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# UNARMED AND DANGEROUS

## The Lethal Applications of Non-Weaponized Drones

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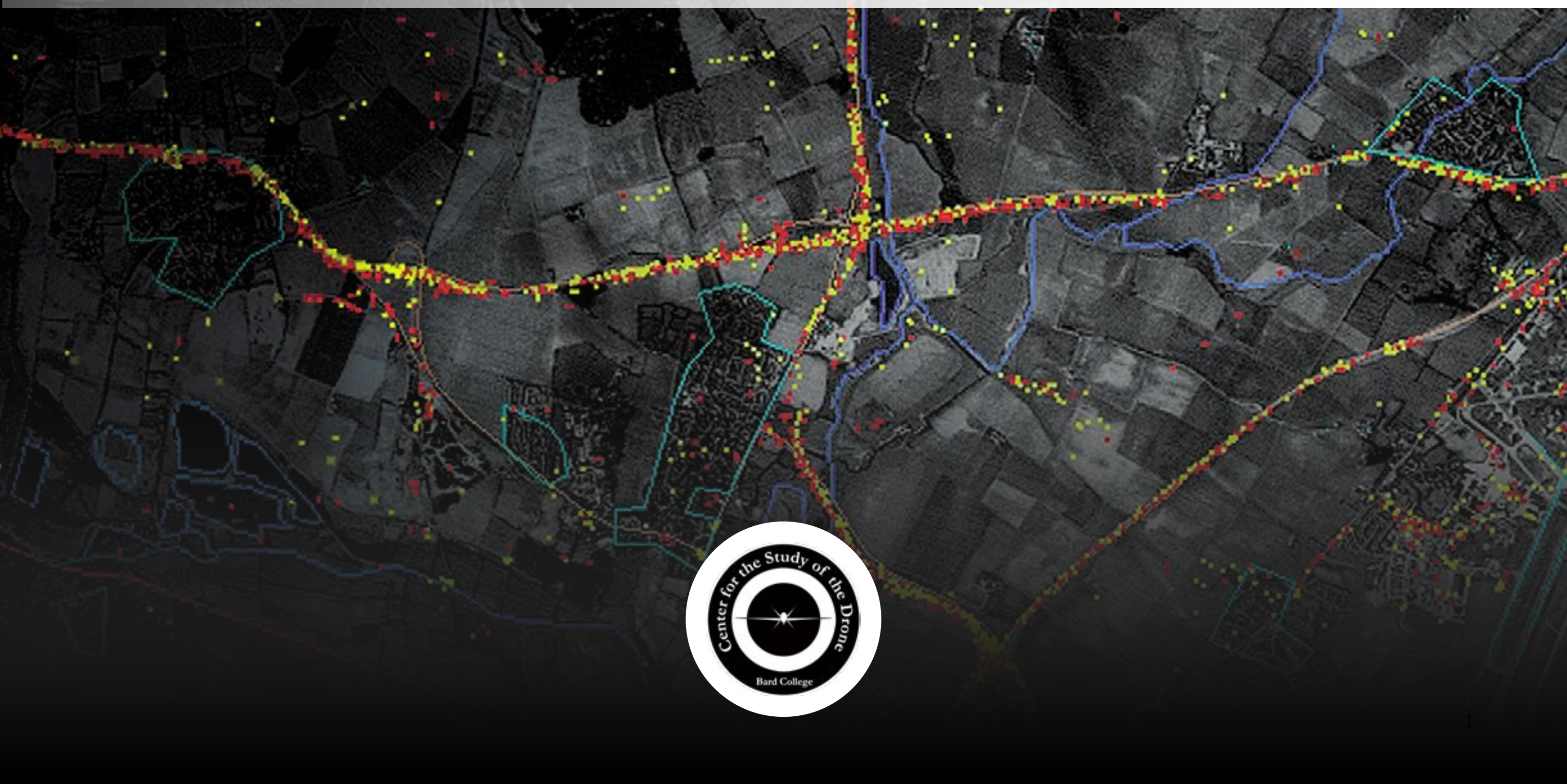

Center for the Study of the Drone
Bard College

## ABOUT THE CENTER FOR THE STUDY OF THE DRONE

The Center for the Study of the Drone at Bard College is an interdisciplinary research institution that examines the novel and complex opportunities and challenges presented by unmanned systems technologies in both the military and civilian sphere. By conducting original, in-depth, and inquiry-driven projects, we seek to furnish stakeholders, policy-makers, and the public with the resources to engage in a robust public debate and develop policies that best address those opportunities and challenges.

## ACKNOWLEDGEMENTS

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Cover photos credit: U.S. Department of Defense.

*"A silent enemy flyer pursued the individual wanderer, and French artillery shells accompanied his path. To run, stand still or lay down, it was all the same."*

—Unnamed German soldier at the Battle of Verdun, June 1916[1]

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## KEY TAKEAWAYS

- Unarmed drones can be used in a variety of roles to directly enable lethal strikes by other weapon systems.
- In many cases, these roles can even be accomplished using small inexpensive unmanned aircraft.
- The use of drones as strike-enablers can significantly expand the effectiveness, scope, range, and lethality of strikes by other weapons.
- The use of drones in these roles raises ethical, legal, strategic, and tactical questions.
- Drone systems with strike-enabling capabilities are proliferating rapidly, with little public scrutiny.
- Advances in miniaturization and autonomy will make these strike-enabling capabilities cheaper, more accessible, and more formidable.

# INTRODUCTION

When Ukrainian soldiers in Donbas see a Russian surveillance drone circling overhead, they may very well know that they ought to run for their lives. Even though the drone itself is unarmed, recent military experience has shown that the drone's presence is often a portent of imminent peril. Within a few minutes[2] of the drone's arrival, the soldiers may be submitted to a barrage of Russian artillery far more destructive than any armed drone strike, guided to its target with devastating precision through the drone's small video camera.

In one case, in August 2014, the appearance of a small camera-equipped artillery-spotting drone over a Ukrainian convoy presaged a volley of precision shell fire that destroyed more than 200 vehicles in one fell swoop.[3] That unarmed strike-enabling drone operation, like so many others of its kind, did not make global headlines. Meanwhile, that same month, a U.S. armed drone fired a volley of no more than four missiles at a single house in Datta Khel, Pakistan, killing five people. The operation was reported by Reuters, Associated Press, Agence France-Presse, and CNN.[4]

There is no doubt that drone strikes like the operation in Datta Khel—and the ongoing development, proliferation, and use of armed drones more generally—are worthy of the intense public scrutiny they receive. But by focusing so exclusively on *armed* drones and ignoring the far more widespread use of *unarmed* drones (see insert on page 3), we have failed to capture the full impact of unmanned aircraft in modern warfare. Specifically, we risk overlooking the deadly effects that unarmed drones can have even though they do not carry ordnance on their wings.

As this report shows, unarmed drones can directly enable lethal strikes by other weapons in a wide variety of ways. In many cases, the use of drones in these roles can significantly expand the effectiveness, scope, range, and lethality of strikes, while also enabling strikes that may have otherwise been too dangerous, too strategically or politically risky, or even physically impossible by other means. As such, unarmed drone use may raise ethical, tactical, strategic, and legal questions that have largely gone unaddressed.

This report seeks to shed light on the many ways that unarmed drones can directly enable kinetic operations. It describes six common strike-enabling roles for unarmed drones and explains why the use of drones in each of these roles is significant. In so doing, the report aims to present a more comprehensive portrait of drone warfare and provide a springboard for further academic inquiry into the full implications of unmanned aircraft for modern conflict.

**Armed Drones: In the Minority**

Unarmed drones vastly outnumber armed drones in use today. According to research by Dan Gettinger in *The Drone Databook*,[5] only 12 of the 95 countries with active military drone inventories are currently confirmed to operate weaponized unmanned aircraft.* (An additional 22 countries are either actively acquiring or developing armed drones, or have operated armed drones in the past but likely do not have an active inventory as of this writing.†) Even the U.S. Department of Defense, which has the most extensive and advanced weaponized drone program in the world, operates far more unarmed drones than armed systems. This is unlikely to change in the years ahead, as current U.S. acquisition and development plans do not call for a significant spike in the number of armed systems in inventory anytime soon.

Furthermore, drones that *do* carry weapons only employ them in a small percentage of missions, especially compared to manned aircraft. Prior to 2014, the year that Operation Inherent Resolve began, U.S. Air Force Predators and Reapers appear to have released at least 1,588 missiles or bombs over the course of 42,986 sorties, or less than four weapons releases per hundred missions. Between 2014 and the end of 2016, Predators and Reapers released some 6,217 missiles or bombs over the course of 35,653 sorties—a rate of about 17 weapons releases per hundred missions. By comparison, available statistics suggest that Predators and Reapers surveilled, on average, more than two targets per sortie.[6]

*An unarmed MQ-9 Reaper operated by the Italian Air Force. Credit: Aeronautica Militare*

In 2015 and 2016, weapons released by Predators and Reapers appear to have accounted for only about 13 percent of all weapons released by U.S. Air Force aircraft in operations over Syria and Afghanistan. Meanwhile, U.S. jets in these operations generally released weapons in about 50 percent of their missions.[7] British drone operations in Syria and Iraq saw a similar proportion of strikes; according to data compiled by Drone Wars UK, between October 2014 and December 2018, RAF Reapers flew 2,423 missions in Iraq and Syria, over the course of which they conducted 398 strikes (about 16.4%). By comparison, RAF manned fighter jets conducted strikes in 1,238 out of 2,979 missions (about 43.1%).[8]

Nor is the use of armed drones for strike missions always necessarily as transformative as one might imagine, particularly among militaries that have only recently acquired the technology. According to field research by the Royal United Services Institute, a British think tank, the acquisition of armed drones only had a measurable impact on airpower norms and behaviors in three out of seven surveyed Middle Eastern countries. In the case of Israel, which has the longest record of modern armed and unarmed drone use of any military in the world, drones are predominantly seen as intelligence collection devices rather than strike weapons. A number of officials interviewed for the RUSI study suggested that the primary motivation for acquiring armed drones was "prestige."[9]

* This tally does not include small non-reusable unmanned aircraft loaded with a warhead—commonly known as loitering munition drones.

† A further 14 countries operate drones that could technically be weaponized, but it is very unlikely that they currently carry weapons.

# IMPLICATIONS OF UNARMED DRONE USE

The use of drones in the strike-enabling roles has a number of unique, and in some cases troubling, implications.

- Since drones can be shot down without loss of human life, **they may be used in circumstances and areas that are too risky for inhabited vehicles**. This expands militaries' ability to achieve kinetic effects on a broader variety of targets that might have otherwise been inaccessible to them.

- **The miniaturization of sensors will enable the use of these systems aboard smaller drones**. Because smaller drones are generally cheaper, they can be acquired in larger quantities. Individual military units that would have previously had to rely on another dedicated drone unit to provide them with aerial support can operate their own drones, with total control over where and when it is used (this is referred to as an "organic" capability). And given that lightweight unmanned aircraft are generally not subject to export controls like the Missile Technology Control Regime,[10] these strike-enabling capabilities will increasingly fall within reach of small militaries or militaries that are barred from buying large drones.

- **Unarmed variants of large drones are subject to less stringent export controls than armed variants**, and yet by employing such systems in these strike-enabling roles militaries can achieve many of the same effects that can be achieved with an armed drone—only with far less international oversight. The proliferation of such systems can be hard to track. For example, it was only revealed in February 2019, through photographs posted to Twitter, that Saudi coalition forces appear to be using German-made LUNA drones that can be equipped with jamming units against the Houthi group in Yemen.[11]

- The advent of small, cheap drones capable of carrying sophisticated sensors **could even place many of the strike-enabling capabilities described in this report in the hands of non-state groups**.

- If employed with virtuous intent, **the use of strike-enabling drones in certain roles could significantly improve the precision and/or accuracy of strikes**—for example, by generating and distributing more detailed data on a given target, or by more precisely guiding ordinance to its target. This could enable willing forces to more closely hew to the laws of armed conflict and avoid civilian harm.

- As a vaunted intelligence-collection tool, **a drone could give even upstanding operational units a false sense of confidence that a target is right and just**. The trust that chains of command place in data obtained from a drone on a persistent orbit can sometimes result in "high-regret actions." For example, in September 2016, U.S. Reaper drones circling for two days over a Syrian base misidentified a large group of individuals as ISIS combatants, leading fighter jets to bomb and kill more than 60 Syrian soldiers.[12]

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* Though not necessarily in environments where the likelihood of a shoot-down is very high, since there's little point in attempting to use a drone for a particular mission if the drones is probably going to be lost before it can carry out the mission.
† For a startling illustration of this phenomenon, see the transcripts of a gunship attack on a civilian convoy in Uruzgan Province, Afghanistan—operators monitoring the convoy through a Predator video feed were convinced that the civilians were Taliban fighters preparing to attack U.S. forces: http://documents.latimes.com/transcript-of-drone-attack/

- Like any form of intelligence, the **data collected by unarmed drones can be shared between militaries** and used to support operations over which the originating country has no direct control. For example, in December 2011, an unarmed U.S. Predator drones operating over the Turkey-Iraq border detected a group of civilians that analysts deemed to be potential Kurdish fighters traversing a mountain pass. Under the terms of an intelligence-sharing agreement launched in 2007, the U.S. military passed the targeting information from the Predator to the Turkish military, which launched an airstrike on the convoy, killing 34 civilians.[13]

- Since traditional anti-aircraft defense systems generally struggle to detect small drones, **such drones may increasingly be used to enable covert operations, strikes in denied airspace, or surprise strikes**.

- These considerations will take on greater urgency as unarmed drones assume more advanced autonomous capabilities. **Automated target detection, tracking, cross-cueing, and command and control will further expand the ways in which drones can enable strikes—not to mention the speed and efficiency with which they do so**. But given how integral such functions can be to the kill-chain, the application of autonomy to such steps raises difficult ethical and legal questions. The current debate around lethal autonomous weapons systems does not fully account for the potentially significant effects of the use of *unarmed* autonomous drones capable of, say, identifying targets of interest on the battlefield; indeed, the Department of Defense's internal policy for lethal autonomous weapons specifically exempts unarmed drones. As a result, the advent of autonomy and AI—which will be applied in unarmed systems far sooner than it will be applied to lethal systems—makes all of the considerations raised in this report all the more urgent.

*Credit: Matthew Klene/U.S. Department of Defense*

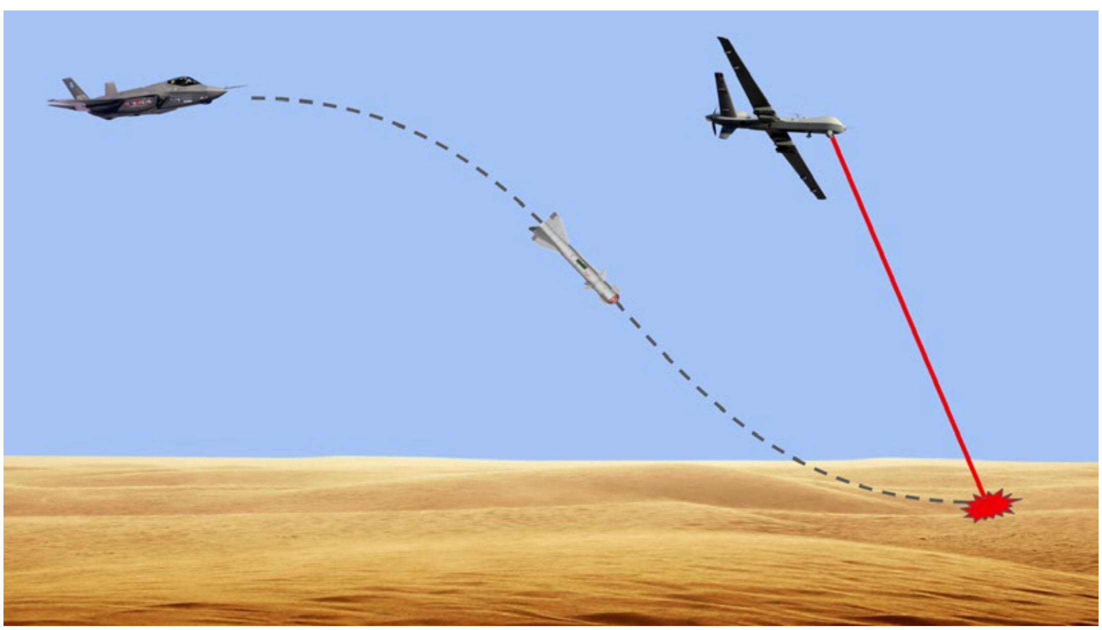
* Small drones can even evade dedicated counter-drone systems.[14]

# BUDDY LASING

The most direct way that a drone can enable kinetic action is to guide laser-guided ordnance fired from another aircraft or platform to its target. These operations are sometimes referred to as Buddy Lasing. In a Buddy Lase, the drone's operators point a powerful laser beam at the target, creating an effect known as a "sparkle"; another aircraft or vehicle then releases a laser-guided missile, bomb, or artillery shell that is programmed to hit that sparkle. (Drones armed with laser-guided weapons often buddy lase for themselves).[15]

The first extensive recorded instances of modern unarmed drones Buddy Lasing for manned aircraft took place in the opening days of the war in Afghanistan, in November 2001, when a small number of U.S. Air Force Predators designated targets for AC-130 gunships and other aircraft.[16] In the years since, U.S. Predators and Reapers have buddy lased for B-1B Lancers, A-10 Warthogs, F-15E Strike Eagles, F-16 Vipers, F/A-18 Hornets, and AV-8 Harriers.[17] Though a total tally of these lases has never been published, the sparse available figures suggest that Predators and Reapers have conducted thousands of Buddy Lases over the last two decades. One Air Force tally covering the period from January 1, 2010 to February 2017 disclosed more than 1,660 Buddy Lases for other aircraft (some of these may have been for other drones).[18] These figures only represent a portion of total U.S. Buddy Lases in theater. The U.S. Army's RQ-7B Shadow surveillance and reconnaissance drone, which is unarmed, carries a designator capable of guiding bombs, artillery shells, and rockets.[19] It also appears that Buddy Lasing by drones has facilitated covert manned aircraft strikes outside of hot battlefields, in Yemen and probably also Somalia.

Other militaries have performed their own buddy lase operations, while a growing number of militaries operate drones capable of conducting this role (see chart). The French Air Force has employed unarmed MQ-9 Reapers to buddy lase for Mirage strike aircraft and Tiger HAD helicopters in Operation Barkhane, a counter-terrorism mission in the Sahel that remains ongoing as of this writing. The U.K. Ministry of Defence has issued numerous operations reports de-



*An illustration of a Buddy Lase operation. The UAV (right) designates the target for a laser-guided munition launched by another aircraft (left).*

scribing how its small fleet of Reapers have "directly supported" coalition airstrikes against ISIS in Syria and Iraq, though it has declined requests by Drone Wars UK, an advocacy group, to release specific tallies of Buddy Lases. In one operation on December 12, 2017, a single Royal Air Force Reaper "supported seven attacks by the coalition jets against several groups of terrorists" near Abu Kamal, Iraq (in the mission, the Reaper also conducted three Hellfire attacks of its own). The U.K. MoD has specified that it designates targets for aircraft operated by other militaries but only when such strikes comply with the RAF's own rules of engagement.[20]

In many of the thousands of Buddy Lases carried out to date, the use of the drone has likely facilitated strikes that may have been difficult or dangerous if conducted *without* the benefit of a lasing drone. Buddy Lasing can, for example, extend the kinetic reach of manned aircraft to targets that are beyond their visual range; a drone with a laser designator might, say, allow a helicopter to strike targets from behind a tree line. Buddy Lasing also enables armed forces, including smaller militaries, to pair less expensive lightweight drones with large ordnance that can only be fired from manned aircraft. The U.S. Air Force employs four types of laser guided bombs, the largest of which, the GBU-28, is a 5,000 lb. warhead. By comparison, the largest warhead carried by any U.S. drone is the GBU-12, a 500 lb. GPS-guided bomb carried by the MQ-9 Reaper. China, Russia, and Turkey—three major unarmed drone producers—all produce high-capacity laser-guided ordnance systems.[21] The Dominican Republic operates a small number of Sky Sapience HoverMast 150 tethered surveillance drones. Though the drones are primarily used for border surveillance, they are equipped with a laser designator sensor pod that could be used in tandem with heavy laser-guided munitions (a military official declined to comment whether it operates such munitions).

Additionally, many laser designation systems can "illuminate" a target in order to visually guide other aircraft or troops to its precise location. In one typical illumination operation in Fallujah in November 2004, an MQ-1 Predator assigned to observe an "insurgent command and control facility" illuminated the target with a 40-foot by 40-foot beam for an incoming F/A-18 fighter jet, which dropped two large capacity bombs on the target (ultimately, both bombs failed and the Predator used its two Hellfires to strike a number of individuals who fled the facility on foot).[22]

The use of laser designators is likely to expand in coming years as a result of the miniaturization of components (see "Miniaturization") and falling price-points, as well as a decision by the U.S. Department of State in April 2018 to ease export restrictions on unarmed drones equipped with designator systems (see insert).[23]

*The Sagem Sperwer, one of the early operational unarmed drones to carry a laser designator. It is currently operated by the Greek military. Credit: Robert Sullivan/Flickr*

**U.S. Export Controls for Drones**

Under a revised export control policy implemented by the U.S. Department of State in April 2018, U.S. unarmed drones with "strike-enabling" technologies such as designators will no longer be subject to the Foreign Military Sales vetting and approval process; instead, manufacturers will be free to market and sell buddy lase-capable drones directly to foreign militaries.[24]

**Selection of Operational Drone Types with Laser Designator Capability**

| Country of Origin | Model | Manufacturer | Operated By |
|---|---|---|---|
| China | CH-4 Rainbow | China Aerospace Science and Technology Corporation | China, Algeria, Iraq, Jordan, Saudi Arabia |
| | Wing Loong II | Chengdu Aircraft Industry Group | China, United Arab Emirates |
| France | Sperwer HV | Sagem | Greece |
| | Watchkeeper | Thales | U.K. |
| Germany | KZO | Rheinmetall | Germany |
| Iran | Mohajer-6 | Quds Aviation | Iran |
| | Shahed-129 | Shahed Aviation Industries Research Center | Iran |
| Israel | Hermes 900 | Elbit Systems | Israel, Azerbaijan,Brazil, Chile, Colombia, Switzerland |
| | Hermes 450 | | Israel, Azerbaijan, Brazil, Colombia Mexico, Philippines, Singapore, Thailand, Zambia |
| | Heron TP | Israel Aerospace Industries | Israel, Azerbaijan, Germany |
| | Sky Sapience HoverMast 150 | Sky Sapience | Dominican Republic |
| Turkey | Bayraktar TB2 | Baykar | Turkey, Qatar, Ukraine |
| | Anka-S | Turkish Aerospace Industries | Turkey |
| | Vestel Karayel-SU | Vestel | Turkey |
| U.S. | RQ-7B Shadow | AAI / Textron | U.S., Australia, Italy, Romania, Sweden |
| | Predator | General Atomics Aeronautical Systems | U.S., Italy |
| | Predator XP | | United Arab Emirates |
| | Gray Eagle | | U.S. |
| | Reaper | | U.S., U.K., France, Italy, Spain, Netherlands, |
| | MQ-5 Hunter | Northrop Grumman | Beligum |
| | MQ-8B/C Fire Scout | | U.S. |

# TARGET ACQUISITION

Target Acquisition is the process by which a target is detected, identified, and tracked in preparation for a strike by another platform such as an aircraft, a ground force, or artillery fires (see "Artillery Spotting").* † Target Acquisition plays a fundamental role in strikes, as it determines who or what will be subject to attack, as well as the precision and accuracy of the operation.

There are several ways that drones can collect intelligence for Target Acquisition missions. This section will describe three main methods: Full Motion Video, Wide-Area Surveillance, and Signals Intelligence. Certain advanced multi-sensor drones, or agglomerations of drones carrying distinct sensors, may perform Target Acquisition by collecting a combination of different types of intelligence.

**Full Motion Video**

In modern drone operations, Target Acquisition is most commonly achieved through Full-Motion Video (FMV), a telescopic video surveillance system that generally consists of both daytime and infrared cameras. FMV enables drones to collect detailed information about targets. Drone crews can then pass the coordinates of a target to a strike aircraft or guide the crew of a strike aircraft to the target using a set of verbal instructions known as a "talk-on."[25] If the drone is able to distribute its video, other units, commanders, and even sometimes aircraft (see "Manned-Unmanned Teaming") can even directly watch a target in real-time.

The FMV capability stands at the core of the persistent surveillance operations that have come to be seen as a hallmark of medium-altitude long-endurance drones. In these operations, a rotation of drones follows a target of interest for extended periods in order to gather intelligence about his activities, identify his associates, determine his status as a combatant, and map out his daily routine (a process sometimes known as "Fixing" a target). These types of operations have become a fixture of counter-terrorism campaigns by the U.S., Israel, France, the U.K., and other militaries in possession of long-endurance drones. U.S. Predator and Reaper drones, which are particularly prized for their long loiter times that are ideal for "fixing" targets, have participated in an astounding number of Target Acquisition missions in support of strikes. By one official tally, between 2011 and February 2017, Predators and Reapers performed combat operations on 127,390 "ISR Targets."[26] (The available data do not specify how many of those operations led to actual strikes). French forces have similarly made heavy use of their small fleet of Reapers for both direct target acquisition as well as to serve as an air mission command platform to coordinate multiple assets in a single complex strike operation (see insert on page 14).

According to a U.S. Army handbook, the use of drones is considered "one of the key pillars of the Russian Target Acquisition Cycle."[27] Similarly, Turkey's Bayraktar TB2 drones are routinely used to acquire targets for strikes by manned Turkish aircraft. Over the course of four months in Operation Olive Branch, a campaign against the Kurdistan Workers' Party in

* A U.S. Army handbook on unmanned systems describes target acquisition as "the detection, identification, and location of a target in sufficient detail to permit the effective employment of weapons."[28]

† Drones are also commonly used in a process known as Battle Damage Assessment, whereby the aircraft is used to assess a site following a strike and determine the extent to which the objectives of the strike were met, if there was any collateral damage, or if further strikes are required.

Afrin, Turkish TB2s acquired targets for strikes that lead to the deaths of 680 people—17 percent of the total recorded casualties from the campaign, according to official figures published by the state-run Anadolu Agency. By comparison, direct strikes by armed TB2s during this period accounted for 449 deaths: 11 percent of casualties.[29] In early 2018, the Turkish government released footage from one of its surveillance and strike drones showing how the unmanned aircraft had tracked a small crew of Kurdish combatants operating a mobile artillery system in Afrin, Syria. Ultimately, the drone tracked the group to a garage, which was subsequently destroyed in a precision strike by another aircraft.[30]

Since a basic FMV capability is available on commercially available drones, it can be used for target acquisition by non-state groups. Reports from the conflict in Syria and Iraq have indicated that ISIS has used drones to help direct vehicle-borne IED attacks, though no thorough evaluation has reported on whether the use of unmanned aircraft in these roles measurably impacted the overall precision of these attacks.[31]

Thanks to advances in miniaturization and propulsion, even relatively small inexpensive drones can collect high-quality FMV data over extended periods, and the capability is becoming wildly popular. The U.S. defense contractor L-3Harris has reported that its orders for FMV systems stand at an all-time high—they reached $500 million in 2018—and attributes this demand largely to the growing global adoption of unarmed drones.[32]

**Wide-Area Surveillance**

Target Acquisition can also be achieved through the use of Wide-Area Surveillance (WAS) systems that can detect objects of interest within an area thousands of times larger than the coverage of FMV cameras (which are known as "soda straw" sensors for their limited field of view). This section discusses two WAS sensor types in particular: Ground Moving Target Indicator (GMTI) and Wide-Area Motion Imagery (WAMI).

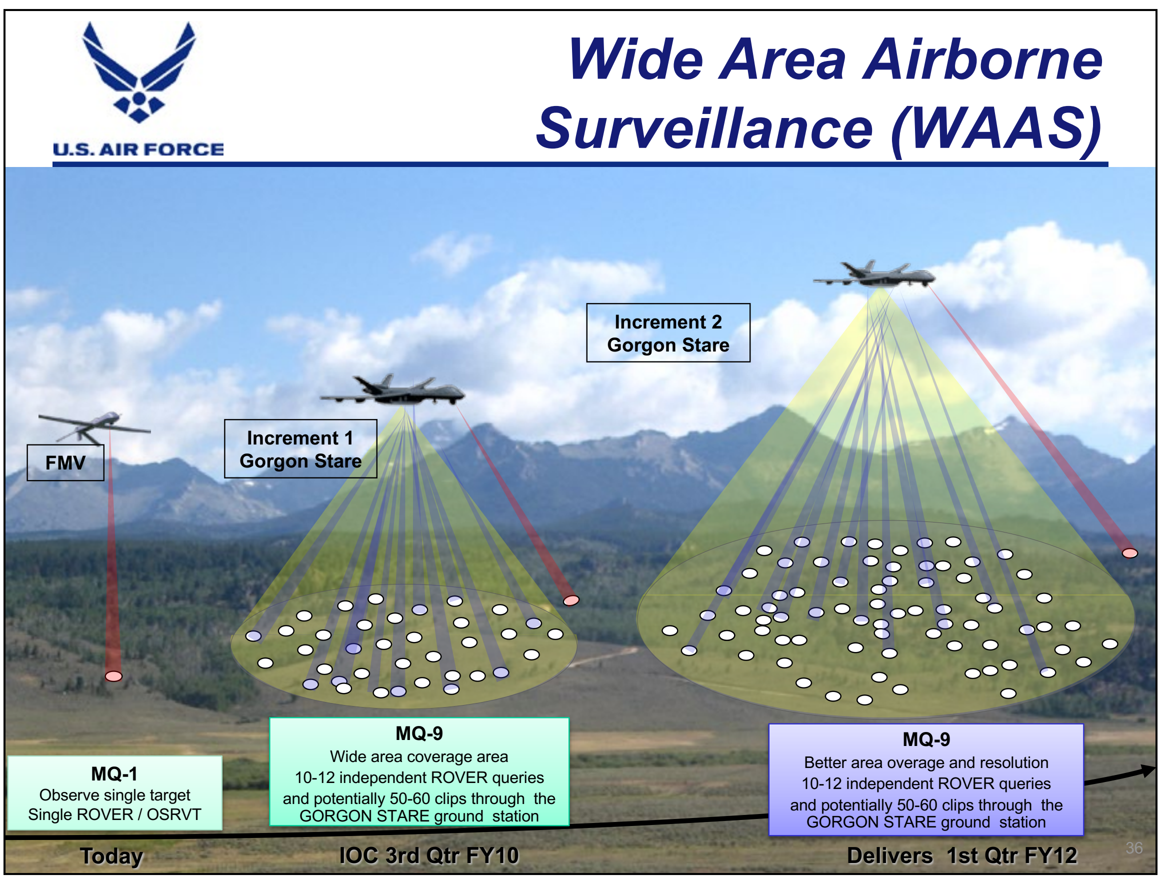
GMTI is a functionality of certain synthetic aperture radar. GMTI detects every moving vehicle within a broad coverage area. If a military knows that adversaries may be operating in a region but has no knowledge of their specific location, GMTI may be used to find them.[33] Depending on the size of the radar, the coverage of GMTI can be enormous, in some cases hundreds or thousands of square kilometers. According to General Atomics Aeronautical Systems, a U.S. drone manufacturer, the Lynx SAR/GMTI radar can detect targets at a range of up to 75km from a medium-altitude long-endurance drone.[34] A study by researchers at the Australian Ministry of Defence modeled a Target Acquisition cycle with GMTI that took 54 minutes from the initial detection of a target to the final strike.[35]

In addition to enabling operators to search enormous amounts of territory for potential strike targets and rapidly line up strikes, GMTI is also notable because it allows Target Acquisition in areas where the operator has no access to the airspace—the surveilling aircraft can operate at the edge of permissive airspace with its radar pointed obliquely to detect objects far beyond the boundary of the contested airspace. For example, in a vignette from the U.S. Army's 2010 UAS Roadmap, a manned E-8 Joint STARS aircraft uses GMTI to monitor the movements of a high-value target who is inside a notional territory


*The sensor pod of an MQ-1 Predator, which includes Full Motion Video sensors and a laser designator. Credit: Staff Sgt. Cohen Young* that U.S. forces do not have permission to enter. Once the GMTI radar detects that the target has entered a bordering territory to which its forces do have access, a long-endurance drone is dispatched to the area to commence a persistent stare mission over the target. Once the target's pattern of life is established, the drone's video is fed to a Special Forces on the ground, which then designates the target with a laser system for a "precision Hellfire Strike."[36] Some have pointed out that because GMTI can identify targets deep inside defended airspace it would be particularly suited for Target Acquisition in a near-peer conflict.[37]

GMTI is a common capability on larger drones. MQ-9 Reapers operated by the U.S., U.K., Italy, and France carry the Lynx Multi-mode Radar, as will the four unarmed MQ-9 Reapers that the Netherlands has purchased from the U.S. The U.S. RQ-170 Sentinel stealth drone also reportedly has a GMTI sensor.[38] The U.S. Customs and Border Protection uses GMTI-equipped Predator B drones to detect individuals crossing the U.S.-Mexico border.[39] The Canadian Armed Forces' future UMS Skeldar V-200 helicopter drone will be equipped with a radar built by British firm QinetiQ for GMTI in Target Acquisition missions.[40] Thales, another British defense firm, sells a 30kg radar called I-Master capable of detecting moving soldiers from up to 15km and vehicles at up to 35km. In early 2013, the company successfully demonstrated the system aboard a Schiebel CamCopter S-100, a tactical rotary drone,[41] and it has sold the system to the U.K. Royal Air Force for use aboard its fleet of Watchkeeper drones,[42] among other customers, with expected sales of more than 200 units around the world by 2027.[43]

Wide-Area Motion Imagery (WAMI) sensors, meanwhile, are very large video cameras, capable of recording city-sized areas in high-resolution. WAMI cameras such as the Air Force's Gorgon Stare, which is mounted aboard a fleet of unarmed MQ-9 Reapers, can track thousands of targets simultaneously. Given its broad coverage area, a single WAMI sensor can be used to conduct numerous surveillance operations on disparate targets simultaneously, or for tracking a single target over vast distances. WAMI sensors also




*A graphic showing the relative coverage area of a Full Motion Video camera (far left) and two WAMI sensors. Credit: U.S. Air Force* have a backtrack function that allows analysts to track a previously unidentified target back in time, to see where they come from—a feature known informally as "combat TiVO." This enables operators to find out where the target lives and whom he associates with and then, in turn, whom these associates associate with, and so on. Certain WAMI sensors can also beam individual steerable frames of footage (known as "chip outs") to ground crews, who can use these to observe anything within the sensor's full coverage area as though they had their own dedicated FMV drone.

Over the years since the technology was first introduced in 2006, more than a dozen different types of WAMI have been used in U.S. operations, usually aboard manned aircraft. Most of the details surrounding these operations remain classified but the limited evidence available suggests that the technology can be extremely effective in enabling lethal operations. One single WAMI system, the Blue Devil I—which was mounted aboard a fleet of four manned aircraft—is "credited" in one Pentagon publication with the killing or capture of more than 1,200 individuals in Afghanistan between 2011 and 2014.[44]

*Moving target detections in the sensor feed from an E-8 Joint Stars aircraft. GMTI enables the tracking of all moving vehicles across a very broad area. Credit: U.S. Department of Defense*

In the coming years, it is likely that WAMI will become a common feature on unarmed surveillance drones. In its 2021 budget request, the U.S. Department of Defense requested $46.1 million for the Gorgon Stare program, more than double what it spent in the previous budget.[45] The U.S. Central Command also asked Congress to fund $238 million for an additional MQ-9 Reaper and other aircraft to carry Gorgon Stare systems in active conflict zones.[46] A growing number of defense firms, including L3Harris, Sierra Nevada Corporation, Logos, PV Labs, Elbit, Israel Aerospace Industries, Sentient Vision, and Controp, are all actively marketing and selling WAMI sensors—including sensors that are not subject to export controls and sensors that are light enough to fit on small surveillance drones.

* For a detailed history of WAMI, see Arthur Holland Michel, *Eyes in the Sky: The Secret Rise of Gorgon Stare and How It Will Watch Us All*, (New York: Houghton Mifflin Harcourt, 2019).

**Automation**

The advent of automated processing software will further enhance the Target Acquisition capability of unarmed surveillance drones by allowing operators to more quickly extract greater volumes of intelligence from the data while at the same time reducing the personnel costs associated with manual analysis surveillance feeds. For example, various DoD agencies have invested heavily in developing software to automatically detect suspicious behaviors in aerial WAMI and FMV footage.[47] Automated target detection software could also be used to enable sophisticated collaborative targeting operations by multiple unmanned aircraft, where one unarmed Target Acquisition drone can automatically hand off targeting information to a second, armed unmanned vehicle. In April 2018, the U.S. drone manufacturer AeroVironment demonstrated an automatic target handoff sequence between an RQ-20B Puma—a hand-launched surveillance drone that is popular with ground units—and a Switchblade loitering munition, significantly reducing the length of the targeting cycle against a fast-moving target (in this case, a boat).[48]

## Signals Intelligence

Signals Intelligence (SIGINT) refers to information derived from collected electronic transmissions of all types, including intercepted communications between devices such as phones, radios, and computers. Information obtained through SIGINT sensors can be used to detect, locate, and identify targets for strikes. SIGINT collected by a drone might, say, allow analysts to trace a call from a number associated with a terror group to a specific home address. This information is then used to "cross-cue" other sensors—either aboard the same aircraft, or from another system—to look at the person in question and confirm their identity (by, say, matching their physical appearance to known images) or their combatant status (by observing their behavior). In certain targeting operations the combination of SIGINT data and Full Motion Video, in particular, has been described as key for establishing target identity.

In an operational vignette presented from a 2010 U.S. Army roadmap, analysts in the U.S. monitoring SIGINT data collected by a drone operating over a city "detect[s] the HVTs [high-value targets] are in the area." The analysts then pass the coordinates of the targeted individuals to a team that mounts a raid on their hiding place. In another vignette from the same document, SIGINT data are used by a special operations unit to establish that a target of interest is going to spend the night at a particular location.[49]

Like many of the other sensor types described in this section, SIGINT devices are becoming a common payload for unarmed drones, large and small—a trend driven by growing demand for the capability. U.S. Air Force Reapers are equipped with a SIGINT capability,[50] as are RQ-4 Global Hawks.[51] Similarly, some U.S. Army MQ-1C Gray Eagles are equipped the Tactical SIGINT Payload, which is capable of intercepting and locating a range of communications.[52] Turkey's National Intelligence Organization operates the Turkish Aerospace Industries Anka-I, a variant of the Anka medium-altitude long-endurance drone built specifically for SIGINT missions.[53] The Anka-S, an exportable satellite-controlled variant of the Anka, has likewise been tested with various SIGINT payloads;[54] as of this writing, the Turkish military has sixteen ANKA-S systems on order.[55] The Israeli-made Elbit Systems Hermes 450, an exportable system that has been sold to Thailand[56] Zambia,[57] and the United Kingdom, is advertised on the company's website with a "choice of payloads" that includes an Electronic Intelligence (ELINT) capability. [58] Elbit Systems subsidiary Elisra is also reportedly developing a multifunction electronic warfare and signals intelligence system designed specifically for unmanned aircraft.[59] Russia, meanwhile, is known to use SIGINT to geolocate targets for artillery fires[60] (see "Artillery Spotting").

### French Reaper-enabled Lethal Operations in the Sahel 2018-2020

As part of Operation Barkhane, the French military operates a small fleet of Reaper drones, which were only modified to carry weapons in January 2020. This table describes disclosed French military operations resulting in casualties that were specifically described as having involved a Reaper in a strike-enabling capacity. This tally likely does not represent the totality of such operations in this period.

| Location | Date | Casualties | Descripion |
|---|---|---|---|
| Menaka, Mali | March 2018 | Unknown | A Reaper transmitted the coordinates of a group of armed combatants who had confronted a joint patrol of French and Malian soldiers to two Mirage jets, which then "neutraliz[ed] most of the enemy group." The Reaper also transmitted the location of additional suspected combatants to a ground crew, which apprehended those individuals.* |
| Soum Province, Burkina Faso | October 3, 2018 | >12 | A Reaper searching for militants who had attacked Burkinabe police officers at a local gold mine discovered a convoy of more than 15 motorcycles. "After observing the group and establishing its terrorist nature," the Reaper crew passed the convoy's location to two Mirage jets, which struck the convoy.† |
| Mopti Region, Mali | November 22, 2018 | "About 30" | A Reaper "supported" airstrikes by Mirage jets, as well as Tiger and Gizelle attack helicopters, resulting in "about thirty" combatant deaths.‡ |
| Border betweeen Niger and Mali | December 2018 | 6 | A Reaper located a convoy of eight "members of an armed terrorist group" travelling on motorcycles and passed its location to a strike fighter and a ground force, which then mounted an attack that killed six of the eight individuals.§ |

* "Barkhane : Le drone Reaper, un atout majeur pour les opérations terrestres," Ministère des Armées, March 30, 2018. https://www.defense.gouv.fr/actualites/operations/barkhane-le-drone-reaper-un-atout-majeur-pour-les-operations-terrestres

† Sophie Louet, "French army carries out air strikes in Burkina after Islamist attack," Reuters, October 3, 2018. https://www.reuters.com/article/us-burkina-security-france/french-army-carries-out-air-strikes-in-burkina-after-islamist-attack-idUSKCN1ME27P and "BARKHANE : Neutralisation du groupe armé terroriste responsable de l'attaque d'Inata au Burkina Faso," Ministère des Armées, October 4, 2018. https://www.defense.gouv.fr/actualites/operations/barkhane-neutralisation-du-groupe-arme-terroriste-responsable-de-l-attaque-d-inata-au-burkina-faso

‡ "Barkhane : opération contre un groupe terroriste de la katiba Massina," État-major des armées, November 29, 2018. https://www.defense.gouv.fr/english/operations/barkhane/actualites/barkhane-operation-contre-un-groupe-terroriste-de-la-katiba-massina

§ "Six Suspected Jihadists Killed in French Airstrike in Mali, Says Military," Agence France-Presse, December 20, 2018. https://www.voanews.com/a/six-suspected-jihadists-killed-in-french-airstrike-in-mali-says-military/4709069.html

**French Reaper-enabled Lethal Operations in the Sahel 2018-2020**

| Location | Date | Casualties | Descripion |
|---|---|---|---|
| Tongo Tongo, Niger | December 27, 2018 | “About 15” | A Reaper provided “initial...intelligence acquisition and characterization” for a air and ground strike operation against a group of alleged combatants. The Reaper also served as the “chef de mission” for the operation, with its crew coordinating the various participating aircraft and soldiers and directing fires from each.[¶] |
| Dialoubé, Mali | February 13, 2019 | “Several” | A Reaper “supported,” an airstrike by Mirage jets in the Dialoubé region of the Inner Niger Delta that killed “several terrorists.”[**] |
| Timbuktu, Mali | February 21, 2019 | 3 | A Reaper detected three vehicles engaged in “suspicious behavior.” When the occupants of the vehicles began firing at a group of commandos on the ground, the Reaper assisted an attack formation of helicopters in bombing the convoy. Yahia Abu el Hamman, the leader of the Emirate of Timbuktu designated terror group, and two of his deputies were among those killed. [††] |
| Dialoubé, Mali | February 23, 2019 | “About 15” | A Reaper “supported” an airstrike by Mirage jets against members of Katiba Macina in the Dialoubé region. “About fifteen terrorists were put out of action,” according to an official statement.[‡‡] |
| Gouma, Mali | April 7, 2019 | “About 30” | A Reaper “supported” four airstrikes by French aircraft in the Gouma region of Mali as part of an operation that killed “about 30” combatants.[§§] |
| Hombori, Mali | February 12, 2020 | “Several” | A Reaper served as air mission commander for successive attacks by a Mirage jet and a Tiger helicopter on a training camp.[¶¶] |

¶ “BARKHANE : Opération du 27 décembre à la frontière malo-nigérienne – Focus sur l’engagement de la composante aérienne,” État-major des armées, January 25, 2019. https://www.defense.gouv.fr/english/operations/actualites2/barkhane-operation-du-27-decembre-a-la-frontiere-malo-nigerienne-focus-sur-l-engagement-de-la-composante-aerienne

** “Point de situation des opérations du 8 au 14 février,” État-major des armées, February 2, 2019. https://www.defense.gouv.fr/english/operations/points-de-situation/point-de-situation-des-operations-du-8-au-14-fevrier

†† “BARKHANE : Neutralisation d’un important chef terroriste,” État-major des armées, February 22, 2019. https://www.defense.gouv.fr/english/operations/actualites2/barkhane-neutralisation-d-un-important-chef-terroriste

‡‡ “Point de situation des opérations du 22 au 28 février,” État-major des armées, March 1, 2019. https://www.defense.gouv.fr/english/operations/points-de-situation/point-de-situation-des-operations-du-22-au-28-fevrier

§§ “BARKHANE : Opération dans le Gourma,” État-major des armées, April 16, 2019. https://www.defense.gouv.fr/english/operations/barkhane/actualites/barkhane-operation-dans-le-gourma

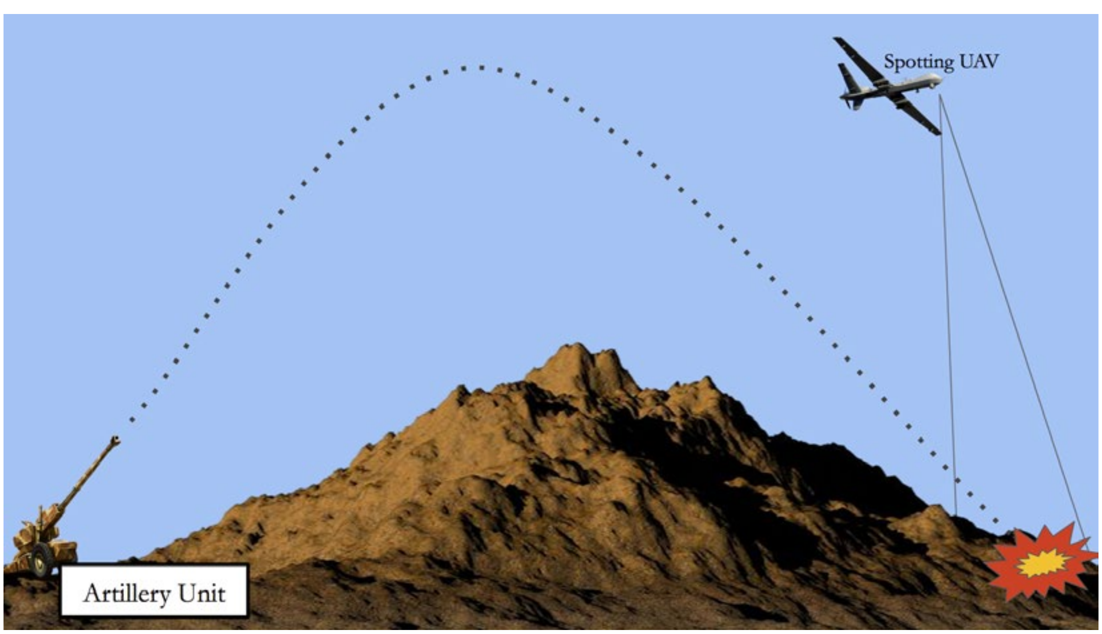
¶¶ “BARKHANE : La fonction d’air mission commander en opération,”État-major des armées, February 20, 2020. https://www.defense.gouv.fr/operations/barkhane/breves/barkhane-la-fonction-d-air-mission-commander-en-operation

# ARTILLERY SPOTTING

Artillery Spotting refers to operations by which an entity within visual range of a target relays information about that target back to an artillery unit beyond visual range (see image). This includes not only locating the target, but also a practice known as fire correction, whereby the observing entity instructs the artillery unit on how to adjust its aim after an initial shot. This enables artillery teams to fire at targets more accurately. While Artillery Spotting can be conducted by a variety of means, such as by manned aircraft and human "forward observers" on the ground, it is well-suited for unmanned aircraft. According to our study *The Drone Databook*. at least 11 militaries around the globe maintain artillery corps that incorporate "organic" spotting drones.[61]

The impact of drones in Artillery Spotting can be significant. Fires experts from the U.S. Marine Corps have noted that even small hand-launched surveillance drones can enable artillery groups to fire against targets that "cannot be observed due to obscuration, distance, darkness, observation angle, or flat terrain."[62] They may also help increase the range of artillery fires. A U.S. Army document describes how unmanned aircraft operated by individual forward observers can enable forces to call fire on locations that are up to "hundreds of miles" away.[63] Drones also enable artillery fires in areas that would be too dangerous or difficult for access by human spotters on the ground.

Exercises by the U.S. Marine Corps have also demonstrated that drones can speed up the fire correction process thanks to software that instantaneously calculates the distance and bearing between two points in the observed area—this feature is important for determining the exact degree of error, and thus the correction necessary, between an initial artillery shot's impact zone and the intended target.* [64] A U.S. Army handbook on Russian formations notes that in the conflict in Ukraine it only takes about 10 to 15 minutes from when a small Russian unmanned aircraft identifies a target to when that target is submitted




*An illustration of an Artillery Spotting operation. The UAV (right) relays video of the target to an artillery unit (left) that is beyond visual line-of-sight."*

to precise artillery fire.[65] The Israel Defense Forces, which maintains extensive tactical drone programs across a number of its units, has suggested that small unmanned aircraft in support of ground operations such as artillery fires have the benefit of being largely undetectable by traditional anti-aircraft radar—making them well suited for surprise barrages.[66]

Unmanned aircraft can also provide Artillery Spotting for shipboard guns. During the First Gulf War, the U.S. Navy's use of RQ-2 Pioneer reconnaissance drones to direct heavy shell fire against land-based Iraqi targets from two World War II-era battleships, the *USS Missouri* and *USS Wisconsin* was so effective that the Iraqi soldiers on the ground soon realized that the presence of the Pioneer overhead was a certain sign of an impending—and precise—artillery barrage. This concept for "Naval Fire Support" remains in favor. A 2014 NATO standards-related document for tactical unmanned aircraft describes how tactical unmanned aircraft can be used for spotting targets for ship-based cannons in areas where the presence of air defenses precludes the use of manned spotting assets.[67] The Royal Canadian Navy, which has been investing heavily in unmanned systems, noted in 2016 that its envisioned fleet of aerial drones would "potentially" include systems for "naval fire support."[68]

Non-state groups also appear to have experimented with small commercially available multirotor unmanned aircraft for directing artillery attacks. In the summer of 2018, multiple videos posted online appear to show precise Houthi artillery attacks on alleged enemy positions as recorded from quadcopter drones—though neither the authenticity of these videos nor the exact effect of the unmanned aircraft in directing the Houthi fires was independently verified. Similarly, coalition forces operating in Iraq have observed that ISIS forces appeared to use camera-equipped quadcopter drones to help direct mortar fire. Lack of verification and evaluation notwithstanding, these attacks suggest that basic commercially available drones can be used for Artillery Spotting without any additional special equipment.

**Case Study: Russian Artillery Spotting**

Among militaries that use drones for Artillery Spotting, Russia has emerged as a clear leader in the practice. Russian artillery forces maintain a detailed and advanced doctrine for using drones in spotting and correction both in the day and at night,[69] and it is predicted that all Russian artillery brigades and regiments will have their own embedded reconnaissance drone companies within the next few years.[70] These arrangements can be devastatingly effective. In August 2014, Russian artillery fires guided by Orlan-10 (Орлан-10) and Forpost (Форпост) surveillance drones destroyed an entire column of vehicles from Ukraine's 92nd Separate Mechanized Brigade in a single melee.[71]

In some cases, Russian forces employ a technique that combines two unmanned aircraft—one high altitude unmanned aircraft operating in a Target Acquisition role to identify potential targets (see "Target Acquisition") and a second, low-flying unmanned aircraft that then moves to within visual range of the identified target in order to precisely direct artillery fire.[72] U.S. Army analysts Lester W. Grau and Charles K. Bartles have pointed out that while Russian forces are still unable to use drones for "more advanced methods of Artillery Spotting," such methods are not necessary for many of the most common artillery missions that these forces engage in. The Russian military has also proposed attaching tethered drones to its next generation T-14 main battle tanks; this would give each tank a 10km sighting range, allowing operators to exploit the full 8km range of the tank's main gun while the tank itself remains in a concealed position.[73]

* The authors of a report reflecting on these exercises, published in the November-December 2018 issue of the U.S. Army bulletin *Fires*, note that the use of unmanned aircraft in such operations would supplement, rather than entirely supplant, the use of traditional forward observers.

# MANNED-UNMANNED TEAMING

Manned-Unmanned Teaming (MUM-T) describes the direct communication or coordination between a manned aircraft or vehicle and an unmanned system. It is a catch-all phrase that can encompass a broad range of operational arrangements, from Target Acquisition and Buddy Lasing to direct control of the drone by the manned aircraft pilot. In this section, we will focus on a subset of MUM-T operations in which manned aircraft pilots receive sensor information to their cockpit directly from an unmanned aircraft. This allows pilots to see exactly what the drone is seeing, even when the drone is tens or even hundreds of kilometers away. Most commonly, such MUM-T systems deliver FMV.

Such "off-board sensing," as it's sometimes known, can be a significant enabler for strike operations. As the Pentagon's "Unmanned Systems Integrated Roadmap 2013-2038," puts it, the goal of MUM-T operations is to achieve "greater lethality."[74] It allows armed manned aircraft to identify targets at an extended range or in inaccessible areas, which can significantly enhance the effectiveness of kinetic actions in certain cases. In a test at Fort Irwin in 2013, a U.S. Army Gray Eagle transmitted video footage directly into the cockpit of an AH-64E Apache gunship that was more than 100km away. Using this video feed from the drone, the gunship's crew was able to "coordinate artillery fire to destroy the identified target," according to the U.S. Army's product manager for Apache sensors (for more on Apache MUM-T, see insert on page 19).[75] The U.S. Air Force has used MUM-T to this exact effect extensively in Afghanistan by pairing Predators with the AC-130 gunship.[76] In such cases, MUM-T may allow large, non-stealthy aircraft like the AC-130 to "fix" a target while remaining out of earshot or visual range, so as not to be detected, and only approach to strike at the very last minute.[77] The capability could similarly be used to keep manned aircraft beyond the range of anti-aircraft defenses.* Additionally, MUM-T enables aircrews to maintain uninterrupted "eyes on" moving targets while en route to the strike location, as opposed to traveling to a location with only the coordinates and a description of the target, which can lead to less precise strikes.

MUM-T is increasingly regarded as a transformative capability for armed forces around the globe, and is set to proliferate widely. The defense contractor L3Harris has described plans to integrate MUM-T systems into every Apache gunship currently in active inventory (there are roughly 800 aircraft in use among 14 militaries beside the U.S.)[78] General Atomics Aeronautical Systems notes in one brochure that its Predator XP—an unarmed variant of the Predator designed specifically for foreign militaries that are barred from acquiring weaponized U.S. drones—can be used in MUM-T operations.[79] In 2018, European firms Airbus Helicopters and Schiebel demonstrated a Manned-Unmanned Teaming capability between an H145 piloted helicopter and a Camcopter S-100 rotary-wing drone.[80] The Russian Navy is in the process of equipping its Tupolev Tu-142MZ/MR maritime patrol aircraft with datalink systems to directly receive targeting video feeds from Forpost (Форпост) surveillance drones.[81] The Sky Hawk (天鹰), a stealth drone currently under development by the China Aerospace Science and Industry Corporation, will also reportedly be capable of sharing data directly with manned aircraft.[82]

* The Pentagon has characterized MUM-T as being "essential" to DoD operations as it shifts its focus from the Middle East to the Asia-Pacific region.[83]

As MUM-T becomes more sophisticated, the technology will greatly expand the types of teaming missions seen on the battlefield. In particular, pilots will be capable of operating their teamed drone directly from the cockpit and, eventually, even command teams of "wingman" drones simultaneously. Multiple U.S. DoD programs, such as the Air Force Research Laboratory's Have Raider,[84] Skyborg, and Mako Unmanned Tactical Aerial Platform (UTAP-22),[85] are developing such systems. These wingmen aircraft will point the pilot to potential targets and alert them to incoming threats, among other tasks. A policy paper published by the Mitchell Institute in 2018 suggested that such programs could significantly shore up the Air Force's fighter and bomber inventory.[86] In March 2019, Boeing unveiled a long-range jet drone designed for teaming. Since the system is developed in Australia, it will be subject to fewer export control restrictions than U.S.-made drones.[87]

*A U.S. Army AH-64 Apache helicopter operating in a Manned-Unmanned Teaming exercise with an RQ-7B Shadow (not pictured) at Fort Bliss, Texas in 2015. Credit: Sgt. Alexander Neely*

**Case Study: U.S. Army Apache MUM-T**

The U.S. Army maintains an extensive ongoing program to develop systems and techniques for teaming its AH-64E Apache manned helicopter gunships with surveillance and reconnaissance drones such as the RQ-7B Shadow and the MQ-1C Gray Eagle.[88] In a typical mission, one or more drones will transmit live video and metadata to the pilots of one or more Apaches. This allows the gunship pilots to see the target well in advance of arriving at their location, as well as attack targets beyond their direct visual range—a useful capability for surprise attacks or attacks in contested areas. For example, the 1st Infantry Division, which has spearheaded the Army's Apache MUM-T initiatives, has shown how drones can transmit the location of a target to Apaches waiting on the other side of a mountain from the target.[89] MUM-T has already been employed extensively by the Army in combat, providing gunships with a MUM-T range of up to 50km. One Apache battalion in Afghanistan reported employing the capability in at least 60 percent of its "direct fire" missions in 2014.[90] In certain circumstances, Apache pilots can even directly control the teamed drone's sensors, rather than having to tell the drone's operators where to look or what to zoom in on. As the DoD continues to expand its Apache MUM-T program and other similar initiatives, such a capability will become routinely available for Apache and other pilots in the field.*

* The U.S. Navy, meanwhile, is looking to develop a similar capability to link its MQ-4C Triton surveillance and reconnaissance drone with the P-8 Poseidon, a weaponized patrol aircraft. According to the commander of the Triton development team, "this would enable the P-8 aircrew to become familiar with a contact of interest and surrounding vessels well in advance of the aircraft's arrival on station."[91]

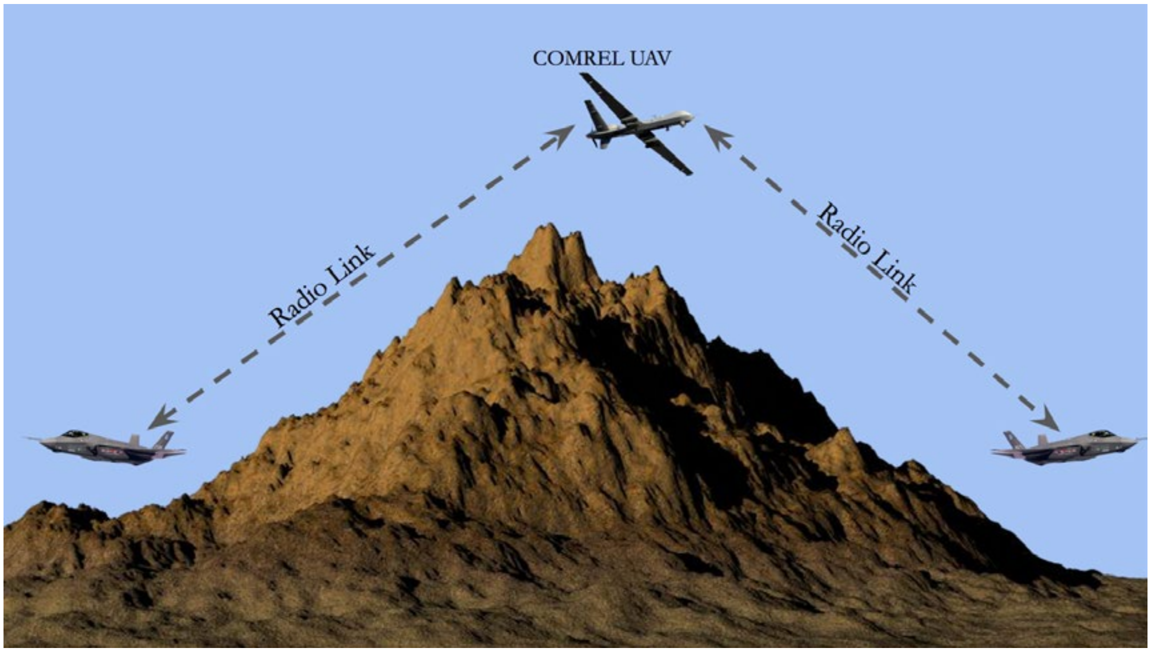
# COMMUNICATIONS RELAY

In Communications Relay (COMREL) missions, a drone connects two or more manned vehicles or ground teams that do not have the ability to communicate with each other directly. For example, if two manned aircraft are operating at low altitude on either side of a large mountain, their pilots may not be able to communicate directly with each other using "line of sight" radio signals; to get around this problem, a drone equipped with radio transmission antennae can be flown in an orbit above the hill. Because the drone maintains a direct line-of-sight with both planes, the two aircraft can communicate with each other by passing their communications through the drone (see image on page 21).

COMREL can also be used to connect entities that use incompatible communications systems. For example, an aircraft or unit using RF radio may wish to communicate with another entity that is only reachable by satellite phone; the Communications Relay aircraft can serve as a gateway to connect the two, similar to how a telephone operator will connect two people who do not have the capability to reach each other directly. In a complex mission, multiple assets attempting to coordinate may be operating either beyond direct communications range of each other or using different communications systems: a single Communications Relay system can tie these communications together. Crucially, and of particular appeal to military users, unmanned aircraft can be used as Communications Relays even while they are conducting a different primary mission.[92]

Though COMREL is rarely discussed, it is directly linked to increased lethality in airstrike operations. In Afghanistan, where mountainous terrain can often block direct communications, U.S. forces have made extensive use of a system known as the Battlefield Airborne Communications Node (BACN) aboard a mixed fleet of EQ-4B Global Hawk drones and E-11A Gulfstream jets. These aircraft can connect disparate data links from multiple types of radio systems, telephones, and satellite communications systems. One DoD diagram illustrating BACN's concept of operations suggests that it is compatible with F-18 and F-16 fighter jets, E-8 and E-3 command and control aircraft, A-10 ground attack aircraft, and combat teams on the ground, among other entities.[93] In 2016 alone, three BACN systems directly participated in more than 7,000 combat strikes over the course of more than 1,500 missions.[94] The BACN Global Hawks have also been deployed extensively in support of operations against ISIS targets in Syria and Iraq.[95] In one mission during that campaign, in December 2016, the U.S. Air Force used a BACN aircraft to support a bombing campaign that destroyed 188 oil transport trucks operated by ISIS. According to post-battle reports, the system played a key role in the mission by enabling direct communication between a diverse assortment of aircraft.[96]

According to U.S. Air Force Captain Dennis Seay, a weapons officer involved in BACN operations in the mid-2010s, the use of COMREL significantly expanded the use of F-16s in the air campaign in Afghanistan because it enabled pilots to communicate with their operations centers using radio and telephone systems rather than having to rely on satellite links, which only gave pilots limited windows of coverage in which to receive and confirm targeting instructions.[97] Similarly, in multiple instances in other campaigns, Navy strike aircraft operators have reportedly refused to conduct a particular mission without the presence of the BACN, as the system is the only way to connect these aircraft with their ships.[98]




*An illustration of a Communications Relay operation. The UAV's COMREL payload relays radio communication between two manned fighter aircraft that are unable to communicate with each other directly because of the terrain.*

**BACN and Special Operations**

An Air Combat Command presentation from 2006, shortly before BACN was fielded, suggests that a single aircraft could also provide cellular communications for up to 160 special operations soldiers on the ground, simultaneously.[99] If true, this could potentially enable covert units on the ground to communicate with an attack plane beyond earshot of their targets.[100]

COMREL has become a common capability aboard a wide range of drone types. The U.S. Army's RQ-7 Shadow, an unarmed tactical surveillance drone, and the MQ-1C Gray Eagle,[101] are both equipped with radio-frequency relay nodes, which allow ground units to communicate with distant aircraft without requiring a satellite communications link. The U.S. Navy and Marine Corps' RQ-21A Blackjack also carries a basic COMREL package that enables radio communication between entities up to 50 nautical miles from each other.[102] The U.S. Navy's MQ-8B Fire Scout[103] rotary-wing drone, and its newer larger variant, the MQ-8C,[104] as well as the MQ-4C Triton,[105] also carry a Communications Relay node. On these maritime drones, COMREL can enable ships, manned aircraft, and terrestrial units to communicate with each other "over the horizon." Tests by U.S. drone maker AeroVironment have also demonstrated the concept of using small, submarine-launched unmanned aircraft as temporary COMREL devices for a wide range of vehicles operating both on the surface of the water and in the air.[106]

Some observers have noted that Communications Relay would be crucial in a near-peer conflict. Communication Relay drones could be used for maintaining viable communications links between units following an adversary jamming attack on primary communications systems, or for stealth attacks in denied airspace.[107] In late 2019, the Air Force acknowledged that it is looking to equip the Valkyrie "loyal wingman" drone, which has some stealth capabilities, with a COMREL system to connect F-35A and F-22 stealth jet fighters.[108] Furthermore, it has been speculated that the U.S. Air Force's secret stealth drones, the RQ-180 and the RQ-170, could be used for COMREL. The prospect of such stealth drones serving as a Communications Relay is significant because it could enable communication between other stealth jets operating inside denied airspace, or between covert units or aircraft inside denied territory and strike packages outside.[109]

As the tactical advantages of COMREL become more widely recognized, the technology will proliferate. Northrop Grumman, the U.S. defense contractor, has advertised an exportable version of the BACN,[110] though as of this writing no foreign military appears to have purchased the system. The Israel Aerospace Industries Heron, an exportable, medium-altitude long-endurance drone, is described by the manufacturer as having a Communications Relay capability.[111] In 2013, a large Russian telecom contractor announced that it was testing a powerful radio relay system aboard the Typhoon-5 (тайфун-5) to extend the range of Russia's ground-based radios from 30km to 100km.[112]

COMREL will likely be a core role for high-altitude pseudo-satellites (HAPS), a type of drone that flies at very high altitude for up to weeks or months on end. A HAPS currently under development by the China Aerospace Science and Technology Corporation is being actively considered for a Communications Relay role.[113]

# ELECTRONIC ATTACK

Electronic Attack (EA) refers to the use of a variety of non-kinetic measures to disrupt, degrade, or destroy enemy weapons systems. Though Electronic Attack systems can take a number of different forms, here we will focus on systems that temporarily jam, or fully disable, communications devices. As militaries across the globe increasingly rely on the electromagnetic spectrum to link soldiers, vehicles, and unmanned systems, such Electronic Attack technologies are gaining currency. These weapons are increasingly being used aboard unarmed and armed unmanned aircraft. Potential targets of Electronic Attack include: space-based sensors, Communications Relay systems, intelligence aircraft, navigation systems, radio networks, deeply buried targets, and even motors and generators.[114] Because of its significant destructive power, the U.S. Army classifies EA as a category of "Fires," alongside artillery.[115] Indeed, it can even be lethal. As one Army targeting manual puts it: "electronic attack could potentially deny essential services to a local populace, which in turn could result in loss of life and/or political ramifications."[116]

Electronic Attack weapons can be used to support kinetic strikes by other platforms in two principal ways. First, such systems can be used to enhance the impact of kinetic attacks. For example, a battalion might employ EA in conjunction with artillery fire to interfere with an adversary's communications systems or degrade the navigation and guidance systems for their aircraft and weapons, thus disrupting their ability to defend themselves or mount a counterattack. Alternatively a jamming system could be used to disable cellular communication between multiple potential airstrike targets—for example, two affiliated insurgent cells—barring them from being able to communicate with each other and coordinate their defenses.

A second way in which EA can enable lethal actions is through jamming, disrupting, or deceiving* an adversary's air defenses, thus clearing the adversary airspace so that manned strike aircraft can enter the area without being shot down. In military jargon, this is known as Suppression of Air Defenses (SEAD).* SEAD is regarded as a potentially significant role for unmanned aircraft because they could replace the manned aircraft that currently perform this role and extend a country's SEAD reach into riskier areas where it wouldn't send human pilots.[117] The Australian Department of Defense has explored the use of jamming systems aboard groups of small cooperative autonomous unmanned aircraft for suppressing air defenses, a capability that one technical document from the program describes as a key to protecting Australia's relatively small number of attack aircraft.[118] In 2019, the U.K. Ministry of Defence launched an initiative to develop intelligent swarming drone systems for overwhelming enemy air defenses, while a consortium of 12 European defense firms has proposed a "SEAD Swarm" system that would leverage autonomous collaborative unmanned aircraft to identify and attack enemy surface to air missile sites and radar.[119] Some groups have even speculated that an effective jamming pod would enable non-stealthy drones like the MQ-9 Reaper to operate in contested airspace.[120] †

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* Decoy missiles, which emit an aircraft-like signature to deceive and/or reveal enemy air defenses, have long been used for SEAD. Decoy missiles like the U.S. MALD series weapons continue to be operational for SEAD today. One of the earliest transformative applications of modern drone technology was Israel's extensive use of small Chukar and Firebee drones in this capacity against Syrian and Egyptian air defenses in the Yom Kippur War in 1973.[121]

† The 2011 intervention in Libya provides an illustrative example of SEAD in action. The U.S. Navy employed airborne jamming weapons mounted aboard manned E/A-18 Growler fighter jets to disable Libyan Armed Forces radar sites in advance of heavy bombing raids by armed attack aircraft.[122]

**Case Study: Russian Electronic Attack**

Russia, a global leader in electronic warfare technologies,[123] operates an Electronic Attack system known as the Leer-3 (Леер-3), which consists of two or three Orlan-10 (Орлан-10) tactical fixed-wing drones and a truck-based ground station. The Leer-3 system can reportedly be used to jam cellular networks up to 60km away.[124] The system can also be used to mimic a cellphone tower, which allows Russian forces to send text messages directly to adversary forces operating in the area, reportedly reaching as many as 2,000 cell phones at once. In Ukraine, Leer-3 systems sent Ukrainian soldiers text messages, some of which were made to look as though they came from fellow soldiers, encouraging them to defect and telling them that they had been abandoned by their commanders or that their forces were suffering heavy losses nearby. Examples of fake messages include: "Leave and you will live," "Nobody needs your kids to become orphans," "They'll find your bodies when the snow melts," and "We should run away."[125] In Syria, the system has been used to send combatants fake application forms for an armistice.[126] According to reporting by Estonia's International Centre for Defence and Security, "it is highly likely" that the system was used in support of Syrian Arab Army attacks on opposition groups.[127] It has also been reported that the Leer-3 has been used to send text messages to local civilian populations, warning them to clear the vicinity of a target in the lead-up to a planned strike and directing them toward safe corridors to avoid crossfire.[128]

The U.S. Department of Defense has invested heavily in efforts to equip drones with EA weapons. The Army, for example, is working to mount jamming pods aboard the MQ-1C Gray Eagle and other drones, with contracts already awarded to Lockheed Martin and BAE Systems.[129] The U.S. Marine Corps is looking to mount the Intrepid Tiger II, a counter-radar EA system, aboard the RQ-21 Blackjack.[130] According to the Teal Group, a research firm, other DoD Electronic Attack programs for drones include the DEACON Electronic Attack Pod and at least two classified systems for U.S. Air Force stealth drones.[131] Under a program called Remedy, the Navy and Northrop Grumman are looking to equip the E/A-18G Growler jet with tube-launched jamming drones that can fly ahead of a strike group, suppressing enemy defenses at close range. According to a company executive, such a system would enable novel, presumably more targeted jamming techniques, as well as cyberattacks against command and control networks.[132]

Interest in jamming drones has also begun to take hold beyond Russian and U.S. forces. According to a report on Chinese military capabilities by the U.S. Defense Intelligence Agency, the People's Liberation Army operates "unmanned aerial vehicle (UAV)-borne jamming systems to support maneuver forces."[133] Israeli firm Elisra markets a combined electronic countermeasures and SIGINT system known as Air Keeper, which can selectively jam a range of devices within the operations area. On its own, the jamming element of the AirKeeper, which can be purchased as a standalone payload (SKYJAM) for unmanned aircraft, weighs just 35kg.[134] The company has already sold manned-aircraft versions of the Air Keeper to Columbia and a number of undisclosed customers.[135]

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* In a test in 2014 at Marine Corps Air Station Yuma, an MQ-9 Reaper and a Northrop Grumman Bat, a small tactical fixed-wing drone, conducted a series of jamming attacks against early warning radars and surface-to-air missile sites so as to clear the airspace for a group of strike aircraft to bomb these and other simulated targets on the ground. The MQ-9, which is much larger and more costly than the Bat, was operated at a greater standoff distance, beyond the reach of the notional anti-aircraft weapons, while the Bat flew much closer to the targets (a smaller, lower energy jamming system must be closer to its intended target to be effective)[136]

# MINIATURIZATION

All of the strike-enabling roles described in this report rely on devices that have shrunk in size significantly over the past few decades, and which will shrink further in the years ahead. This miniaturization can place strike enabling capabilities in the hands of militaries that can only afford small drones.

For example, modern laser designators can weigh as little as a few hundred grams.[137] Similarly, the AeroVironment Mantis i45 sensor package has roughly the same specifications as the sensor ball mounted on the early variants of the Predator, and yet it is more than sixty times smaller and lighter. The same wide-area motion imagery capability that in 2006 required 500kg of cameras and computer stacks now comes in a 14kg pod.[138] Horizon Technologies, a British firm, recently released a version of its Xtender satellite phone locator and interceptor that is small enough to fit on a cheap DJI Mavic quadcopter;[139] U.S firm VStar Systems, meanwhile, has developed a drone-mounted SIGINT sensor, capable of tracking over a thousand radio emissions, that weighs just two pounds.[140] IMSAR, a U.S. firm, sells synthetic aperture radars designed specifically for drones that weigh 16.4lbs[141] and 7.4lbs.[142]

Another result of miniaturization is that it is becoming increasingly common for militaries to mount multiple types of sensors aboard a single aircraft. These agglomerations of sensors enable a single target to be observed and tracked in various different ways, through a variety of spectra, so as to build a fuller picture of its identity and activities—or they can enable a single drone to conduct a variety of separate strike-enabling operations simultaneously. As Col. Stephen Jones, commander of the U.S. Air Force's 432nd Wing/432nd Air Expeditionary Wing, explained, "In the past, [it] took an entire constellation of Reapers just in terms of power and range that we can [now] get out of a single [intelligence] pod; we're able to cover wider areas, and we're able to get greater degrees of fidelity with the things that we are collecting."[143]

*Thanks to recent advances in miniaturization, significant sensing capabilities can be packaged into small, hand- or catapult-launched systems. Here a U.S. Marine launches an RQ-20 Puma, which is capable of carrying the powerful i45 Mantis multi-sensor pod. Credit: Lance Cpl. Ana Madrigal*

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