distributed forces from drone attack are large stockpiles of short-range kinetic interceptors and well-developed resupply plans as part of the U.S.-contested logistics initiative. Supplying distributed forces with enough interceptors for sustained counter-drone operations would be challenging, and China has sufficient drones to launch hundreds of waves of the types of attacks posited in the TTX. In the Middle East, where logistics are not contested, American soldiers scrambled to resupply bases with more interceptors when stockpiles of Coyote missiles were depleted. In a conflict with China, interceptors would need to be transported hundreds of miles to dispersed bases while under attack. Because of shallow stockpiles and contested logistics, U.S. forces need more high-volume, short-range defenses. These should include emerging technologies such as high-power microwaves to defeat swarms, but also modest upgrades to plentiful existing capabilities like cannon shells. Creating optionally powered proximity-fused cannon shells offers an affordable and proven way of ensuring widely available short-range air defenses with great magazine depth, while making use of the nearly ubiquitous guns and cannons on existing weapons.

Maneuverable counter-drone sensors and interceptors will improve survivability when conducting fixed and mobile counter-drone operations.

Distributed forces do not equate to mobile forces. In both vignettes, Blue forces were equipped with C-UAS that varied in maneuverability. For the MLR on Yonaguni, Blue players were easily able to reposition the MADIS vehicle-mounted C-UAS interceptor platforms, enabling mobile operations across the island. On Mindanao, however, players representing the U.S. Army employed their maneuverable C-UAS platform, M-LIDS, as a movable Coyote launcher that could be repositioned at different locations on the air bases being defended, thus enabling mobility within a fixed site point defense operation. In both scenarios, Blue players leveraged the maneuverability of the C-UAS technology to employ "shoot-and-scoot" tactics to avoid counter-fire and increase survivability. However, managing the emissions from counter-drone systems, which largely rely on radars for detection and fire control, is challenging with current systems. While radar like AN/TPS-80 Ground/Air Task Oriented Radar (G/ATOR) and AN/MPQ-64 Sentinel A3 Radar can be moved and repositioned, it may not be at the speed required for the future drone fight. Ultimately, to increase the survivability of mobile and fixed distributed forces, the DoD should invest more in maneuverable C-UAS capabilities.

The United States needs to field emerging technologies to counter advanced drone threats.

Even with planned improvements, U.S. forces likely will struggle to defeat large, pulsed salvos, complex attacks, and autonomous swarms without new technologies such as high-power microwaves and AI. At a certain point, defenses that counter incoming drones one by one are going to become saturated and either run out of interceptors or fail because they cannot re-aim quickly enough to intercept the drones before they impact.

To defeat large and complex attacks, U.S. sensors and interceptors must be seamlessly integrated into an automated, AI-enabled C2 system. As the size of drone attacks increases from several drones to dozens or hundreds, U.S. defenders must be able to react rapidly to multiple threats in increasingly shorter time frames. Given the speed of decision-making when intercepting drones, U.S. forces will need AI-enabled systems to optimize firing choices and coordinate responses across different defensive platforms. Additionally, defeating complex attacks with multiple types of air threats, such as slow-moving drones, fast-flying ballistic or hypersonic missiles, and intermediate-speed supersonic cruise missiles, necessitates the employment of multiple different types of effectors optimally and with simultaneity. In a heterogeneous attack, weapons approach from different azimuths and at different speeds, with the intention of forcing a defender to make choices about what to defend, and in doing so, leave areas exposed that then can be exploited by the other weapons. AI decision-support algorithms need to be incorporated to automate and optimize the engagement process.

Even with AI-enhanced command and control, at a certain point, defenses that counter incoming drones one by one will become saturated. They may run out of interceptors or simply fail because they could not re-aim quickly enough to intercept a drone before impact. High-power microwaves are the only effective counters for defeating swarms of small UAS en masse. However, HPM only does so at very short range and therefore should not operate alone but as the final layer of defense. Moreover, China is likely to invest in hardening of at least some UAS against HPM defenses. Other directed energy weapon technologies, such as high-energy lasers, do not seem to be mature enough yet to be fielded at scale. Unlike HPM, lasers only engage one target a time, require dwell time, and then need to be re-aimed. They also require large amounts of power and are easily disrupted by atmospheric conditions. Less powerful lasers that can dazzle the optics of drones might be better suited for maneuvering forces managing a few drones at a time.

Finally, the United States should continue to invest in high-resolution passive sensors, which would enable U.S. forces to detect and target inbound drones at greater range without emitting. Players in the TTX discussed using a network of cellular towers as passive sensors and advanced computer processes to create high-resolution tracks. While this may not be feasible in the real world, passive sensors with enough range and fidelity to enable precise targeting would be incredibly useful.[222]

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CHAPTER 6

CONCLUSION AND RECOMMENDATIONS FOR THE DEPARTMENT OF DEFENSE

AFTER DECADES OF AIR DOMINANCE and a near monopoly on precision strike, the United States now is faced with a dramatically different, more hostile world as the proliferation of cheap drones has democratized mass precision fires. It is likely that in any future conflict, drones will pose an unavoidable threat to American forces. With the dissolution of the Soviet Union, the U.S. military allowed its short-range air defense capabilities to atrophy, creating a significant vulnerability gap that is exacerbated by drones. Today, the threat of preprogrammed, long-range military kamikaze drones and small commercial UAS continues to grow, as they are inexpensive enough for adversaries to build large stockpiles and their size and flight profiles allow them to exploit weaknesses in traditional U.S. air defenses. Russia and Iran learned about the drone threat the hard way during Ukraine's Operation Spider's Web and Israel's Operation Rising Lion, respectively.[223] In these attacks, small drones caused significant damage to large, defenseless, expensive weapons systems. The United States needs to learn from these failures and prioritize countering drones or risk suffering a similar fate.

As this report's analysis of U.S. defense spending reveals, the Pentagon has invested in both legacy and emerging capabilities to counter UAS for nearly a decade. However, these efforts have been hindered by insufficient scale and urgency. This is in part because counter-drone procurement is victim of the perennial bureaucratic budget battles and the insufficient defense industrial capacity that limits defense production more broadly. Only intermittently has the DoD prioritized counter-drone procurement, resulting in a Joint Force that lacks sufficient purpose-built counter-drone systems, large reserves of affordable interceptors, and a modern short-range air defense capacity. Moreover, for decades, the Defense Department has spent billions of dollars on basic research and development for next-generation counter-drone systems, such as high-energy lasers, high-power microwaves, and long-range passive sensors, and none have yet to enter full-scale production.

Despite the Pentagon's shortfalls in procuring purpose-built C-UAS capabilities, U.S. counter-drone operations in the Middle East have been notable. In defending bases across the region, U.S. Army soldiers leveraged a patchwork of C-UAS systems and neutralized the majority of drones fired at them. In the Red Sea, U.S. sailors deftly employed the surface fleet's integrated and layered air defense capabilities in concert with Air Force fighter coverage, resulting in a high rate of interception. Yet the cost-exchange ratio of these naval engagements was decidedly unbalanced, as the fleet relied on multimillion-dollar munitions to neutralize low-cost Iranian-made drones, revealing the unsustainable nature of current Navy shot doctrine.

As adversaries like China and Russia continue to invest in more sophisticated drones with greater autonomy and procure them in massive quantities, the United States' counter-drone and air defenses are not keeping pace. There is no easy answer to this problem, and no one technology offers a silver bullet solution. Current U.S. air defense systems are sufficient against current threats, like modest numbers of DJI quadcopters and Iranian Shaheds, but would be quickly overwhelmed by large autonomous drone swarms or complex, pulsed salvos that pair low-cost drones with sophisticated missiles. Thus, the United States must invest in air defenses and self-protection capabilities optimized for counter-drone missions, as well as emerging capabilities designed for the accelerating future threat.

China is investing heavily in kamikaze drones and developing autonomous drone swarms, and it will soon have one of the largest and most capable drone forces in the world. Without deep magazines of substantially enhanced counter-drone capabilities, Chinese drones could undermine U.S. distributed warfighting concepts and jeopardize mission success. The PLA could employ low-cost drones to degrade U.S. operations within the First Island Chain—using long-range one-way attack systems and uncrewed surface vessels to launch swarms of quadcopters against U.S. forces and bases—undermining American operational objectives and potentially leading to strategic failure.

The future drone threat is nearly here: The Pentagon is running out of time to acquire new capabilities; adopt new tactics, techniques, and procedures; and train its forces. The DoD must move with urgency. The stakes are not theoretical—without adequate defenses, even the most advanced systems and tactics will be rendered irrelevant in the face of overwhelming drone attacks. As former Chairman of the Joint Chiefs of Staff General Mark Milley said: "None of this is going to matter if you're dead. That's why you need air defense."[224]

Overall Recommendations for the Department of Defense

Prioritize counter-drone defense and extend capabilities beyond the air defense community. Drone defense cannot be siloed to dedicated air defense units. Every unit will need the ability to defend itself against small UAS. The Joint Force must invest in more sensors and effectors that are optimized for the drone threat. Beyond traditional air defense units armed with large systems, individual vehicles and dismounted soldiers will need man-portable and mobile counter-drone capabilities for self-protection.

Expand counter-drone training across the Joint Force. U.S. operations in the Middle East have been so successful because U.S. forces have adapted in real time. As the drone threat intensifies, the likelihood for error increases. The Pentagon needs to develop and share best tactics, techniques, and procedures and ensure that all forces are trained in drone self-protection.

Improve the rigor and realism of counter-drone prototype testing. The current test and evaluation process fosters a false sense of confidence in prototype counter-UAS systems, as they are often assessed using unrealistic enemy drone facsimiles and low-fidelity tests of weapons that use electromagnetic energy. The Pentagon should remedy these deficiencies and intensify testing conditions to ensure U.S. warfighters are receiving the strongest weapons possible. Furthermore, the DoD should take advantage of opportunities for allies and partners to test capabilities in real battlefield settings where possible, as has occurred in Ukraine.

To Be Prepared for Today's Drone Threat, the DoD Must Invest in Proven Capabilities

Build resilient defenses with layered active defenses and passive countermeasures. U.S. forces must be operationally resilient, meaning they have the ability to defeat or absorb drone attacks while continuing with their other missions. Resilience requires layered active defensive systems with multiple types of sensors and effectors. No one single type of sensor or weapon has the ability to defeat the full range of drone threats the United States faces, which is why a layered and multifaceted defensive system is needed.

It is impossible for air defenses to be 100 percent effective at all times, and passive protection is essential for resilience. Some drones are likely going to get through. Large complex attacks can overwhelm even densely layered active defenses and destroy valuable assets, such as fighter jets and missile launchers. Many counter-drone defenses are likely to be biased toward intercepting specific types of threats, which may make them more vulnerable to other threats. For instance, HPM systems designed to destroy small drone swarms will be vulnerable to antiradiation missiles. Given that smart adversaries are likely to design attacks to exploit these vulnerabilities in active defenses, a robust system of passive defenses is a necessity. American forces have shown great tactical prowess by intercepting most of the kamikaze drones fired at them in the Middle East. Nevertheless, some drones have hit their target, taking the lives of U.S. soldiers in the process.

Strengthen mobile counter-drone capabilities and tactics for maneuvering forces. The Army's experience defeating drones in CENTCOM revolved entirely around fixed sites, and the preponderance of the C-UAS defenses that the DoD is purchasing are immobile. The United States has not developed appropriate mobile defense for maneuver formations, nor has it fielded sufficient handheld capabilities for dismounted infantry. More needs to be done to consider what type of C-UAS capabilities will work for ground forces on the move and to develop tactics and operational concepts for maneuvering in the presence of many hostile drones.

Procure large stockpiles of high-volume, short-range kinetic interceptors. U.S. forces in the Middle East seriously depleted interceptor stockpiles. Specifically, more Coyote missiles, which are battlefield-proven systems, need to be bought, though they are too expensive to be the sole solution. High-volume air defenses likely include future technologies like HPM and DE, which do not need interceptors, but also more gun-based defenses and rocket interceptors like APKWS II. The Navy should procure specialized shells for its 5-inch guns, while the Army and Marine Corps should buy proximity-fused ammunition for their large cannons.

To Be Prepared for the Future Drone Threat, the DoD Must Also Invest in Emerging Capabilities

Invest in AI-enabled processing of sensors and AI command and control to speed up C-UAS kill chains. Command and control networks for counter-drone defenses are siloed, and the process of identifying and engaging drones remains manual. As the size and complexity of drone attacks increases, U.S. operators are going to be overwhelmed and will not be able to complete all the steps in the kill chain and manually engage multiple simultaneous drones. Integrating the command and control of different counter-drone defenses and using AI to speed up the identification and engagement processes is needed. It will also help to realize the Pentagon's goal of Joint All-Domain Command and Control (JADC2).

Transition promising and rapidly emerging technologies, especially high-power microwaves, to programs of record. HPM is the technology most capable of defeating swarms or high-volume attacks. It will not long be long before enemies will launch large drone attacks that overwhelm kinetic defenses. Truly autonomous drone swarms that independently coordinate and optimize their behavior also will soon be a reality. HPM can neutralize many drones simultaneously by using electromagnetic energy to fry their electronic components. However, this is a last line of defense and should be integrated into a layered drone defensive system.

Invest in high-resolution passive sensors. Early detection of drones is a critical first step that can determine whether there is sufficient time to defeat drones or whether personnel should instead take shelter from an inbound attack. Right now, U.S. forces are dependent on active radar systems for finding, fixing, and tracking drones. These sensors are incredibly capable but also release emissions that broadcast their locations to enemies. Long-range, high-resolution passive sensors offer a more survivable alternative to finding drones and would reduce the amount of time that active radars would need to be turned on. If this technology were widely available, it could fundamentally shift the competition between attackers and defenders in favor of the defense.

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57. Hagen et al., *The Foundations of Operational Resilience*, 64; Vick et al., *Air Base Defense*, 50.

58. Hagen et al., *The Foundations of Operational Resilience*, 68. All of the U.S. services are focused on some form of dispersed operations; see: Bill Hix and Robert Simpson, "Accelerating into the Next Fight: The Imperative of the Offense on the Future Battlefield," Modern War Institute, February 26, 2020, https://mwi.westpoint.edu/accelerating-next-fight-imperative-offense-future-battlefield/; Miranda Priebe et al., *Distributed Operations in a Contested Environment: Implications for USAF Force Presentation* (RAND Corporation, July 17, 2019), https://www.rand.org/content/dam/rand/pubs/research_reports/RR2900/RR2959/RAND_RR2959.pdf; and Ronald O'Rourke, "Defense Primer: Navy Distributed Maritime Operations (DMO) Concept," Congressional Research Service, December 12, 2024, https://www.congress.gov/crs-product/IF12599.

59. This includes passive and active sensing, command and control software and systems, and kinetic and nonkinetic defeat and disrupt.

60. This is inclusive of large precision-guided munitions (PGMs) systems, which may account for the high number compared to other estimates. See citation 65: U.S. Army, "AN/MPQ-64 Sentinel A3 Radar (Line Item Number 0125WK5057)"; U.S. Army, "AN/TPQ-50 Counterfire Radar (Line Item Number 8386BA5500)"; U.S. Army, "AN/TPQ-53 Counterfire Radar (Line Item Number 8386BA5500)"; U.S. Army, "AN/TWQ-1 Avenger (Line Item Number 2690CE8710)"; U.S. Army, "Army Integrated Air and Missile Defense (AIAMD) IAMD Battle Command System (Line Item Number 9280BZ5075)"; U.S. Army, "Counter Small Unmanned Aerial System Intercept (Line Item Number 9216C82200)"; U.S. Army, "FIM-92 Stinger (Line Item Number 2684C20000)"; U.S. Army, "Hellfire (Line Item Number 1338C70000)"; U.S. Army, "Indirect Fire Protection Capability Inc 2-I (Line Item Number 8930C61001)"; U.S. Army, "Land-Based Phalanx Weapons System (Line Item Number 0173BZ0501)"; U.S. Army, "Lower Tier Air Missile Defense Sensor (LTAMSD) (Line Item Number 7265C12000)"; U.S. Army, "M-SHORAD Inc. 1 (Line Item Number 8082C14300)"; U.S. Army, "MIM-104 Patriot (Line Item Number 0962C50700)"; U.S. Army, "PAC-3 MSE Missile (Line Item Number 8260C53101)"; U.S. Navy, "Physical Security C-UAS (Line Item Number 8128)"; U.S. Navy, "Evolved Sea Sparrow Missile (ESSM) (Line Item Number 2307)"; U.S. Navy, "AMRAAM (Line Item Number 2206)"; U.S. Navy, "AN/SEQ-4 ODIN (Line Item Number 5510)"; U.S. Navy, "AN/SLQ-32 (Line Item Number 2312)"; U.S. Navy, "AN/SPY-1 (Line Item Number 2981)"; U.S. Navy, "Advanced Precision Kill Weapon System (APKWS) (Line Item Number 0151)"; U.S. Navy, "Cooperative Engagement Capability (CEC) (Line Item Number 2606)"; U.S. Navy, "Close-In Weapon System (CIWS) Mods (Line Item Number 4205)"; U.S. Navy, "Drake 2.0 C-UAS Afloat (Line Item Number 5509)"; U.S. Navy, "Evolved Sea Sparrow Missile (ESSM) (Line Item Number 2307)"; U.S. Navy, "Hellfire (Line Item Number 2254)"; U.S. Navy, "Joint Crew (JCREW) (Line Item Number 3177)"; U.S. Navy, "MK 2 Ship Self-Defense System (SSDS) (Line Item Number 5231)"; U.S. Navy, "RIM-116 Rolling Airframe Missile (RAM) (Line Item Number 2242)"; U.S. Navy, "Shipboard Panoramic Electro-Optic/Infrared (SPEIR) (Line Item Number 2981)"; U.S. Navy, "Sidewinder (Line Item Number 2209)"; U.S. Navy, "Standard Missile-2 (SM-2) (Line Item Number 2356)"; U.S. Navy, "Standard Missile-6 (SM-6) (Line Item Number 2234)"; U.S. Air Force, "3D Expeditionary Long-Range Radar (PE 0207455F)"; U.S. Air Force, "Air Base Air Defense System (ABADS) – Medium-Range Intercept Capability (MRIC) and Counter-small Unmanned Aircraft Systems (C-sUAS)"; U.S. Air Force, "Advanced Medium-Range Air-to-Air Missile (AMRAAM) (Program Element 0207163F, Project 673777)"; U.S. Air Force, "Counter-Unmanned Aircraft Systems (C-UAS) Directed Energy (DE) Prototyping (Project 640200)"; U.S. Air Force, "High Power Microwave Development and Integration (Project 633152)"; U.S. Air Force, "High Power Solid State Laser (Project 633151)"; U.S. Air Force, "AIM-9X Sidewinder (R&D, Program Element 0207161F, Project 674132)"; U.S. Navy, "Aegis (R&D, Program Element 0604307N)"; U.S. Navy, "AMRAAM (R&D, Program Element 0207163N, Project 0981)"; U.S. Navy, "AN/SPY-1 (R&D, Program Element 0604501N)"; U.S. Navy, "APKWS (R&D, Program Element 0607142A, Project EW9)"; U.S. Navy, "C-UAS (R&D, Program Element 3241)"; U.S. Navy, "Cooperative Engagement Capability (CEC) (R&D, Program Element 0607658N)"; U.S. Navy, "Drake 2.0 (R&D, Program Element 0604636N)"; U.S. Navy, "High Energy Laser Counter ASCM Project (HELCAP) (R&D, Program Element 0603925N)"; U.S. Navy, "JCREW (R&D, Program Element 0603654N, Project 3177)"; U.S. Navy, "MK 2 Ship Self-Defense System (SSDS) (R&D, Program Element 0604755N)"; U.S. Navy, "MK-57 NSSMS (R&D, Program Element 0604756N, Project 0173)"; U.S. Navy, "ODIN (R&D, Program Element 0603925N, Project 9823)"; U.S. Navy, "Phalanx CIWS SEARAM (R&D, Program Element 0604756N, Project 9081)"; U.S. Navy, "RIM-116 (R&D, Program Element 0604756N)"; U.S. Navy, "Sidewinder (R&D, Program Element 0207161N, Project 0457)"; U.S. Navy, "SM-2 BLK IIIC (R&D, Program Element 0604366N, Project 0439)"; U.S. Navy, "SM-6 (R&D, Program Element 0604366N,

Project 3092)"; U.S. Navy, "SM-6 BLK IB (R&D, Program Element 0604366N, Project 2063)"; U.S. Navy, "SPEIR Block I (R&D, Program Element 0604501N, Project 3243)"; U.S. Navy, "Surface Navy Laser Weapon Systems (R&D, Program Element 0603925N, Project 3402)"; U.S. Marine Corps, "AN/TPS-80 Ground/Air Task Oriented Radar (G/ATOR) (R&D, Program Element 0204460M, Project 9C89)"; U.S. Marine Corps, "Common Aviation Command and Control System (CAC2S) (R&D, Program Element 0206335M, Project 3373)"; U.S. Marine Corps, "Installation-Counter small Unmanned Aircraft Systems (I-CsUAS) (R&D, Program Element 0605520M, Project 2278)"; U.S. Marine Corps, "Light Marine Air Defense Integrated System (L-MADIS) (R&D, Program Element 0605520M, Project 2278)"; U.S. Marine Corps, "Marine Air Defense Integrated System (MADIS) (R&D, Program Element 0605520M, Project 2278)"; U.S. Marine Corps, "Medium Range Intercept Capability (MRIC) (R&D, Program Element 0605520M, Project 2578)"; U.S. Army, "DE M-SHORAD (Inc. 2) (R&D, Program Element 0604117A, Project CR9)"; U.S. Army, "30mm MMPA M-SHORAD Inc 3 (R&D, Program Element 0604802A, Project DC9)"; U.S. Army, "ALPS (R&D, Program Element 0604820A, Project PS1)"; U.S. Army, "AN/MPQ-64 Sentinel A3 Radar (R&D, Program Element 0604820A, Project E10)"; U.S. Army, "AN/TPQ-53 (R&D, Program Element 0604823A, Project L88)"; U.S. Army, "AN/TWQ-1 Avenger (R&D, Program Element 0203801A, Project 038)"; U.S. Army, "APKWS (R&D, Program Element 0607142A, Project EW9)"; U.S. Army, "Army Integrated Air and Missile Defense (AIAMD) (R&D, Program Element 0605457A, Project S40)"; U.S. Army, "C-sUAS (R&D, Program Element 0605531A)"; U.S. Army, "Containerized Weapon System (R&D, Program Element 0604115A, Project AX3)"; U.S. Army, "FAAD C2 (R&D, Program Element 0604741A, Project 146)"; U.S. Army, "FIM-92 Stinger PIP (R&D, Program Element 0203801A, Project DT5)"; U.S. Army, "IFPC 2 - Block 2 (R&D, Program Element 0605052A, Project EY8)"; U.S. Army, "IFPC 2 Intercept (R&D, Program Element 0604319A, Project DU3)"; U.S. Army, "IFPC-2 Block 1 (R&D, Program Element 0605052A, Project EY7)"; U.S. Army, "IFPC-HEL (R&D, Program Element 0604019A, Project BU9)"; U.S. Army, "IFPC-HPM (R&D, Program Element 0604019A, Project CO6)"; U.S. Army, "Lower Tier Air Missile Defense Sensor (LTAMSD) (R&D, Program Element 0604114A, Project EX2)"; U.S. Army, "M-SHORAD Inc 3 (R&D, Program Element 0604117A, Project CS1)"; U.S. Army, "M-SHORAD Inc. 1 (R&D, Program Element 0604117A, Project FI4)"; U.S. Army, "MIM-104 Patriot (R&D, Program Element 0607865A, Project DV8)"; U.S. Army, "SS-HPM (R&D, Program Element 0604115A, Project AX3)"; and U.S. Army, "C-UAS (R&D, Program Element 0604741A, Project FG5)."

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68. See citation 65: U.S. Army, "AN/MPQ-64 Sentinel A3 Radar (Line Item Number 0125WK5057)"; U.S. Army, "AN/TPQ-50 Counterfire Radar (Line Item Number 8386BA5500)"; U.S. Army, "AN/TPQ-53 Counterfire Radar (Line Item Number 8386BA5500)"; U.S. Army, "AN/TWQ-1 Avenger (Line Item Number 2690CE8710)"; U.S. Army, "Army Integrated Air and Missile Defense (AIAMD) IAMD Battle Command System (Line Item Number 9280BZ5075)"; U.S. Army, "Counter Small Unmanned Aerial System Intercept (Line Item Number 9216C82200)"; U.S. Army, "FIM-92 Stinger (Line Item Number 2684C20000)"; U.S. Army, "Hellfire (Line Item Number 1338C70000)"; U.S. Army, "Indirect Fire Protection Capability Inc 2-I (Line Item Number 8930C61001)"; U.S. Army, "Land-Based Phalanx Weapons System (Line Item Number 0173BZ0501)"; U.S. Army, "Lower Tier Air Missile Defense Sensor (LTAMSD) (Line Item Number 7265C12000)"; U.S. Army, "M-SHORAD Inc. 1 (Line Item Number 8082C14300)"; U.S. Army, "MIM-104 Patriot (Line Item Number 0962C50700)"; U.S. Army, "PAC-3 MSE Missile (Line Item Number 8260C53101)"; U.S. Navy, "Physical Security C-UAS (Line Item Number 8128)"; U.S. Navy, "Evolved Sea Sparrow Missile (ESSM) (Line Item Number 2307)"; U.S. Navy, "AMRAAM (Line Item Number 2206)"; U.S. Navy, "AN/SEQ-4 ODIN (Line Item Number 5510)"; U.S. Navy, "AN/SLQ-32 (Line Item Number 2312)"; U.S. Navy, "AN/SPY-1 (Line Item Number 2981)"; U.S. Navy, "Advanced Precision Kill Weapon System (APKWS) (Line Item Number 0151)"; U.S. Navy, "Cooperative Engagement Capability (CEC) (Line Item Number 2606)"; U.S. Navy, "Close-In Weapon System (CIWS) Mods (Line Item Number 4205)"; U.S. Navy, "Drake 2.0 C-UAS Afloat (Line Item Number 5509)"; U.S. Navy, "Evolved Sea Sparrow Missile (ESSM) (Line Item Number 2307)"; U.S. Navy, "Hellfire (Line Item Number 2254)"; U.S. Navy, "Joint Crew (JCREW) (Line Item Number 3177)"; U.S. Navy, "MK 2 Ship Self-Defense System (SSDS) (Line Item Number 5231)"; U.S. Navy, "RIM-116 Rolling Airframe Missile (RAM) (Line Item Number 2242)"; U.S. Navy, "Shipboard Panoramic Electro-Optic/Infrared (SPEIR) (Line Item Number 2981)"; U.S. Navy, "Sidewinder (Line Item Number 2209)"; U.S. Navy, "Standard Missile-2 (SM-2) (Line Item Number 2356)"; U.S. Navy, "Standard Missile-6 (SM-6) (Line Item Number 2234)"; U.S. Air Force, "3D Expeditionary Long-Range Radar (Line Item Number 833060)"; U.S. Air Force, "Air Force Physical Security System (ABADS) (Line Item Number 834130)"; U.S. Air Force, "Advanced Medium-Range Air-to-Air Missile (AMRAAM) (Line Item Number MAMRA0)"; U.S. Air Force, "Expeditionary Scalable Mobile Air Traffic System (Line Item Number 833010)"; U.S. Air Force, "Sidewinder (AIM-9X) (Line Item Number M09HAI)"; U.S. Marine Corps, "Advanced Man-Portable Air Defense Systems (A-MANPADS) (Line Item Number 3006)"; U.S. Marine Corps, "Common Aviation Command and Control System (CAC2S) (Line Item Number 4644)"; U.S. Marine Corps, "FIM-92 Stinger (Line Item Number 3006)"; U.S. Marine Corps, "Light Marine Air Defense Integrated System (LMADIS) (Line Item Number 3006)"; U.S. Marine Corps, "Medium Range Intercept Capability (MRIC) (Line Item Number 3006)"; U.S. Marine Corps, "Marine Air Defense Integrated System (MADIS) (Line Item Number 3006)"; U.S. Marine Corps, "AN/TPS-80 Ground/Air Task Oriented Radar (G/ATOR) (Line Item Number 4655)"; U.S. Marine Corps, "Installation-Counter small Unmanned Aircraft Systems (I-CsUAS) (Line Item Number 3006)"; U.S. Air Force, "3D Expeditionary Long-Range Radar (R&D, Program Element 0207455F)"; U.S. Air Force, "Air Base Air Defense System (ABADS) – Medium-Range Intercept Capability (MRIC) and Counter-small Unmanned Aircraft Systems (C-sUAS)"; U.S. Air Force, "Advanced Medium-Range Air-to-Air Missile (AMRAAM) (R&D, Program Element 0207163F, Project 673777)"; U.S. Air Force, "Counter-Unmanned Aircraft Systems (C-UAS) Directed Energy (DE) Prototyping (R&D, Project 640200)"; U.S. Air Force, "High Power Microwave Development and Integration (R&D, Project 633152)"; U.S. Air Force, "High Power Solid State Laser (R&D, Project 633151)"; U.S. Air Force, "AIM-9X Sidewinder (R&D, Program Element 0207161F, Project 674132)"; U.S. Navy, "Aegis (R&D, Program Element 0604307N)"; U.S. Navy, "AMRAAM (R&D, Program Element 0207163N, Project 0981)"; U.S. Navy, "AN/SPY-1 (R&D, Program Element 0604501N)"; U.S. Navy, "APKWS (R&D, Program Element 0607142A, Project EW9)"; U.S. Navy,

"C-UAS (R&D, Program Element 3241)"; U.S. Navy, "Cooperative Engagement Capability (CEC) (R&D, Program Element 0607658N)"; U.S. Navy, "Drake 2.0 (R&D, Program Element 0604636N)"; U.S. Navy, "High Energy Laser Counter ASCM Project (HELCAP) (R&D, Program Element 0603925N)"; U.S. Navy, "JCREW (R&D, Program Element 0603654N, Project 3177)"; U.S. Navy, "MK 2 Ship Self-Defense System (SSDS) (R&D, Program Element 0604755N)"; U.S. Navy, "MK-57 NSSMS (R&D, Program Element 0604756N, Project 0173)"; U.S. Navy, "ODIN (R&D, Program Element 0603925N, Project 9823)"; U.S. Navy, "Phalanx CIWS SEARAM (R&D, Program Element 0604756N, Project 9081)"; U.S. Navy, "RIM-116 (R&D, Program Element 0604756N)"; U.S. Navy, "Sidewinder (R&D, Program Element 0207161N, Project 0457)"; U.S. Navy, "SM-2 BLK IIIC (R&D, Program Element 0604366N, Project 0439)"; U.S. Navy, "SM-6 (R&D, Program Element 0604366N, Project 3092)"; U.S. Navy, "SM-6 BLK IB (R&D, Program Element 0604366N, Project 2063)"; U.S. Navy, "SPEIR Block I (R&D, Program Element 0604501N, Project 3243)"; U.S. Navy, "Surface Navy Laser Weapon Systems (R&D, Program Element 0603925N, Project 3402)"; U.S. Marine Corps, "AN/TPS-80 Ground/Air Task Oriented Radar (G/ATOR) (R&D, Program Element 0204460M, Project 9C89)"; U.S. Marine Corps, "Common Aviation Command and Control System (CAC2S) (R&D, Program Element 0206335M, Project 3373)"; U.S. Marine Corps, "Installation-Counter small Unmanned Aircraft Systems (I-CsUAS) (R&D, Program Element 0605520M, Project 2278)"; U.S. Marine Corps, "Light Marine Air Defense Integrated System (L-MADIS) (R&D, Program Element 0605520M, Project 2278)"; U.S. Marine Corps, "Marine Air Defense Integrated System (MADIS) (R&D, Program Element 0605520M, Project 2278)"; and U.S. Marine Corps, "Medium Range Intercept Capability (MRIC) (R&D, Program Element 0605520M, Project 2578)."

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98. For FY25 numbers, see: Gettinger, *Department of Defense Counter Unmanned Aircraft Systems*, 14–15.

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