DRONES

WHAT EVERYONE NEEDS TO KNOW®

SECOND EDITION

SARAH E. KREPS
JAMES PATTON ROGERS

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FOREWORD: A NEW DRONE WORLD

In 2020, a new PhD student joined Cornell's Department of Government and expressed an interest in studying drones. It seemed like a risky topic given that drones had been the subject of considerable academic scrutiny in the two decades prior. In more recent years the intensity of the debate had waned, especially as the use of drones by the United States for counterterrorism had ebbed from peaks in Pakistan (2010) and Yemen (2017).[1] But this was just a lull. In 2020, war broke out between Armenia and Azerbaijan and armed drones played a prominent role.[2] In 2022, Russia invaded Ukraine and drones again were at the center of combat.[3] In 2023, Israel and Hamas went to war and drone attacks by both sides made international headlines. Israel deployed quadcopters into buildings before sending in soldiers,[4] used drones to search underground tunnel systems,[5] and conducted strikes against high-profile targets,[6] all while Hamas used drones to drop explosives, and the Houthis in Yemen sent drones over hundreds of miles to strike Tel Aviv in reaction to said Israeli strikes.[7] By 2024, and into 2025, drones had again become a staple in the domestic and international news cycle. From a drone-aided assassination attempt on Donald J. Trump, the first fatal drone strike on members of the US military, and thousands of reported "unidentified" drone sightings above the US East Coast, it had become clear the lull was over.[8] Drones were here to stay.

Now not a day goes by without another spectacular story about how drones, both remote-controlled and autonomous, are transforming the world around us. Also referred to as unmanned or uncrewed aerial vehicles (UAVs), these versatile systems—some weighing a few pounds and others a few tons—are often put to use in tasks deemed too dull, dirty, dangerous (or expensive) for humans to carry out. Chinese power companies fit drones with flamethrowers to incinerate garbage hanging from powerlines;[9] US police use drones to track violent criminals in high-speed car chases;[10] authorities in New Zealand experiment with fully autonomous drones for pest control and to fight invasive species;[11] Alphabet's Wing drone delivery service has now surpassed 350,000 deliveries;[12] and scientists have announced that drones are a "game-changer" when it comes to tracking everything from hurricanes to meteorites.[13] These stories have a way of captivating the mind. They bring together the world of science fiction and twenty-first-century consumer culture that values instant gratification, personalized service, and high-tech solutions to long-held problems.

The first edition of *Drones* focused disproportionately on the initial use case: the American use of drones for counterterrorism strikes. While those are not fully in the rear-view mirror, that application is now overshadowed by more common uses of drones in contemporary war. In recent wars, actors have found that medium-altitude long-endurance drones such as Predator or Reaper, used by the United States, were either not available due to export restrictions imposed by the United States, or simply too expensive, and so turned to China, Turkey, or Iran for their military drone needs. Other countries and violent nonstate groups have increasingly turned to lower-cost, mass-produced drones that can be bought commercially or manufactured locally. These have been used for reconnaissance and precision strikes (as Islamic State of Iraq and Syria, known as ISIS, demonstrated during Operation Inherent Resolve[14]), or for swarm-like effects, such as when Ukraine deployed over 150 drones against multiple Russian energy targets in the hope that some, even if a handful, would make it through.[15] Drones have also taken to the seas and land with underwater drones, surface drones, and unmanned ground vehicles utilized in increasingly numbers by militaries around the world. While the focus of this volume is still concentrated on airborne systems, we go deeper than ever before into these expanding areas of drone experimentation and application.

As the primary users, tactics, and domains of drones have changed in the last decade (between 2015 and 2025), debates have also evolved. Aerial drones now are more like any other aircraft, a more mundane and yet more varied platform than the Predator or Reaper that the United States had used for counterterrorism strikes and that had taken on near-mythical status. At the same time, more broadly, there are different types of drones emerging around the world and being used in functions that were not foreseen a decade ago. Thus, a new edition of the *Drones* book is warranted, as is a new perspective. With this new approach comes an understanding that not all drones are put to malicious ends. It is noted that the year 2024 was hailed as "the year of the drone" thanks to the record number of drone deliveries transforming logistics and transportation; to the fascinating light shows with thousands of drones creating mid-air masterpieces;[16] and to the drone revolution that is taking place in construction, agriculture, the arts, and scientific research, offering novel solutions to long-held problems. As such, this new volume recognizes the positive impact of the drone alongside the darker side of our possible drone future.

As in the first edition, Sarah Kreps is an author on the volume, bringing the perspective of a former Air Force officer turned academic whose research combined real-world experiences with drones after 9/11 and the scholarly study of national security and emerging technology. She has now joined forces with James Patton Rogers, who approaches the study of drones and national security from the perspective of a war historian and policy advisor, and who works closely with the UN and NATO on countering the global proliferation of drones and autonomous weapons to violent nonstate actor groups. This updated edition incorporates both sets of insights, alongside cutting-edge developments in industry, military, and academic thinking, to bring readers up to date on the topic of drones.

We appreciate the tireless Dave McBride for suggesting an updated edition to the *Drones* book, and to Esteban Lau, Anika Kolanu, Abigail Srulevich, Elizabeth Redmond, and Olaf de Rohan Willner for helpful research assistance. We also want to thank the expert peer reviewers for their welcome feedback.

1
DEFINING DRONES

What is a drone?

The term "drone" has come to loosely refer to unmanned or uncrewed aerial vehicles (UAVs). Nevertheless, the terminology used and definitions adopted can vary between organizations. The US Federal Aviation Administration (FAA) refers to a drone as an "unmanned aircraft system" (UAS), while the US Air Force refers to its largest drones as "remotely piloted aircraft" (RPA).[1] The latter organization prefers to incorporate the word "pilot" because of the significant training required, even for a remotely positioned operator. It also emphasizes that there is a human in the loop of control, albeit remotely. All of these names speak to the attribute that unifies drones: that they operate without pilots on board. Yet various other air vehicles—including missiles, rockets, balloons, or kites—do not have pilots on board. So how are drones different?

In line with its UAS designation, the FAA specifically defines a drone as "an unmanned aircraft and the equipment necessary for the safe and efficient operation of that aircraft."[2] With the hardware and means of control in mind, the FAA goes on to state that "[a]n unmanned aircraft is a component of a UAS. It is defined by statute as an aircraft that is operated without the possibility of direct human intervention from within or on the aircraft."[3] Put simply, key points in the FAA's definition include the flying component without a human onboard; a control station, or equipment used to control the unmanned aircraft remotely; a datalink, or some link between the aircraft and a control station; and support equipment (other components necessary to operate the drone). Although useful in tying together the aircraft and its control components, such a broad understanding of the drone could include everything from small hobbyist quadcopters to large military surveillance and combat drones, offering us only minimal additional criteria to aid in our understanding.

Canadian law offers a bit more distinction, although not much. It defines a drone as an "RPA—a navigable aircraft, other than a balloon, rocket or kite, that is operated by a pilot who is not on board."[4] Although this definition is still limited and could include all types of varied drone technologies, we get a clearer sense of what a drone is not and how it differs from other forms of unmanned flight. Kelsey Atherton of *Popular Science* offers more descriptiveness that supports this broader distinction: "'drone' as a category refers to any unmanned, remotely piloted flying craft, ranging from something as small as a radio-controlled toy helicopter to the 32,000-pound, $104 million Global Hawk. If it flies and it's controlled by a pilot on the ground, it fits under the everyday-language definition of drone."[5] As such, it is clear to see what a drone is and is not, but a little harder to get to the specifics of the different types of drones, their uses, and their capabilities. This is why, as the rest of this chapter will show, classification is needed beyond the broad label of drone.

Let's start by tackling the specific, and often misunderstood, difference between a drone and cruise missile as this will help us explore the different classifications of drones we see today. While the Missile Technology Control Regime (MTCR, which will be discussed later in Chapter 3) consolidates some drones and missiles as potential delivery systems for weapons of mass destruction, they are actually distinct platforms.[6] Cruise missiles can be confused with drones because they too are unmanned. However, more traditional larger drones like the Predator or Reaper (known as Medium Altitude Long Endurance, MALE drones) are, according to the US Defense Department, meant to be recovered while cruise missiles are one-way systems. Furthermore, a cruise missile's munitions are integrated into its airframe, while the MALE drones are traditionally more segregated and detached.[7] In addition, while both drones and cruise missiles are used for stand-off strikes, large drones like a MQ1-B Predator often have a shorter range (1100 kilometers miles, compared to 2,400 kilometers) and are slower than cruise missiles (135 mph, compared to 550 mph).[8] The one-way nature of cruise missiles, their long-range capability, and their speed as compared to these larger drone systems impacts the types of missions for which cruise missiles and drones are used. Drones, at least the type that was used for counterterrorism strikes by the United States, are therefore more likely to require forward-operating bases because of their limited range and mission objectives compared to cruise missiles.[9]

Even these practical differences between drones and cruise missiles can become blurred by some of the drones operated around the world. For example, Israel developed fixed-wing weapons systems that are considered drones (named the Harop and Harpy) and are essentially one-way attack (OWA) systems in which the platform itself acts as the munition.[10] Although these drones carry limited amounts (no more than 30 kilograms) of explosives in their nose, the drones are essentially acting as missiles because they deliver explosives to a target and detonate on impact. What makes these drones different from a cruise missile is their ability to loiter over a target; after loitering, they attack by self-destructing upon reaching the target. In Ukraine, similar OWA drones—sometimes called loitering munitions, kamikaze, or suicide drones—have played an important strategic and tactical role since the Russian invasion in 2022. Strategic OWA systems include the Ukrainian FP1 and the Iranian supplied Shahed 136, which has become one of the most widely deployed drones in the war. Also known as the Geran-2 (its Russian designation), the Shahed has a 2.5 meter wingspan, 2000 kilometer range, and has been widely used (sometimes in rudimentary swarms) by Russia in deep strikes against Ukrainian cities and critical infrastructure.[11] Tactical OWA drones, on the other hand, include the Switchblade, released in the smaller 300 and larger 600 model and used to target Russian bunkers, vehicles, and personnel on the entrenched battlefield.

AeroVironment, the American manufacturer of the Switchblade, notes that “not all drones are created equal.”[12] Indeed, these fixed-wing drones were designed to be small, portable, and capable of being launched one-way by a soldier, loitering in the air and conducting surveillance (with integrated cameras and sensors) before striking a target. Worthy of note here is that this drone also has “automated features” where a human is not in direct control at all times. Like an increasing number of drones today, the operator of the Switchblade “is not flying the aircraft, the operator’s simply indicating what (s)he wants to look at, what (s)he wants the camera to be pointing at, and the onboard computer flies the aircraft to that point and maintains on target.”[13] As such, the Switchblade’s role and label as a drone shows how the generalized definition of a drone has allowed the drone vernacular to include almost any aircraft, while finding it hard to keep up with the latest semi-autonomous and fully autonomous developments that challenge the idea that all drones will always be remotely controlled by a pilot. With this in mind, let’s better categorize this quickly expanding family of varied systems, including the MALE and OWA drones.

What are the different types of drone platforms?

Airborne drone platforms generally fall into one of four broad categories – multirotor, fixed wing, single rotor, and vertical take-off and landing (VOTL) drones. Multirotor drones have between four and eight rotors, with four, better known as quadcopters, most common for recreational use, photography, and videography (DJI Mavics and Skydio X10s). Six rotor, or hexacopters, are used for their stability and lifting capacity for professional filming or aerial inspections (LJI ZD700 PRO and BVH616).Eight rotor (octocopters), on the other hand, are preferred for heavy lifting, such as professional cinematography and industrial applications (Tarot X8-Lite and HLM Octocopter). These multirotor drones typically have a range of 11.6–16 kilometers depending on the model. Smaller and cheaper consumer drones typically range between 1.6 and 6.5 kilometers and a battery life of

15–40 minutes per charge, with some high-end models extending flight time by using larger batteries or multiple battery packs. Given that many of these drones are modular by design, it is not uncommon to see both hobbyists and military personnel (especially those in Ukraine and Russia) modifying their drones and creating bespoke systems that push the limits of how fast and far a drone can fly.

Fixed-wing drones, including the OWA and MALE systems, are similar to airplanes in that they have wings not rotors and can be used for longer-range missions, such as mapping, surveying, and agriculture. They can also be used by hobbyists for long-duration flights but with limited maneuverability compared to multirotors. Indeed, the consumer and commercial versions of these systems have a longer range of 16–160+ kilometers, depending on size and application, and a battery life of between one and five hours. They are more efficient than multirotors and can stay airborne much longer, making them ideal for the longer-distance roles.

As is often the case, in the military domain, these fixed-wing drones have been designed to have a much longer range and are powered by an internal combustion engine. The Orlan-10, the workhorse of the Russian military, is but one example of a smaller fixed-wing military drone. It has a wingspan of 3.1 meters, a length of 2 meters, a maximum range of 600 kilometers, and is powered by a four-stroke piston engine.[14] This drone is unarmed, but as with most military drones today, it can carry an assortment of interchangeable payloads, some of which can be used for electronic warfare capabilities.[15] At the larger end of the scale, you have the Chinese Wing Loong-3 fixed-wing MALE drone—a more advanced version of the highly successful Wing Loong-2, which China has sold around the world.[16] With a reported 10,000-kilometer range, this drone is one of the few in the world that has a truly intercontinental range, with only the US Global Hawk drone (an unarmed fixed-wing High Altitude Long Endurance, HALE, surveillance system) able to fly further (over 22,500 kilometers).[17] The Wing Loong-3 is powered by a turboprop engine and has nine external mounts, which can carry up to 16 missiles or guided bombs.[18] Other reports suggest the drone may be able to carry smaller OWA drones making the

Wing Loong-3 a drone “mothership.”[19] The range of these new large drone systems once again blurs the definitional and operational lines between cruise missile and drone, but it is the distinct ability to loiter, deploy weapons systems, and return that separates these drones from their missile counterparts.

Next you have single-rotor drones, which are tantamount to an uncrewed helicopter by design, with one large rotor and a small tail rotor for stability. They offer longer flight times and can carry heavier payloads compared to multirotors, but are more challenging to control. They have ranges of 16–32 kilometers for high-end commercial models and a battery life of one to three hours, which offers longer flight times compared to multirotor models due to their aerodynamic design and efficient use of power. The Vapor 55MX is an indicative example of what a higher-end single-rotor drone can deliver, with a 32-kilometer range, 75-minute battery life, and up to 10.9-kilogram usable payload.[20]

Hybrid vertical take-off and landing drones (VTOL) are a combination of multirotor and fixed-wing capabilities, used for long-range delivery services, mapping, and industrial inspections, but also for recreational enthusiasts who want both the versatility of multirotors and the endurance of fixed-wing drones. They have a range of 16–160 kilometers and a battery life of one to four hours, efficient for longer-range missions, and often used for industrial and commercial purposes, like delivery or surveillance. Again, when it comes to the military application of these technologies, we have seen a greater payload and range. For instance, the so-called S-76 being developed in Russia is a hybrid VTOL system with a reported 300-kilogram payload that can be used to transport supplies to hard-to-reach locations, such as bases in the militarized Russian Arctic, and replace vulnerable crewed helicopters in the region.[21] This drone is said to have a 1,000-kilometer range; although it is currently billed as “commercial,” the Russian military and defense companies have been experimenting with VTOL technologies like this for over a decade as they are ideal for military logistics and transportation.[22]

Finally, in addition to these categories of drone hardware, it's important to add the crosscutting element of First-Person View (FPV) drones, which are controlled by a pilot with a Virtual Reality (VR) or Augmented Reality (AR) headset/glasses or FPV Goggles. FPV drones can technically be any of the above types of drones, just so long as they are controlled by a FPV headset wearing pilot who can guide the drone through a feed to the camera and sensors onboard. In practice, however, FPV drones are often quadcopters adapted for speed and agility and are commercially used for drone racing and competitive events. They are typically lightweight and have fast acceleration but are limited in range. These drones fly less than 1 kilometer and have a battery life of 5–10 minutes. They are built for speed and maneuverability rather than endurance, so they have short flight times but quick charge cycles. According to the Drone Racing League (DRL) and the Guinness Book of World Records, the fastest drone in the world is a small FPV racing drone called the RacerX. This drone was able to achieve an average speed of 165.2 mph, with a top speed of 179.78 mph.[23] It was handmade in New York City out of 3D-printed thermoplastic polyurethane, carbon fiber, copper wire, and fasteners, highlighting the innovations taking place in civilian drone development. With this in mind, what is interesting to note here is how the fastest drone in the world has been created by civilians for civilian use and produced out of easy-to-access materials. This is important because the use of such drones in war is becoming increasingly prevalent exactly because of the low barrier to entry. Although explored in more detail in Chapter 6, such drones are now "by far the most prevalent type of drone on the Ukrainian battlefield," becoming the preferred platform for hunting down other FPV drone pilots, "mounting explosives and executing targeted strikes."[24]

How do drones work?

Regardless of the type of drone, the key feature (as it is for other aircraft) is the ability to achieve and sustain flight. It's safe to say the most popular and populus drones today are the multirotors, like the quadcopter, hexacopter, and octocopter class of drones mentioned above (see *What are the different types of drone platforms?).* The drone's movement is controlled by varying the speed of these rotors. To move forward, backward, or side-to-side, the drone adjusts the speed of individual rotors. For example, to move forward, the rear rotors spin faster, generating more lift at the back of the drone and causing it to tilt forward. This tilt results in forward thrust. Similarly, changing the relative speeds of the rotors can cause the drone to yaw (rotate), pitch (tilt up or down), or roll (tilt side-to-side).

In fixed-wing drones, such as those used for long-range surveillance or military missions, the drone operates more like an airplane. It has a single wing that generates lift, and a rear-mounted piston-driven propeller or jet engine that provides forward thrust. As the discussion of drone definitions highlighted (see *What is a Drone?*), fixed-wing drones are generally more efficient over long distances but lack the ability to hover in place like multirotor drones.

Drones are typically controlled through a ground control system (GCS), which communicates with the drone via a radio link, allowing the operator to send commands and receive data from the drone. However, as the Switchblade highlighted, many modern drones are capable of autonomous operation (using onboard computers) and pre-programmed flight paths to carry out missions with little to no human input. In these cases, a combination of Global Positioning System (GPS) and inertial measurement units (IMUs) enable the drone to know its exact location and orientation in space.

GPS receivers allow the drone to pinpoint its exact position using signals from satellites. These systems are vital for autonomous flight, as they enable drones to follow precise flight paths or return to a specific location (such as to the operator or launch point) if communication is lost. The IMU combines accelerometers and gyroscopes to measure the drone's acceleration, tilt, and rotation, helping it maintain stable flight. When GPS signals are weak or unavailable (e.g., in indoor, urban, or hostile environments), the IMU helps the drone stabilize and navigate based on sensor data.

Drones require real-time communication to be remotely controlled, which is typically achieved through radio-frequency (RF) communication between the operator’s controller and the drone. For military and commercial applications, satellite communications (SATCOM) are often used to control drones over long distances. The communication system transmits—from the ground control station—commands to the drone, such as changing altitude or adjusting course, and relays data back to the operator, including telemetry data, battery status, and live video feed.

FPV technology allows the user—both recreational or professional—to see the drone’s perspective in real time through a camera feed—through their AR, VR, or FPV Goggle headset—revolutionizing the experience for both recreational and professional drone use. In some cases, 5G technology is built in to enable faster data transmission, lower latency, and increased bandwidth, which is particularly useful for drones that perform tasks like high-resolution video streaming, environmental monitoring, or real-time object tracking.

Most consumer and many commercial drones are powered by lithium-polymer (LiPo) batteries, providing a balance between energy density and weight. The power demands of drones are significant, with the motors, navigation systems, cameras, and communication systems all drawing power. Balancing an aircraft’s weight involves carefully distributing its mass so that it remains stable, controllable, and aerodynamically efficient. However, this process involves trade-offs, where improving one aspect may negatively impact another.

As this discussion suggests, the battery life of a drone is one of its biggest operational limitations. A typical small recreational drone may have a flight time of 15–30 minutes, while more advanced commercial drones, like those used in agriculture or inspections, can last up to 45–60 minutes. Military-grade drones with larger power systems, such as fuel-powered or hybrid drones, can fly for hours or even days, depending on their mission profile. Some developers are considering power sources such as solar panels for high-altitude, long-endurance drones, and hydrogen fuel cells, which offer greater energy efficiency than traditional batteries.[25] However, these technologies are mostly in the development or specialized-use phase.

One of the most critical aspects of drones is the array of sensors they carry. These sensors are responsible for everything from basic flight control to sophisticated data collection. The types of sensors a drone uses can vary dramatically depending on its intended application. Most drones, from hobbyist to professional ones, carry cameras as their primary sensor. These can range from basic HD cameras to thermal imaging or hyperspectral cameras for more advanced applications. Light detection and ranging (LiDAR) sensors measure distance by illuminating the target with laser light and measuring the reflection. This technology is commonly used for mapping terrain or creating 3D models of structures. Infrared sensors are often used in search-and-rescue operations or military applications for detecting heat signatures. Environmental sensors can measure air quality, temperature, humidity, or radiation levels, often used in scientific research, industrial inspections, or disaster/crisis monitoring.

The most advanced drones use artificial intelligence (AI) and machine learning to navigate, identify objects, and even make decisions in real time. For example, AI enables drones to avoid obstacles autonomously, track moving objects like vehicles or people, perform complex tasks like package deliveries, or crop monitoring without human intervention. This fusion of AI with drone technology is rapidly expanding the capabilities of drones in both civilian and military sectors (see Chapter 7).

What is the overall size of the drone market?

The global drone market, encompassing both commercial and military sectors, has seen rapid growth in recent years. The overall global drone market, based on 2023 estimates, is about $30 billion. This is projected to grow to nearly $90 billion by 2033, at a compound annual growth rate of about 10 percent from 2023 to 2033.[26] Much of that growth is commercial, estimated at $20 billion–$25 billion in 2023 and expected to grow to around $54 billion by 2028 due to increasing use in several areas: agriculture (precision farming and crop spraying); infrastructure inspection (power lines and oil rigs); surveying, mapping, and construction; film and media (cinematography and photography); and delivery services (logistics and medical supply).[27] As of August 2024, there were over 390,000 commercial drones and over 388,000 recreational drones registered in the United States alone, with over 406,000 remote pilots certified with the FAA.[28] This market is projected to almost double in the years to come.

The military drone market is estimated at $14 billion–$16 billion, with a projected growth to $23 billion by the early 2030s.[29] The key drivers are increasing defense budgets worldwide (particularly in the United States, China, the EU, and Israel), the rising adoption of drones for surveillance, reconnaissance, combat, and logistics, as well as advancements in drone swarming technology, AI-powered drones, and counter-UAV systems. Although Israel helped initiate and deploy many of the unmanned military technologies in the 1980s, it was the United States that represented more than half of the world's research, development, and procurement through the 1990s and into the first decade of the twenty-first century.[30] This is likely to remain the case into the near future. The Teal Group predicts that the United States will be responsible for 81 percent of worldwide military research, development, test, & evaluation (RDT&E) spending and 59 percent of military procurement through the 2030s.[31] While the key driver of this spending has historically been the wars in Iraq, Afghanistan, "and other countries where terrorist groups were or are active," it has become the rise of China and a resurgent Russia that drive the US investment in drones.[32] This dominance is projected to change in the longer term as the rest of the world increases its spending, but the United States,—in particular the US military,— represents a useful starting point in terms of understanding the drone market.[33] For example, the Pentagon's $1 billion Replicator Initiative seeks to "field thousands of autonomous systems across multiple warfighting domains" as a means to keep pace with Chinese technological development, deter aggression, and learn lessons from Russia's offensive war against Ukraine.[34]

Which countries manufacture and export drones?

A record number of countries are producing and exporting drones, with the market for both commercial and military drones rapidly expanding. Countries involved in drone production and export can be categorized based on factors such as market share, number of exports, number of importing countries, or leaders in drone innovation. The United States has historically dominated the high-end military drone market, especially with combat drones like the MQ-9 Reaper, which it has traditionally restricted to close NATO allies. In the commercial sector, American companies like Skydio are emerging, but they lag behind Chinese firms.

One company, China's Da-Jiang Innovations (DJI), holds over 70 percent of the global commercial drone market, dominating consumer and small commercial drone segments.[35] China is also increasing its military drone market share, with more than 17 exporting countries, particularly in the Middle East and Africa. For example, its Wing Loong and CH series are widely exported to countries such as Pakistan, Saudi Arabia, Iraq, Egypt, and Algeria.[36]

Turkey has rapidly grown in the military drone sector, particularly with its Bayraktar TB2 drones, which have been prominent in recent conflicts. Turkey has exported the TB2 to over 24 countries (including Ukraine, Azerbaijan, Poland, and Qatar), and its export numbers continue to grow due to its relatively low cost and battlefield effectiveness.[37] Israel, however, has historically been the largest exporter of military drones by number of importing countries, selling to over 50 countries, including India, Brazil, Germany, and the United Kingdom, along with many others in Africa and South America.[38]

Iran also has a burgeoning drone manufacturing and export business. Its drones are primarily low-cost and designed for asymmetric warfare. Their focus is not on high-end combat drones but on more affordable models, like the Shahed series, which is made up of the long-range loitering OWA drones that can travel over 2,000 kilometers and are often flown in multiples to saturate enemy targets.[39] The Shaheds have been exported primarily to Russia and nonstate actors like the Houthis and the broader "Axis of Resistance," a deceptively large markets given the amount of drones these actors deploy due to the ongoing conflicts they are involved in. This market may expand further with reports of new international drone agreements under discussion between Iran, Bolivia and Venezuela.[40]

Indeed, China, Turkey, and Iran are three of the fastest-growing armed drone exporters, a fact that is supported by the latest data on arms sales. According to the SIPRI Arms Transfer Database, China delivered 301 armed drones to countries such as the United Arab Emirates, Saudi Arabia, Egypt, and Pakistan from 2008 to 2023. The Turkish drone industry is on an even more dramatic upswing, delivering 208 armed UAVs from 2019 to 2023, of which drones to Ukraine account for over 34 percent of exports.[41] Iran's strike on Israel using an estimated 170 suicide drones (2024) was one of the largest drone strikes in history and brought increased attention to Iran's drone industry.[42] SIPRI finds that the bulk of Iran's drone exports are going to Russia with an estimated 1,200 being delivered in 2022.[43] Additionally, Iran was reported to be providing technical assistance for the construction of a Russian factory which aims to produce 6,000 OWA drones by the summer of 2025.[44] By March 2024, Russia had deployed approximately 4,400 Iranian designed suicide drones in Ukraine.[45] Iran has also reportedly sold small quantities of armed drones to Sudan and Ethiopia (at least two visually confirmed by open-source satellite intelligence).[46] As mentioned, Iran's exports are not limited to countries. An assessment done in 2022 by Scott Berrier, director of the Defense Intelligence Agency, detailed the use of Iranian drones by nonstate actors such as militia groups in Iraq, Hezbollah in Lebanon, militias in Syria, and the Houthis in

Yemen.[47] From 2015 to 2023, the United States and its allies were able to intercept 18 shipments, including at least three types of armed drones enroute to the Houthis.[48] Utilizing this technology, from 2015 to 2022, the Houthis carried out over 350 drone attacks.[49]

The exact quantity of drones and drone parts exported by Iran is difficult to ascertain as Iran often denies allegations of sales and attempts to smuggle drones into countries, but intelligence gathered from the hacking of Iranian systems revealed that the sale of drones to Russia alone amounted to approximately $1.8 billion.[50] Although actors such as the Houthis or Hezbollah claim to have indigenously produced drones, they are often nearly identical to Iranian drones and are either supplied directly from Iran or copied from Iranian designs locally.[51] In the very near future, it is important to note that Russia and Ukraine are likely to take a more prominent place in this league table of drone exporting nations, largely due to their respective investment in their own drone industrial base in response to the Russia-Ukraine War. Ukraine is especially seen as a leading innovator in both offensive drone systems and counter drone capabilities and have reportedly deployed military drones in both Sudan and Syria.[52] In fact, Ukraine produced over one million drones in 2024 and was set to produce 4.5 million in 2025 at a cost of $2.6 billion.[53]

Overall, it is clear to see how the drone landscape has changed since the first volume of this book was published a decade ago (2016). Back then, 60 nations were working on acquiring military drones and had an active drone program.[54] Today, 118 nation-states possess a varied assortment of military drones, an increase of 96.7 percent in a decade.[55] In addition, at least 65 nonstate actor groups now have access to these systems, with the truth being that anyone who wants a drone (for hobbyist, commercial, or nefarious means) is now able to procure one. It is this history, evolution, and proliferation of drone technologies (and drone warfare) that we now explore in Chapter 2 and Chapter 3.

2
MILITARY DRONES
A HISTORY

In January 2020, the Trump administration approved the targeted killing of General Qasem Soleimani, Iran's most powerful military leader. As the head of Quds Force, the elite unit of the Iranian Revolutionary Guard Corps, Soleimani had been responsible for the death and injury of American and coalition forces and the supply of weapons (including drones) to violent nonstate actors across the Middle East.[1] According to the US Department of Defense, Soleimani was also actively developing additional plans to "attack American diplomats and service members in Iraq and throughout the region."[2] The strike itself was swift and effective; a US MQ-9 Reaper drone delivered a precision missile onto Soleimani's convoy as it drove from Baghdad's international airport in Iraq. The explosion killed 10 people, including Soleimani and Abu Mahdi al-Muhandis, deputy commander within the Popular Mobilization Forces, a prominent group of Iraqi militias.[3]

For President Trump, this drone strike was necessary because Soleimani was "the number-one terrorist anywhere in the world."[4] For others, it raised worrying questions about just how expansive and uncontrolled the US deployment of drones had become. While UN Secretary General António Guterres expressed deep concern and worry about the drone strike triggering "another war in the Gulf," Agnes Callamard (UN Special Rapporteur on extrajudicial, summary, or arbitrary executions) concluded that the strike was a violation of international law.[5] This legal judgment was, in part, based on the fact that the Trump administration had, in choosing its course of action, targeted Soleimani in a third-party country (Iraq), without the permission of that country. In doing so, they violated the sovereignty of a nation-state and undermined international law.[6] As Callamard explained, "[t]he targeted killing of Mr Soleimani completely swept away the standard related to extraterritorial use of force by a state."[7] The concern here was that norms had been eroded and the region destabilized.

Since then, the Middle East has experienced ever-increasing conflict, with US troops deployed to the region in greater number.[8] In addition, Iran has doubled down on its supply of weapons (especially drones) to its "Axis of Resistance" across the Middle East, with these drones used against international shipping, the civilian centers of major cities, critical infrastructure, industrial hubs, and even US military bases and diplomatic sites. Infamously, this wave of attacks culminated in the killing of three US military personnel by an enemy drone strike in January 2024, the first such deaths by hostile enemy airpower since 1953, during the Korean War.[9]

As such, it is evident how the 2020s opened as a decade defined by drones. Since the beginning of this decade, the use of drones in war, and the array of drone technologies deployed, has only grown. We need only look at the growing drone war in the Middle East and at the war-defining use of drones in Ukraine for pertinent examples of how drones are altering the character of modern conflict. With these pivotal events in mind, this chapter tracks the long history of military drones, documenting how today's drone-dominated world has emerged.

What is the historical genealogy of military drones?

Identifying the first appearance of drones in warfare depends on the definition of drone being used—which, as the previous discussion in

Chapter 1 (*Defining Drones*) suggests, can present a vexing question. If one considers a drone simply to be a remotely controlled aerial vehicle, then one could say that the first balloons adapted for use in battle were drones. Indeed, using this definition (which would require some conceptual stretching), "drones" were used for the first time in 1849, when Austria attacked Venice with nearly 200 explosive-laden unmanned hot air balloons.[10] Once the balloons were over Venice, the explosives were detonated remotely "by means of a long isolated copper wire with a large galvanic battery" that trailed behind the balloons to a control point on the shore.[11] While the Austrian attack may well have been an early inspiration for the use of drones in war, the operation was far from a glowing success: some of the balloons were blown back over Austrian lines. Moreover, although these vehicles were remotely detonated, they were not completely remotely controlled, instead reliant on the wind for direction.

World War I saw the testing and development of another set of uncrewed aerial vehicles. One example, developed by Orville Wright and Charles Kettering, was known as the "Bug" or the "Kettering Bug." This was a fixed-wing system with a propeller and explosives, and it looked a lot like you would expect an ancestor of a modern drone would look like. Although none were actually deployed in combat before the war ended due to their lack of reliability, the Bug marked the first American experimentation with armed uncrewed military technologies. It was a 12-foot-long wooden biplane, with a 14-foot wingspan, and it weighed 530 pounds (including its 180-pound bomb).[12] To "program" the Kettering Bug to fly the right distance, operators had to account for wind speed and direction, and then calculate the correct number of engine revolutions required; then, the vehicle would act as an aerial torpedo and strike a target at a set distance and trajectory.[13] The Dayton-Wright Airplane Company built around 50 of the unmanned vehicles, though this system acted more as the One Way Attack (OWA) drones or missiles discussed in Chapter 1, rather than what we would think of as the two-way Predator or Reaper. It is for this reason that today there is debate over whether the Bug is truly an early drone or more of a precursor to a modern cruise missile.

Between World War I and World War II, the United Kingdom and the United States both developed a series of radio-controlled drones which they used primarily as aerial targets on which their pilots could practice. In the 1930s, the Royal Air Force began developing the de Havilland Tiger Moth, a manned biplane used to train pilots. The principles of aircraft design and aerodynamics learned from developing and operating aircraft like the Tiger Moth informed the design of the de Havilland DH.82B, modified for radio control. The aircraft was called the "Queen Bee," and is thought to be the namesake for the term "drone" used to describe unmanned systems today. As such, this was arguably the true first drone. The aircraft was launched from a catapult pad on an airfield (or from floats to be used at sea) and was remote-controlled, flying as many as 300 miles at about 17,000 feet and providing target practice for anti-aircraft gunnery training.[14] The aircraft could be either manned or unmanned, which allowed for flexibility in training scenarios. When unmanned, it was controlled by radio signals from a ground station or chase aircraft, constituting one of the first successful radio-controlled aircraft and setting the stage for future developments in unmanned aerial vehicles (UAVs).[15]

Around the same time, Reginald Denny, an actor and former member of the British Royal Flying Corps, formed a model-plane shop that eventually became the Radioplane Company—and was acquired by Northrop Grumman.[16] The Radioplane Company developed inexpensive radio-controlled aircraft that could be used for training anti-aircraft gunners, similar to the purpose of the Queen Bee. The company's most popular aircraft was the OQ-3 target drone, with over 9,000 manufactured for the US Army during World War II. It is this aircraft that Norma Jeane, who later became known as Marilyn Monroe, helped assemble during the war. She was spotted by an Army photographer David Conover in June 1945, photographed, and, as a veteran of drone-building in World War II, became a model soon after the war's end and ultimately a global superstar.[17]

During World War II, both Germany and the United States also began developing more sophisticated unmanned platforms. At the beginning of the war, Adolf Hitler commissioned a project to develop an unmanned vehicle for use in combat, which resulted in the V-1 rocket. Again, although more like an early cruise missile than drone, the V-1 had a range of approximately 150 miles, permitting the Germans to use launch sites in France to hit targets across the Channel.[18] The weapon resulted in 5,475 deaths, with 16,000 injured, in London alone during World War II.[19] To counter German V-weapons, especially the V-3 super gun, the US Navy developed their own drones that were able to destroy launch sites. These drones were B-17 Flying Fortress bombers or B-24 Liberator bombers that had been cleared of all unnecessary equipment and packed with a powerful Torpex explosive. The "drone" took off with a two-person crew that would bail after setting a course for the target. The vehicles were then flown by remote control from a mothership tailing further behind and directed into their target. One such pilot on these missions was Joe Kennedy Jr., the older brother of the future president John F. Kennedy. As a fellow officer described, Kennedy flew "a 'drone' Liberator bomber loaded with 21,170 pounds of high explosives into the air," the plan was to stay "with it until two 'mother' planes had achieved complete radio control over the drone. They were then to bail out over England; the 'drone,' under the control of the mother planes, was to proceed on the mission which was to culminate in a crash-dive on the target."[20] On this occasion, however, Kennedy and his co-pilot would lose their lives as the drone exploded prematurely over the English coast. As one eyewitness described, the explosion was like a "gigantic octopus" in the sky with tentacles of smoke billowing down.[21]

In the postwar period, the United States focused on the target-drone business, developing a series of Firebee aircraft that could be launched from the air or the ground. The subsequent generations of Firebees made slight modifications on this principle until the contractor produced a reconnaissance version, called the Lightning Bug, which was used extensively in Vietnam.[22] Toward the end of the Vietnam War, the United States transferred a number of Lightning Bugs, along with cheaper Chukar target drones, to Israel.[23] At this time Israel was facing challenges from Soviet SA-2 surface-to-air missile systems that had been purchased by Egypt. Drones were considered as a way to identify where these air defense systems were and to also act as a decoy against them. This is exactly how the drones were used during the 1973 Yom Kippur War, "this time as part of a deliberate, phased attack plan designed to suppress missile defenses."[24] Along with some knowledge transfer with the West Germans on UAV technologies, and Israel's own engineering of the Tadiran Mastiff and the IAI Scout, these drones were part of a new age of Israeli interest in drones during the 1970s.[25] In fact, it was during this period that Israel began to expand its own drone industry, becoming a leader in drone innovation by the 1980s—especially during the invasion of Lebanon in 1982, where the drones were used to monitor troop movements. As drone expert Chris Cole puts it, the more contemporary drones we see today were "the offspring not of the American initiatives of the 1960s but of the Israeli initiatives of the 1980s."[26] During this time, Israel began building several surveillance drones—including influential systems that were sold to the United States—leading the nation to become one of the world's largest drone producers.

The RQ-2A Pioneer was an unarmed surveillance drone designed by Israeli Aircraft Industries, in cooperation with the US aerospace and defense company AAI Corp. This drone was acquired by the US military for "a wide variety of reconnaissance, surveillance, target acquisition and battle damage assessment missions" and used widely by the US Navy in Grenada, Lebanon, Libya, and the 1991 Gulf War, helping to spot Saddam Hussein's troop movements and direct cruise missile strikes.[27] Around this time, Israeli engineer Abraham Karem—known as the founding father of modern military drones (or the "DroneFather")—developed the Gnat-750. This drone was revolutionary in terms of its long endurance, tactical surveillance, and support capacity. Indeed, it could fly up to 48 hours without landing for fuel—a true innovation in drone technology.[28] It would not be long before Karem sold the drone to General Atomics, who used the design as the archetype for its Predator drone, variants of which are in service today and have gone on to become one of the most impactful weapons in modern warfare.

Although Karem has been reluctant to take credit for the legacy of his invention, stating that he was "not the guy who put missiles on the

Predator," it is safe to say it was the Gnat that spawned America's most widely used and feared military drone.[29] Initially, the United States deployed a modified Gnat-750 for surveillance in the early 1990s in Yugoslavia, yet this was soon followed by the newer Predator during the conflict in Bosnia and Kosovo. The Predator was unarmed at this point, like the Gnat, but improved upon the Gnat-750 with more accurate targeting technology using advanced sensors.

Like previous drones, the Predator remained unarmed through the mid-1990s. The US Air Force discussed the possibility of arming the aircraft and investigated whether or not an armed Predator would be compliant with the Intermediate-Range Nuclear Forces (INF) Treaty. This treaty bans warheads from a "self-propelled vehicle that sustains flight through the use of aerodynamic lift over most of its flight," specifically "a ground-launched cruise missile that is a weapon-delivery vehicle."[30] In their legal deliberations, the US Air Force, in consultation with the State Department, determined that an armed drone was outside this ban and that an armed drone would not violate the treaty.[31] Nonetheless, while General Atomics had equipped a Predator with a Hellfire missile and successfully fired it during a practice flight in February 2001, the decision to field armed Predators had languished until the 9/11 attacks. As Michael Hasting has argued, "it was the War on Terror that finally enabled the military to weaponize drones, giving them the capability to take out designated targets."[32] This is a topic to which we will return later in this volume; needless to say, armed drones became a way to hunt and kill suspected terrorists, but without additional risk to American personnel. The model of warfare was clearly appealing and, in the years that followed, the technology would diffuse both to state actors (with the capacity to develop or acquire them) and nonstate actors (through state sponsorship or commercial supply chains). Today, the global drone arsenal is a varied assortment of evolving and adaptable unmanned systems. In order to better explain these drones, and visualize how they are used, we now pause the overview of the history to review the different approaches to the technical categorizations of drones.

How can military drones be classified?

What all drones have in common is that they are all unmanned remotely or autonomously piloted systems that can loiter over targets. Beyond those similarities, differences are vast. Drones vary enormously in terms of control, size, capability, and range. Some are semiautonomous, meaning they rely on a human in some fashion—even if it is to monitor their actions without direct "hands on the wheel" control. Others are autonomous, in which case the drone is controlled based upon the determinates of a preprogrammed algorithmic "brain," often aided by machine vision. Although built by a human to begin with, the drone's "brain" is an artificial intelligence capable of making decisions in reaction to external stimuli. Some are armed and can identify targets; others are used for intelligence, surveillance, reconnaissance, or logistics. Some are piloted upon launch; others can take off and land by themselves. Given the large range of aircraft that can plausibly fit under the heading of "drone," and their variations in control, it is not surprising that there are many ways to categorize them.

When it comes to how a drone is controlled, a simple categorization refers to when a human is "in the loop" (meaning a pilot is in real-time remote control of the system); "on the loop" (meaning a pilot is monitoring the drone's actions, and likely the actions of multiple drones at once, only to intervene when required); and "outside the loop" (meaning the drone is fully autonomous and left to go about its AI-powered duties). In the case of operating outside the loop, a human might take control, or check on the drone's actions—or they might not. Outside the loop control functions are not yet widespread in war, but such a prospect concerns policymakers and human rights defenders alike due to the possibility of unaccountable machines taking human life without a human inside the real time decision-making process.

Drones can also be categorized by capacity—an aggregation of dimensions such as altitude, range, and endurance—which tends to correlate with the type of mission or operation that the drone could carry out. These categories, drawn from the Government Accountability Office report on drone proliferation, are comprised of mini, tactical, and strategic drones (see Table 2.1).[33]

Table 2.1 Categories of Military Drones

Category	Mini	Tactical	Strategic
Altitude	Low	Low to medium	Medium to high
Endurance	Short	Medium	Long
Range	Close-range	Line-of-sight (300 km or less)	Long-range
Example	Raven	Shadow	Global Hawk

Source: Government Accountability Office.

Although such categories often fail to take into account some of the latest technological advancements and can draw too firm a line between drone classifications, they are broadly useful in helping us to see the different layers of drone use in war.

"Mini-drones" are designed for quick deployment and easy mobility, making them ideal for reconnaissance, surveillance, target acquisition, and rapid precision strike. Beyond the quadcopters detailed in Chapter 1 that can be used for kinetic strikes, these mini-drones include the Raven, which was up until recently "the most widely deployed unmanned aircraft system in the world."[34] These small fixed wing systems have a 1.3 meter wingspan, weigh 2 kilograms, are launched by hand, powered by an electric motor, and have the capability to be operated remotely or operated autonomously using Global Positioning System (GPS) navigation. Because they do not require elaborate support systems, mini-drones are ideal for rapidly supporting forward-deployed units within the military, especially infantry or Special Operations Forces (SOF).

Tactical drones are designed for reconnaissance, battle damage assessment, surveillance, target acquisition and coordinated strike; they are often launched from a pneumatic catapult and recovered with equipment meant to decelerate the drone as it lands (such as crash nets). One of the most common examples of the tactical drone in the 2010s was the RQ7B Shadow Tactical Unmanned Aircraft System (TUAS), a 212 kilogram drone with a 6.2 meter wingspan that the US military had planned to weaponize contingent on having sufficient funds.[35] These tactical drones were weaponized by both Ukraine and Russia during the war that started in 2022 (ongoing at the time of writing), showing how this category has endured over time.

Strategic drones are used for many of the same purposes as tactical drones but are able to fly higher, farther, and for longer periods of time. Strategic drones include the Global Hawk and Altair—the latter is used primarily by the National Aeronautics and Space Administration (NASA)—but also the MQ-9 Reaper, the Predator B's successor, which has a large number of functions including reconnaissance, surveillance, weapons delivery, and targeting. It can fly for over 30 hours without refueling (contingent on being unarmed, which reduces the payload and increases the flying time). Most recently, this has been surpassed by the newer MQ-9B SkyGuardian, which can fly for over 40 hours.[36]

Yet this is not the only way to classify drones above the battlefield. The RAND Corporation has a different typology, classifying drones into four categories based on a two-by-two matrix describing whether the technology is long- or short-range or high- and low-technology: (1) long-range, high-technology—such as the Predator or Reaper; (2) long-range, low-technology—such as the Iranian Ababil; (3) short-range, high-technology—such as the Raven; and (4) short-range, low-technology—such as model airplanes or potentially cheaper quadcopters.[37]

Yet another way to think of the differences across drones would be based on function. The typologies and categories we have just listed tend to group nonlethal and lethal drones together; for example, the Global Hawk and Reaper would both be considered strategic or Category I drones under the RAND typology. Treating these two types of drones in the same category is potentially misguided considering the distinctly different uses of each: the Global Hawk is used for reconnaissance and the Reaper for directly striking suspected terrorists. A classification that would address the wide range of distinct applications might instead consider drones used in the service of surveillance and reconnaissance (not directly lethal) and those that are equipped with weapons and used directly for lethal purposes, while also taking into account range. Other typologies have built on this distinction between lethal and nonlethal drones, classifying drones into three groups: (1) tactical drones that are smaller-scale drones—such has the Raven and Shadow; (2) advanced, unarmed drones—such as the Global Hawk; and (3) advanced, armed drones—such as the Predator and Reaper.[38] Still, in today's modern drone world where drones of all sizes are increasingly modular by design – meaning they can be armed or unarmed depending on the desired function of the end user – it is increasingly difficult to apply or obtain much functional use from such an approach to drone classification.

The Center for the Study of the Drone used a classification system that drew upon the NATO Standardization Agreement 4760, which was created to train drone operators. NATO's classification of drones is divided into Class I, Class II, and Class III, an approach that is similar to the Federal Aviation Administration, International Civil Aviation Organization, and the European Union Aviation Safety Agency, which divide models based on endurance, range, payload capacity, and types of missions (see Table 2.2).

Table 2.2 Classification of Drones Based on NATO Standards

	Class I	**Class II**	**Class III**
Endurance	1–3 hours	10 hours	24 hours
Max Range	≅ 80 km	100–200 km	> Several thousand km
Payload Cap	5 kg	< 70 kg	Several hundred kg
Top Speed	62 mph	125 mph	> 300 kph
Launch Type	Hand & pneumatic rail	Runways	Runways
Wing Type	Fixed & rotary wing	Fixed & rotary wing	Fixed & rotary wing

Source: NATO JAPCC. (2022). "A Comprehensive Approach to Countering Unmanned Aircraft Systems." Retrieved from https://www.japcc.org/wp-content/uploads/A-Comprehensive-Approach-to-Countering-Unmanned-Aircraft-Systems.pdf

	Class I	Class II	Class III
Mission Type	Reconnaissance and surveillance	Tactical missions, reconnaissance, and surveillance	Mostly for intelligence gathering and armed attack missions
Arms Capabilities	No, but loitering munitions count	Usually unarmed but can be equipped with lightweight ordinance	Capable of carrying weapons
Extra Features	Electro-optical and infrared sensors	Electro-optical and infrared sensors, laser designators or illuminators, communications equipment	Electro-optical and infrared sensors, laser designators or illuminators, communications equipment
Notes	The NATO definition of Class I includes three sub-categories—Micro, Mini, and Small—but they are all combined as Class I for this index.	Known as "tactical" drones in NATO classification guideline	The NATO definition of Class III includes three sub-categories—"medium-altitude long-endurance" (MALE), "high-altitude long-endurance" (HALE), and strike/combat—but they are all combined as Class III for this index.
Example	Mavic III, RQ-11 Raven, Puma 3 AE	RQ-7 Shadow, Lancet, Bayraktar TB2, Hermes 450	MQ-9 Reaper, RQ-4 Global Hawk, Wing Loong III

Source: NATO JAPCC. (2022). "A Comprehensive Approach to Countering Unmanned Aircraft Systems." Retrieved from https://www.japcc.org/wp-content/uploads/A-Comprehensive-Approach-to-Countering-Unmanned-Aircraft-Systems.pdf

As Table 2.2 makes clear, Class I covers small, lightweight systems such as the Black Hornet Nano and DJI Mavic, typically operating below 150 meters with an endurance of under two hours — ideal for close-range reconnaissance and infantry support. Class II includes tactical drones like the RQ-7 Shadow and Hermes 450, operating below 3,000 meters with endurance between two and ten hours, providing battlefield surveillance and target acquisition. Class III encompasses larger, strategic systems such as the MQ-9 Reaper (MALE) and RQ-4 Global Hawk (HALE), capable of persistent ISR and strike missions at altitudes exceeding 3,000 meters and for durations over 24 hours. This classification remains a useful tool for NATO in managing airspace, assigning operational responsibilities, and supporting interoperability across allied forces. However, it is increasingly challenged by technological developments, including drones that defy traditional altitude and endurance boundaries, the proliferation of loitering munitions, and the operational integration of autonomous swarms. As these systems blur the lines between categories, NATO will need to adapt its framework to remain operationally relevant in future conflict environments.

As such, there is still work to be done on the accurate categorization of drones; a difficult and likely never-ending task due to the pace of drone innovation. Nevertheless, by reviewing the different approaches to classification, and their drawbacks, we can better understand the different types of drones out there today and the work still to be done to fully map and comprehend the drone landscape.

When did nation-states start using drone strikes and for what purposes?

We now return to the use of drones after the 9/11 attacks and pick up our journey through drone history. The United States ushered in the prolific use of drones when it deployed the MQ-1 Predator to Afghanistan almost immediately after the 9/11 attacks. The first attack was on October 7, 2001; by November, the Central Intelligence Agency (CIA) had conducted about 40 Hellfire missile strikes in Afghanistan. In comparison to the number of airstrikes by manned platforms, which numbered 6,500 in the first three months of the war, the reliance on drone strikes was still minimal. Nevertheless, the scope of operations soon expanded to places other than Afghanistan. In 2002, the first drone strike outside an active combat zone occurred in Yemen. The CIA used a Predator to target Ali Qaed Senyan Al-Harthi, who was linked to the bombing of the USS *Cole* in 2000, as well as six individuals suspected of being al-Qaeda affiliates.

What followed was a roughly two-year pause in counterterrorism drone strikes outside active warzones, in part because military assets were refocused on the new war in Iraq (2003). In 2004, however, the United States expanded these strikes into Pakistan, conducting the first strike of this kind against a suspected al-Qaeda facilitator Nek Muhammad and four other suspected militants. The strike began a long and sharp increase of drone strikes in Pakistan, especially when Bush left office and President Obama came to power in 2009. While the United States conducted 52 strikes in total between 2001 and 2008, it conducted at least 300 in Pakistan alone during the following four years (2009–2012). This was a steep escalation, so severe that it made the United States the largest and most active drone power in the world.[39] So reliant was Obama on drones during this period, that he would become known as the 'Drone President' for his advocacy of the weapons. Drones were often presented positively by the administration and lauded for their success. As such, it was not long before allies were keen to follow suit. Specifically, it was the British, in support of the United States and with US drone technologies, who launched their own attacks. These strikes grew in scale accounting for about one-fifth of all drone strikes in Afghanistan by 2012.[40] Put simply, although slow at first, the use of drones in the decade after the 9/11 terrorist attacks began to reveal the transformative character of armed drones.The Obama Administration has since been defined by this greatly expanded US drone program, especially in terms of its controversies. While the United States did not report many details of its strikes—and generally did not acknowledge them at all until the later years of the second Obama administration—advocacy groups spent considerable resources trying to uncover the details and impact of the drone program. The Bureau of Investigative Journalism (TBIJ), Reprieve, the New America Foundation (NAM), *The Long War Journal*, and later AirWars, all collected data on the number of strikes; Amnesty International, Human Rights Watch, and Stanford/NYU Law added case-specific details to these data, conducting on-site interviews in communities impacted by drone strikes. The reporting that these organizations undertook was illuminating, offering credible sources of information on US drone strikes, especially those in non-active battlefield zones. This was far from easy with many of the strikes, even those conducted by the US Air Force, operationally under the command of the CIA and thus harder to analyze due to increased secrecy. Nevertheless, as Figure 2.1 shows, drawing on data from TBIJ, many of the strikes we know about took place in Pakistan, with over 120 strikes in 2010, but dozens of others took place in Somalia and hundreds more in Yemen over the decade. As drone expert Micah Zenko stated when reflecting on the 500th non-battlefield-targeted killing in November 2014, the "tactic, once intended to be rare, [had] become completely routine."[41] With the data and reports now in the public domain, questions began to be asked about the morality, ethics, effectiveness, and legality of the rapidly expanding use of drones.

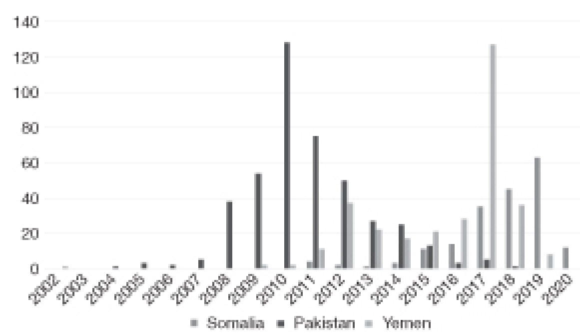

Figure 2.1 Estimates of the Number of American Counterterrorism Strikes by Target Country (2002–2020)

Source: Bureau of Investigative Journalism. Data at https://www.thebureauinvestigates.com/projects/drone-war

Despite claims that the drones were part of a "just war" that was waged proportionately and saved lives, the operational reality was far more complex.[42] The term "collateral damage" became a frequent headline in the press as reports emerged detailing ever-growing numbers of civilian casualties. Only between 64 and 116 civilians were officially reported as casualties from counterterrorism strikes in Afghanistan, Iraq, and Syria under the Obama administration. Notably, human rights organizations have since produced their own figures, recording far expanded numbers of civilian fatalities, often many times the amount of the official figures.[43]

Critics pointed out that official figures often obscured the true impact of drone warfare, failing to distinguish between drone strikes and conventional airstrikes, and likely underestimated the human cost (both in terms of lives lost and the broader psychological and gendered impact of drone strikes which contributed to high levels of mental health issues and death by suicide).[44] In total, the Council on Foreign Relations estimated the number of fatalities as 3,797, with at least 10 percent of those documented as civilians.[45] In response to this mounting criticism, the Obama administration initiated several strategic shifts. Controversial "signature strikes," which targeted individuals based on suspicious behavior,[46] and a list of pre-defined "terrorist characteristics" rather than confirmed identities, were re-evaluated in favor of more discriminate, intelligence-driven "targeted killing" approaches. This shift reflected a growing recognition that drone warfare needed to adhere to stricter moral and legal standards.

As part of this new approach, control over armed drones transitioned from the CIA to the Department of Defense, signaling an attempt to bring more oversight and accountability to drone operations. New deployment criteria mandated a "near certainty" of zero civilian casualties outside designated conflict zones, although achieving this level of precision proved elusive. Overall, despite the intention to set a global standard for drone warfare, civilians continued to be caught in the crossfire. The president himself acknowledged the shortfalls, stating, "[c]ivilians were killed that shouldn't have been. I think that over the last several years, we have worked very hard to avoid and prevent those kinds of tragedies from taking place."[47] Interestingly, as the data in Figure 2.1 show, the rate of strikes decreased directly after 2010. There are several potential reasons for the drop during this period. One is that the strikes eliminated many of the high-value targets that were on the strike list. Another factor, not incompatible with the first, is that the United States became more aware of criticism and the potential drawbacks of the strategy, and thus careful with the strikes it did conduct. A number of former US officials have since expressed concern about whether the strikes created more terrorists than they were killing due to radicalization and revenge attacks; that is to say they were working tactically but not strategically. Such pressure internally within the administration at the time may well have led to a raising of the bar in terms of targets, focusing on killing the most notable "high-profile" and "high-value" individuals. Thus, when President Obama ushered in a new policy on drones that would be more restrictive and transparent—a move some critics suggested was more about words than actions[48]—longtime observers, such as Scott Shane of *The New York Times*, attributed the shift to "a changing calculation of the long-term costs and benefits of targeted killings."[49] In other words, the administration had come to see drones as less valuable against the broader set of possible remaining targets, with the costs of each strikes mounting under the watchful eye of public scrutiny and international condemnation. Such restrictions would be rapidly revoked under the first Trump administration in 2017, a point to which we return in Chapter 3, alongside a broader assessment of how drone warfare changed globally in the post-Obama era.

Have drones shifted the culture within militaries?

Military services, such as the US Air Force (USAF), have historically been pilot-centric. After World War II, the US Army Air Force (USAAF) spun off USAF as a service separate from the Army. While the Army still has a flying component, USAF has been far more focused on the flying mission, and the pilots have been at the center of that mission and culture.

Reliance on drones has required a culture shift for air forces, including USAF, that have been pilot-centric. Initially, many drone operators were reassigned from piloting other aircraft whether because of physical obstacles in the way of flying airplanes—e.g., eyesight problems, age—or because of backlogs in training for the manned aircraft they were assigned to fly. In these initial years, many USAF pilots transitioned from another weapons system to the new specialty code for "Attack RPA Pilot." Training included 25 hours of manned, powered flight, then training on the unmanned Predator or Reaper.

Operating drones has some appeal for individuals. As one former drone pilot reported, “there is an honorable element. We do good work. We produce tactical effects for combatant commanders. We kill enemies and save friends.” He went on to say that since drone operators are “perpetually at war,” they can have more impact than the manned pilots who deploy for four months and then return for eight to 12 months.[50]

Despite this appeal to some, mainstream military culture is still somewhat antithetical to the business of drone operations. While drone training offered a savings compared to the $1.5 million that it cost to train one traditional pilot, the path from a traditional platform to drone operator could justifiably seem like a letdown for individuals who had entered the air force to fly planes. According to the drone operator we have already quoted, “those of us who wanted to fly traditionally manned aircraft wanted to be Maverick or Ice Man. There is a man-machine interface, but there is still a ‘cowboy’ kind of mentality. It is the front line, the tip of the spear of the AF. Sitting on the ground in a trailer does not satisfy this desire.”[51] The shift work is onerous, doing the same thing day in and day out, which is not what many individuals envisioned when they joined the military.[52] As a result, drone operators began “leaving the Air Force in droves,”[53] the tempo of operation being exhausting and overwhelming. The problem was particularly acute at the initial peak of drone strikes in 2010…, when 30 percent of drone operators reported “burnout.”[54] Since that period, the requirements for a RPA pilot have become more rigorous in an attempt to better prepare personnel for the operational realities of the role.

As of 2024, the training of a drone pilot in the USAF includes two months of initial flight training, ten weeks for a RPA Instrument Qualification course, five weeks for a RPA fundamentals course, and four to six months with a formal weapons system employment unit.[55] The Government Accountability Office continues to release statistics saying they are under-enrolled. In 2019, they were authorized to have 1,652 pilots but had only 1,320, 20 percent less than their target. While the number of pilots has grown over the years, so has the number of authorizations with increased need for operators. Reasons for these shortfalls include private contractors paying two to four times more than the service can, staffing shortages at the training base, and the lack of attention paid to the low quality of life issues, such as continuous rotations and inadequate childcare support.[56]

A Military Psychology review of the health and well-being of military drone operators (2017) found that while mental health diagnoses, such as post-traumatic stress disorder (PTSD), were low, levels of physiological stress were higher compared to other military roles. Tiredness and mental fatigue also emerged as significant concerns for drone operators.[57] Monotony is clearly one of the factors that would contribute to operator dissatisfaction and stress—especially for the many individuals who joined the military with the expectation of being fighter pilots like Top Gun. While strikes are undertaken, the majority of an operator's time is spent monitoring vast swathes of large open space and urban environments, providing persistent overwatch and intelligence gathering.

There have even been several efforts to address the cultural distance between being a manned aircraft pilot and a drone operator. Some units have tried to bring some of the traditional flying culture into drone operations, though by most accounts few can change the sense that the operators are playing the role of robots themselves, surveying the ground over the long, monotonous shifts. Plans to introduce a Distinguished Warfare Medal for drone operators and cyberwarriors were scuttled after two months because of a sense among members of Congress and some veterans "that it was unfair to make the medal a higher honor than some issued for valor on the battlefield."[58] The medal was originally proposed by outgoing defense secretary Leon Panetta to honor those who were making a difference in combat from afar. Yet it was Chuck Hagel, who—upon assuming his position as defense secretary on April 15, 2013—replaced the medal with a "new distinguishing device that can be affixed to existing medals to recognize the extraordinary actions of this small number of men and women."[59]

At least in terms of numbers, the potential pool of recipients is not actually small. By 2015, the Air Force had trained more drone pilots than fighter and bomber pilots combined, which meant there were more individuals trained to fly drones than bombers.[60]

At least initially, higher training rates had been essential given that drone pilots leave the service at three times the rate of pilots of manned aircraft, though some aviation analysts have suggested that a more appropriate approach would be to follow that of the Army, which allows warrant officers with a high school diploma to oversee and execute tactical unmanned aerial systems. This approach has proven imperfect too. One problem has been that these operators are sometimes pulled over to non-drone activities, including guard duty and even lawn care, which has made it difficult for the Army pilots to stay current with their training hours.[61] Another problem has been cultural, with the Army not organized primarily around flying, let alone unmanned platforms. Services like the US Marine Corps have also lagged behind in maintaining capacity. In 2022, the Marine Corps trained just 38 of the 68 drone pilots it needed to fly the Reaper, although in 2024 it reported it had intensified its training to meet said goals.

In short, drone pilots have clearly occupied an uneasy space in a culture dominated by fighter pilots. Trying to address the drone culture runs up against structural obstacles as there is an interest in maintaining the prestige as an officer-only specialty while dealing with the fact that the job entails unenviable shift work. This is a problem that will only continue in years to come, at least while human operators are still required to remain “inside the loop of control.”

3
DRONE PROLIFERATION

A lot has changed since the peak deployments of the Global War on Terror, when the United States dominated the use of armed military drones. Back in 2009-10, there were a number of nation-states that wanted to acquire drones, keen to capitalize on the seemingly novel unmanned and remote-controlled utility of these robotic aerial vehicles. In fact, by 2010, 60 countries had established a military drone program—innovating, developing, and acquiring their own drone technologies.[1] Today, however, the global drone landscape has expanded dramatically. By 2025, 118 nation-states had acquired their own military drones, a considerable 97 percent increase in 14 years.[2] To be clear, these countries are not stuck in the process of developing their first drones; instead, their drone ambitions have matured to the point where they are ready and able to deploy a diverse arsenal of Class I, II, and/or III systems (as defined by NATO and discussed in Chapter 2).[3] As Figure 3.1 shows, the majority of these are the smallest (and cheapest) Class I systems, a trend that is also reflected in the nonstate acquisition of drones. As of 2024, 65 nonstate actors possed weaponized commercial and military-grade drone technologies, the majority of which were the smaller quadcopter systems.[4] This record proliferation (documented and visualized by continent in Figure 3.2) has, and continues to have, considerable implications for regional and international security. Table A.1 in the Appendix delineates by category and country the global picture on drone possession, reflecting this geographical spread and the technological trends in procurement. Yet, how did we get to this point in history where drones have become the weapon of choice for nation-state and non-state actors alike? To find out, we start by mapping key examples of drone use beyond the United States, helping to establish a more international understanding of drone warfare and its recent evolution.

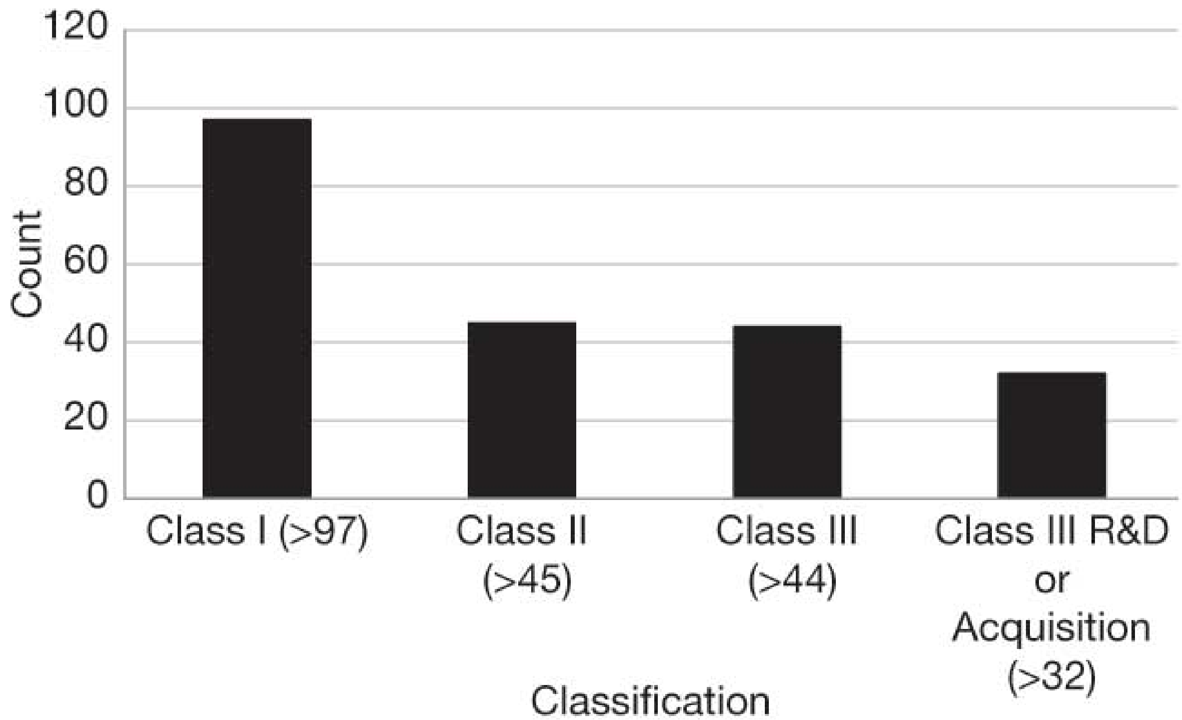

Figure 3.1 International Drone Capabilities by NATO Classification

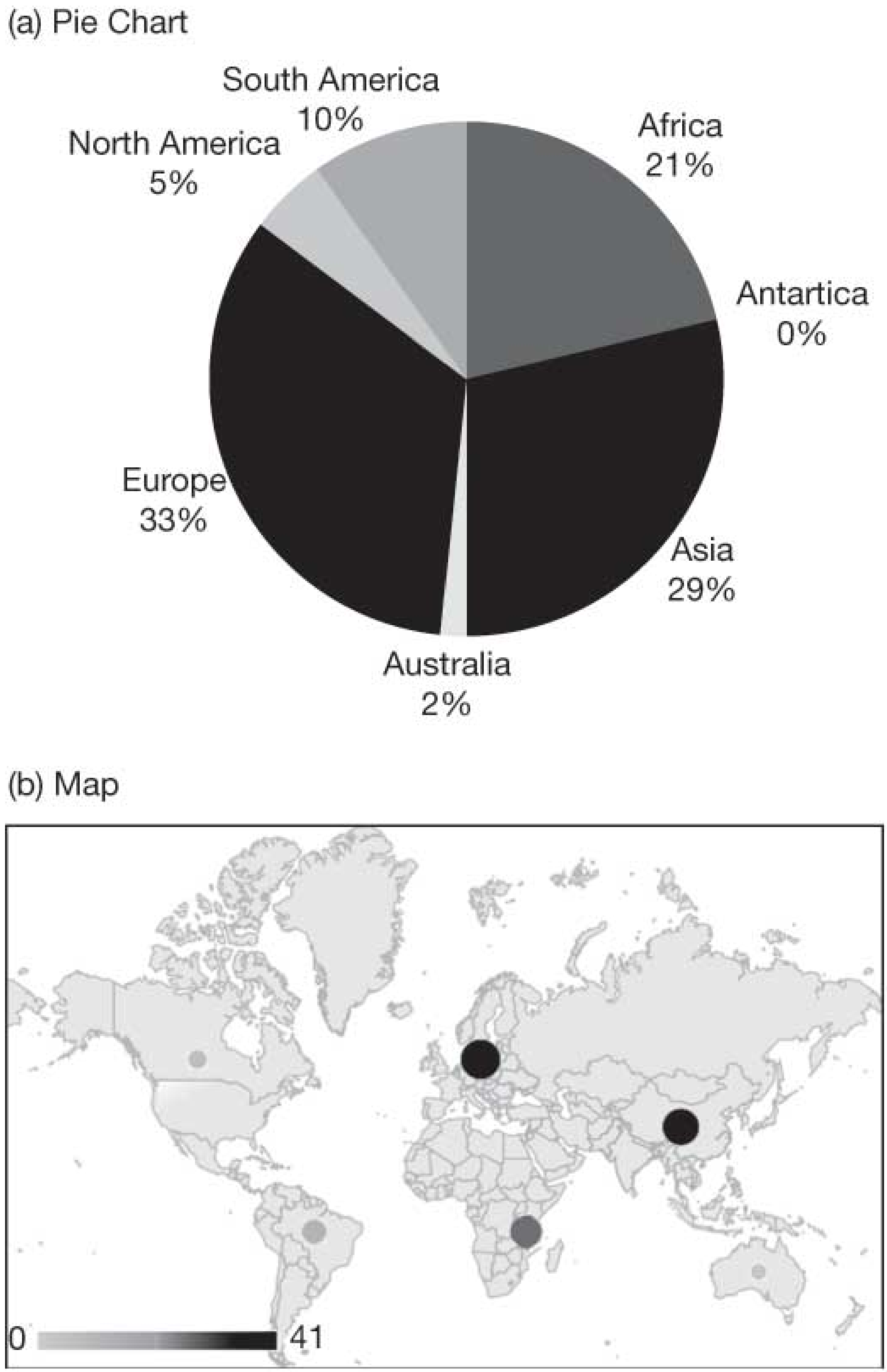

Figure 3.2 Drone Capabilities by Continent

What non-US countries are using drones in combat?

In 2011, a headline in *The New York Times* blared, “Coming Soon—The Drone Arms Race.”[5] The piece opened with the line: “what was a science-fiction scenario not much more than a decade ago has become today’s news.” “Today’s” news meant that US strikes in Afghanistan, Pakistan, Yemen, and beyond had left other countries rushing to catch up. This was especially evident as the US drone war expanded to tackle a new terrorist group, the Islamic State (IS).

From 2015, the United States and the United Kingdom both conducted drone strikes in Iraq and Syria, with the intention of targeting IS strongholds. The United States killed a British individual - Junaid Hussain - who led the Cyber Caliphate, an Islamic State unit that had hacked American military accounts. The British approved the killing of so-called Jihadi John (Mohammed Emwazi), who had also been a senior member of IS in Syria. With their perceived success in degrading IS command through these (and many other) high profile decapitation strikes, the demand soon grew from countries that saw drones as a ‘panacea technology’ that could solve their own domestic and international security challenges. Indeed, the appetite for drones, and the drone industry (both commercial and defense), grew quickly over this period. As defense analyst Patrick Tucker observed in 2015 “virtually every country on earth will be able to build or acquire drones capable of firing missiles within the next ten years. Armed aerial drones will be used for targeted killings, terrorism and the government suppression of civil unrest.”[6] In this statement, Tucker proved somewhat prophetic.

With there now being 118 nation-states that have military drones, this means that 117 of these are not the United States. However, it would be impractical—and likely beyond the publisher’s printing budget—to give an in-depth appraisal of each use case. Instead, this chapter attempts to give as full an understanding as possible of the different regions where drones have been used in combat and the different types of drones deployed. To do so we start with the Israeli and British deployments in the Middle East, followed by French deployments in the Sahel (Africa), and then Russian and Ukrainian deployments in Europe.

Though the evidence is thin, due to the highly secretive nature of the Israeli program, Israel likely first used armed drones in 2004. It was at this time that *The Jerusalem Post* claimed a "pilotless aircraft" had been used to strike targets in Gaza.[7] Later that year, it appeared that Israel used a drone to target a suspected Palestinian Jihadist militant. During the 2006 Lebanon War, drones were likely used, as they probably also were in late 2006 during an American military strike targeting Gaza. Palestinian sources suggest that Israel again sent armed drones to strike targets in Gaza in 2007, and most notably in 2008–2009, during Operation Cast Lead, where about a dozen drones were airborne at all times.[8] One Palestinian rights group claimed that during this conflict Israel conducted 42 drone strikes, killing 87 civilians. The Israeli Air Force again used armed drones in its 2012 Gaza conflict, Operation Pillar of Defense, with an estimated 24 civilians killed.[9] Israel has also used drones in isolated cases in Sinai, targeting militants suspected of trafficking in weapons from Egypt.[10]

Drones have become a common feature of Israel's conflict in Gaza and the West Bank. In 2021, the Israeli Defense Force (IDF) announced its first AI-powered drone "swarm," and there have been increased levels of advanced drone deployment at both a strategic and a tactical level since the infamous October 7 attacks by Hamas on Israel in 2023.[11] Critics refer to the IDF's long-term reliance on drones as taking a page from the US occupation of Iraq or Afghanistan, minimizing the user's casualties in a way that has allowed the country to engage in perpetual war.[12] The IDF defends the strikes by suggesting that the approach is more mindful and capable of distinguishing between civilians and combatants than other forms of military force. This, it is argued, is due to persistent surveillance, the legal counsel required to strike, and the precision of the strike itself, leading to a more humane way to rout out and deter terrorists.[13]

The United Kingdom has also been a prolific user of drones in the Middle East. Between 2008 and 2014, the British conducted almost 5,000 Reaper sorties, firing more than 450 missiles during that period. Between January and June 2015, the United Kingdom conducted 350 Reaper missions in Iraq, and 107 in Syria, though the strikes appear to be restricted to Iraq, which saw 97 actual strikes during that time period.[14] An updated UK government report in 2024 stated that since 2014, the Royal Air Force had carried out a total of 1,080 airstrikes in Iraq and 600 in Syria, though the numbers included both manned Typhoon strikes alongside Reapers, making it difficult to parse.[15]

France has also conducted strikes in regions of strategic (and historical) interest; in particular across the African continent. In December 2019, France carried out its first drone strike with US supplied Reapers in an attack against alleged terrorists in central Mali; a strike that killed 40 people in a weekend-long set of strikes. France had just acquired armed MQ-9 Reapers from the United States and finished testing the missiles at an airbase in Niger—a shift from its use of Reapers simply for intelligence, surveillance, and reconnaissance.[16] France conducted a number of other strikes in Mali, some of which mistakenly targeted civilians, with a wedding party confused for a "suspicious gathering of people."[17] A UN investigation into the incident in 2021 found that 19 civilians were killed by the French strike.[18] With the military coup in Niger in 2023, the drawdown of French military operations in the region, and the increased terrorist presence across the Sahel, it is clear the French drone program did not deliver the intended long-term aims of the French government.

Beyond the US and its closest allies, by far the most visible state use of drones has been in Ukraine by both the Russians and Ukrainians. The discourse surrounding this war has brought up questions regarding the impact drones will have on future battlefields because of how significantly they have altered fighting at a tactical level in this region since 2022. In the beginning, Ukraine dominated with Turkish-made Bayraktar TB-2 medium-altitude long-endurance (MALE) drones—to strike advancing Russian forces, mainly when Russian air defenses were still disorganized—

capitalizing on the element of surprise. However, as the Russian air defenses adjusted to present threats, the TB-2s became a vulnerable target, their large size and low speed making them easy to shoot down.[19] Yet instead of abandoning the drone program, Ukraine mobilized its citizens, creating a national effort to manufacture a variety of different weaponized drones to help push the Russians back. These ranged from small First-Person View (FVP) drones adapted from commercial systems to large converted single-seat planes, such as the Aeroprakt A-22, that could travel up to 1,000 kilometers and strike deep into Russia. In addition, they created volunteer collectives and crowdfunding campaigns to buy and assemble parts in Kyiv workshops that would later be sent to the frontlines. Some online websites even provided tutorials on how civilians could build do-it-yourself attack drones in their homes to help the war effort in a context where ammunition resupply presented challenges.[20]

Additionally, the Ukrainian government did all it could to promote entrepreneurial growth in the private weapon-manufacturing sector, trusting that they would move quickly. The first step was deregulation: procedures to create businesses were simplified, timelines for approval were shortened, and the steps a company must take to sell to the military were streamlined. Over the first two years of the war, the government provided hundreds of companies with tax breaks, start-up grants, and technical support. The second step was removing a Soviet-era cap on defense profits. It used to be illegal for arms manufacturers to generate more than 3 percent a year, but that soon changed with profits capped at 25 percent, allowing for more research and development in this sector in Ukraine. As of 2024, the most popular drones were small, first-person drones, 9–13 inches in length and propelled by rotors. Other popular domestically manufactured models included the Ukrainian Furia, a hand-launched, fixed-wing unmanned aerial vehicle (UAV) designed for reconnaissance, and the longer-range FP-1 systems. This substantial effort culminated in hundreds of Ukrainian drone manufactures producing millions of drones to aid the nation's efforts to repel Russian advances. According to Ukraine's First Deputy Minister of Defense, Ivan Havryliuk, Ukraine went from producing 20,000 drones a month at the beginning of 2024 to 200,000 drones a month from January 2025.[21] Its total drone production for 2025 was projected to be between 3 and 4.5 million, highlighting the scale of the industry expansion, the success of the Ukrainian initiatives, and the importance of the drone to Ukrainian resistance. As research by the Atlantic Council documented, these drones have become “a central pillar of Ukraine’s war effort, inflicting up to 80 percent of Russian battlefield casualties”.[22] However, Ukraine has not been alone in its reliance on drones.

On the other side of the war, Russia also adopted drones in order to sustain its offensive capacity. Before the war started, the Russian Ministry of Defense (MOD) had planned a gradual shift toward more advanced autonomous drones for precision strikes, including swarming capabilities and partnership with crewed aircraft. The war in Ukraine may have delayed the timeline for introducing these more hi-tech systems due to resource reallocation and Western sanctions. Instead, Russian forces began to increasingly rely on commercial quadcopters, mostly devised from imported Chinese parts (motors, batteries, controllers, etc.), to increase their air surveillance and short-range strike capabilities for tactical-level support and reconnaissance. Their utilization of civilian systems was not as advanced as Ukraine’s, but their citizen volunteer groups were able to produce up to 100,000 FPV drones per month. As President Putin stated in September 2024, the plan was for Russia to produce at least 1.4 million quadcopter drones through to 2025.[23] Nevertheless, it’s not just quadcopters that were a priority for Russia.

Due to shorfalls in long-range strike capabilities, Russia also started to import Iranian-made Shahed one way attack (OWA) drones in large volumes to overwhelm enemy air defenses and target critical infrastructure or even urban civilian areas. In most cases, Ukraine would shoot down a large proportion of the drones (up to 80 or 90 percent), but the intention was for a few heavily armed drones (some armed with thermobaric munitions) to penetrate the air defenses and deliver considerable damage. In 2024, Russia completed building a manufacturing facility to produce 6,000 Shahed attack drones per year. Factories like this – of which there were at least two by 2025 – had a considerable impact on Russia's deep-strike capability. According to CSIS, from September 2024, "Russia significantly ramped up its use of Shahed drones, increasing from approximately 200 launches per week to more than 1,000 per week by March 2025 as part of a sustained pressure campaign".[24]

There are numerous other dimensions to the Ukrainian and Russian use of drones—including the maritime and ground domain—but these will be covered later in the book (see Chapter 5 *Drones for Ground and Sea*). There are also a number of other state drone actors, such as Turkey that both deploy and drive broader drone proliferation. These are covered later in the chapter (see *What types of institutions are in place to deal with the proliferation of drones?*). Other nations states, like Nigeria and Burkina Faso, Sudan, Myanmar, are also making headlines for their (mis)use of drones, issues which are covered in this chapter (*Would further proliferation of drones present security risks?*) and in Chapter 4. Yet, what the Israeli, French, British, Russian and Ukrainian examples highlight is the diversity of the modern drone landscape and how MALE, OWA, and FPV quadcopters are increasingly the spearheads of national militaries.

What nonstate actors have used drones in combat?

Similarly to the use of drones by nation-states, nonstate actors have also seen advantages to deploying remote technologies. In November 2004, Hezbollah piloted a drone into Israeli airspace, hovering over and observing the town of Nahariya for roughly 20 minutes before returning to its launch site in Lebanon. The next two attempts to send drones into Israel, in April 2005 and August 2006, were intercepted by the Israeli military. Hezbollah stopped sending drones into Israel for six years, before picking up again in 2012. Specifically, on October 6, 2012, Hezbollah sent an Iranian supplied "Ayub" MALE fixed wing drone (also known as the Shahed 129) over Israel, seemingly sending it to the town of Dimona, the site of Israel's nuclear weapons complex. After shooting down the drone, the Israeli military examined the wreckage and claimed that the drone had the capability of communicating information about the nuclear facility back to Hezbollah. Weeks later, a member of the Iranian parliament claimed that the nation had received images of Israeli nuclear facilities from the drone.[25]

In its summer 2014 conflict with Israel, Hamas also appeared to be interested in the psychological dividend of having drones, taking to social media to brag about "armed drones" being part of their expanded and powerful arsenal. Israel was unimpressed and ultimately shot down two of the drones, which appeared to be quite rudimentary compared to the earlier launches.[26] In the conflict with Hamas two years earlier, Israel reported that it had targeted a Hamas drone production facility, which may have stunted production. In defiance of such attacks, however, Hamas flew a drone in its December 2014 memorial to mark the group's twenty-seventh anniversary, prompting Israel to scramble warplanes, though the aircraft never crossed into Israeli airspace.[27]

Since then, drones have become a mainstay of Hezbollah and Hamas attacks on Israel. In mid-May 2024, Hezbollah conducted a cross-border strike using a drone that hit one of Israel's air surveillance systems. Israel's Iron Dome defense system was designed to defend against incoming missiles and rockets, but was vulnerable to drones that could fly low and slowly, effectively evading these air defenses.[28] As one Israel-based think-tank concluded of the strike, "[t]his attack reflects an improvement in accuracy and the ability to evade Israeli air defenses." Israel had intercepted many of Hezbollah's drones since the start of the conflict in Gaza in 2023, but the sheer volume of the drone attacks, and the tactics used, made it impossible to have a 100 percent success rate on defense. Former Hezbollah leader, Hasan Nasrallah, had proudly pointed to the longevity of its drone program, resourced in large part by Iran.[29] Indeed, Iran has been a driver of drone proliferation among its "Axis of Resistance" across the Middle East. This included providing drones to Houthi rebels in Yemen, who managed to conduct long-range drone strikes across numerous civilian and military sites in Israel, a point we will examine later (see *Are there defenses against drones?*).

In the October 7 attacks on Israel, however, Hamas used small tactical drones against Israel's communications towers and cameras to pave the way for their ground forces. Hamas also equipped drones with munitions and used them against tanks and first responders across the border. This approach was similar to the use of drones by state actors, like Russia and Ukraine. As research published in the *Bulletin of Atomic Scientists* outlined, these tactics also proved effective in the Russia-Ukraine war, although as the authors noted, it is most likey that "Hamas didn't learn how to use drones from the Russians and Ukrainians; the Russians and Ukrainians learned how to use small drones from violent nonstate actors."[30] This is especially true when it comes to IS and their pioneering of weaponizing commercial drones in the mid-2010s.

IS was no stranger to drones and had in fact become master drone engineers and operators by the end of Operation Inherent Resolve. They became the Emir of Drones, with their own rudimentary remote-controlled 'air force'. In 2016, the group weaponized commercially acquired drones in their thousands, creating what at the time was framed as flying Improvised Explosive Devices (IEDs). This innovation led to considerable concern about the potential advantages such drones might provide terrorists against state militaries.[31] Observers noted that these flying IEDs could transcend and circumvent barriers intended to prevent ground vehicles and suicide bombers from advancing. In an incident in 2016, for instance, IS used a rudimentary drone, covertly packed with explosives, to kill two Kurdish military personnel in Syria, raising concerns about how nonstate groups could adapt and innovate commercial technologies.[32] By 2017, the IS drone program had advanced further, with as many as 83 drones in the skies above the United States and allied forces in a 24-hour period.[33] Some would provide persistent overwatch, others would be armed with adapted mortars and grenades and sent in to cause chaos among advancing forces. At their peak in the spring of 2017, the group had enough drones amassed to conduct up to 100 attacks per month. As such, it is a fair assessment that it was nonstate innovation, enabled by unchecked access to commercial technologies, that laid the foundations for many of the state and nonstate deployments of drones in war today.[34] This is likely a trend, and feedback loop, we will see repeating in the future, with ever more advanced drones—including increasingly autonomous systems—falling into the hands of cartels, traffickers, criminal gangs, and terrorist groups around the world.

What types of institutions are in place to deal with the proliferation of drones?

Currently, the only formal institution for controlling the transfer of larger advanced drones is the Missile Technology Control Regime (MTCR). Although it should be said this arms control regime has been weakened by state reinterpretation in recent years. Specifically, in July 2020, the first Trump administration announced it would “unilaterally reinterpret how the United States will implement the 35-nation Missile Technology Control Regime (MTCR) in order to expedite sales of unmanned aerial vehicles (UAVs) to other countries.”[35] Yet despite this statement, many of the MTCR’s principles still hold and are important to understand, in terms of both the positives and the regulatory shortfalls.

The MTCR was created in 1987 as a nuclear nonproliferation arrangement designed to limit the spread of nuclear weapons delivery vehicles. The organization has questionable relevance because of the membership composition and rules. While the United States has generally adhered to the MTCR, the regime excludes some of the world’s other key drone producers, including Israel, China, and Iran.

The discussion of drone proliferation should, therefore, be taken in the context of which drone-producing countries are part of the MTCR and thus bound by MTCR guidelines. Out of the 35 countries, perhaps Turkey (and the United States) stands out as one of the world’s most prolific producers. With this in mind, all MTCR members have agreed that they will engage in consultation with other MTCR members before exporting anything on a list of items that has been deemed sensitive. It is important to note that the MTCR has its own classification system of drones, distinctly separate and the inverse of the previous NATO classifications. Specifically, the organization has a strong presumption of denial when it comes to Category I drones, which they categorize as having a payload of over 500 kg and a range of 300 kilometers or greater. The organization states that these should be exported rarely and reviewed for approval on a case-by-case basis. These drones include Global Hawks, which are only used for reconnaissance and surveillance, and armed Predators and Reapers, which carry missiles and had traditionally only been approved for export on rare occasions. Category II drones are thought to be of less concern from the standpoint of nuclear proliferation. Category II systems include drones that are less sensitive but still capable of covering a range up to 300 kilometers, irrespective of payload, and have less stringent export prohibitions. An example includes Turkey's TB2, one of the most prolific drones sold around the world. This drone is 6.5 meters long, has a 12-meter wingspan, is armed, and can fly a maximum range of 300 kilometers.[36] Some drones fall outside the MTCR altogether, meaning they can be exported without any scrutiny. These include smaller-scale, limited-range drones, or smaller drones that are designed for one-way missions. "Other" refers to even less sensitive drone technology that falls outside the purview of the MTCR. These include technology demonstrators such as the nEUROn, made by a European consortium, or smaller commercial quadcopter drones that are considered fully exportable.

Another challenge with the MTCR is that some drone-manufacturing, exporting, and using countries are not party to the regime. Established drone producers like China and Iran, and rising producers like Taiwan and United Arab Emirates, are not in the MTCR but capable of producing advanced drones. China and Iran in particular are not at all restrictive in terms of their drone transfer activity.[37] That the MTCR is a regulating agency that does not incorporate all of the countries producing drones implies a major flaw in its institutional design or a lack of continued buy-in and interest internationally since its inception. Even if it is not a legally binding treaty, the nation-states that are members have generally adhered to the MTCR's guidelines. For example, despite the reinterpretation under Trump, the United States has exported advanced drones on a restrictive basis, denying requests from countries such as Pakistan, Turkey, and the United Arab Emirates and exporting just to a handful of allied countries.[38]

Beyond the fact that many countries are outside the MTCR, another limitation of the regime arises from the arbitrary threshold of its guidelines: payloads over 500 kilograms and ranges over 300 kilometers. The threshold includes many systems that do not necessarily create nuclear security problems as a result of their proliferation. Global Hawk could, for instance, fit under this broad heading but does not carry any munitions as part of its payload. Yet on the other hand, as one Air Force general cautioned, Global Hawk, if armed, could be seen as "ultra, ultra-long range cruise missiles" due to the system's 22,000 kilometer range[39] It is in this spirit that talks with Japan about the proposed sale of Global Hawks had been sensitive. On the other hand, the Global Hawk's surveillance capability could actually create much-needed transparency in regions such as East Asia, where tactical miscalculations resulting from inadequate data can result in escalating conflict. It was with these ambitions in mind that the United States arranged a sale of a European variant of the Global Hawk, the Euro Hawk, to Germany and negotiated a proposed sale of Global Hawks to South Korea, which had required that South Korea reduce its commitments to the MTCR. Indeed, as *Jane's Defense Weekly* reported, the 2012 deal had "relaxed" South Korea's commitments to the MTCR.[40] While the German program was ultimately cancelled, as of 2025 both South Korea and Japan still operate the Global Hawk drones.

Further, the MTCR's focus on larger drones is anachronistic, drawing on a time when the goal was to prevent the proliferation of nuclear delivery vehicles. Smaller, affordable, and ever longer-range drones have proliferated to such an extent that the initial objectives of the MTCR seem ill-suited to the contemporary security environment. As this discussion implies, the MTCR is an imperfect proliferation control measure for a technology that has evolved in ways that were not envisioned at its inception in 1987.

Some scholars have proposed a new drone proliferation organization, or a Drone Technology Control Regime (DTCR),[41] either of which could address the regulation gap between member countries in the MTCR and those outside of its jurisdiction.[42] Philosopher Allen Buchanan and political scientist Robert Keohane have advocated an informal regime that promotes accountability in drone strikes. Before an attack takes place they propose "requiring that states specify appropriate procedures in their decision-making process for all drone strikes"; and, after a drone attack, states must make "public justifications for specific strikes."[43] Such a system acknowledges that strikes via drones are qualitatively different from F-16 strikes in that they tend to be able to be conducted covertly and therefore are beyond the traditional umbrella of international law. The regime would bring these strikes out of the covert world and require more transparency in the targeting process. This proposal builds on previous ones that have acknowledged the loopholes in the MTCR's regulations—particularly, as mentioned, that the countries seeking to export or import drones are often outside the purview of the MTCR. This makes the organization's arbitrary export thresholds easily sidestepped. Other proposals acknowledge similar problems, and recognize that involving countries who are currently outside of the MTCR and who stand to gain financially from drone exports, such as China and Israel, would be difficult.

In addition to the MTCR, the UN created two Special Rapporteurs meant, in part, to monitor and report on the use of drones for counterterrorism. One of the UN's Special Rapporteurs was charged with ensuring the promotion and protection of human rights and that fundamental freedoms were not violated during counterterrorism activity. The activities, as outlined in a 2013 report, included examining drones in the context of counterterrorism operations, in particular whether the civilian casualties resulting from these drone strikes were compatible with international law. In a report published in 2014, the then Special Rapporteur Ben Emmerson reported on reductions in the rate of civilian casualties in Pakistan. Yet he also acknowledged that between 24 and 71 civilians were killed in Yemen between 2009 and 2013, and concurred that the European Union's condemnation of strikes outside a declared war raised serious concerns about the legality of these strikes under international law. Finally, he drew attention to the continuing opaqueness in terms of the specific strikes conducted by the United States—specifically, which civilian casualties are sustained, how, and why—even in the context of ongoing conflicts, such as those in Afghanistan.[44]

As Emmerson's report indicated, the findings were intended to be read in tandem with that of the investigation of the Special Rapporteur on extrajudicial, summary, or arbitrary executions. This Special Rapporteur's 2013 report noted concerns that drones themselves were not illegal but could "make it easier for States to deploy deadly and targeted force on the territories of other States."[45] He added that the broad justifications deployed to legitimize drone strikes ran the risk of undermining international legal limits to the use of force. The report also foreshadowed the future landscape, which consisted of a proliferation of multiple drones by nation states and non-states against a backdrop of more actors using force less discriminately.[46] Since these reports, consecutive UN Special Rapporteurs have reported on the concerning changing character of drone warfare around the world, with Agnes Callamard's 2020 report warning that "drone technologies and drone attacks pose fundamental challenges to international legal standards, the prohibition against arbitrary killings, the lawful limitations on permissible use of force and the very institutions established to safeguard peace and security."[47] Such concerns are clearly echoed by the real-world cases of drone deployment presented in this chapter.

Other than through multilateral institutions, the other way sought to affect the future acquisition or use of armed drones has been through state practice. As this chapter has made clear, the country that has been most involved in drone technology has been the United States; this fact gives to the United States the potential to help establish legal precedents, not just in terms of the sale of armed drones but also in how drones are used in conflict. To this end, the United States was frequently under pressure to clarify certain aspects of its drone program, including what it defined as “imminence,” the actual conditions under which it considered capture would not be feasible—meaning that killing is warranted—and criteria for targeting.[48] The United States, however, tended to resist such pressure and maintain latitude for discretion. Such a lack of regulation or consistent international norms around the use of drones today, including state misuse of the technologies, could be tied back to this lack of US leadership and the inability to set robust standards both in terms of their own use, but also the setting of an example to the world.

Why are drones increasingly prevalent in warfare?

Several factors have made armed drones appear to be the “cure-all” for counterterrorism, as President Obama had put it, setting a global precedent and demand for the weapons.[49] First, drones allow for sustained presence over potential targets. The existing US arsenal of armed drones—primarily the MQ-9B SkyGuardian—can remain aloft, fully loaded with munitions, for over 40 hours, compared to four hours or less for F-16 fighter jets and A-10 ground attack aircraft, or around two hours for an F-35 (without refueling). Thus, the advantages for loitering and persistence compared to manned aircraft are evident.

Second, drones provide a near-instantaneous responsiveness—dramatically shrinking what US military targeting experts call the “find-fix-finish” loop—that most other platforms lack. For example, a MALE drone loiters over targets, collecting intelligence in real time for hours, days, and sometimes weeks. Then the drone-fired missile travels faster than the speed of sound, striking a target within seconds—often before it is heard by people on the ground. This ability stands in stark contrast to the August 1998 cruise missile salvo targeting Osama bin Laden, which had to be programmed based on projections of where he would be in four to six hours, in order to allow time to analyze the intelligence, obtain presidential authorization, program the missiles, and fly them to the target.

Third, and most important, unmanned systems do not face the human limitations associated with manned systems. In particular, drones do not risk the death or capture of human pilots or ground forces since unlike manned aircraft or raids by soldiers, drones fly directly over hostile territory without placing pilots or ground troops at risk of injury, capture, or death. Nation-states with armed MALE drones, for instance, can conduct strikes with reduced risk to the lives of their own forces, which minimizes casualties, thereby reducing public outcry at home and sparing the lives of pilots, who are in short supply and difficult to train and replenish.

Finally, it should also be noted that drones also allow for a morbid convenience for some state actors, allowing them to argue that due to drones, their only option (or perhaps preferred option) is to kill targets, rather than travel great distances across difficult terrain to capture people suspected of terrorism. As part of a 2012 Department of Justice memo, the Obama administration highlighted what it deemed to be a restrictive set of conditions under which it would engage in targeted killings. In this memo, the administration stated that it would kill an individual who presented an "imminent threat" and if capture were not "feasible."[50] To be sure, it seized some suspected militants. For example, the United States had detained a number of high-profile suspects through raids. In 2011, the United States seized Ahmed Abdulkadir Warsame, an interlocutor between Al-Shabab and al-Qaeda in the Arabian Peninsula (AQAP), off Somalia, bringing him aboard the USS *Boxer*, where he was interrogated and then brought to New York for a trial. In addition, in 2013, the United States conducted a set of raids in Libya that captured Abu Anas al-Liby, who had been accused of carrying out the East Africa embassy bombings in 1998 and was later held in a secure location outside Libya and eventually taken to New York. He later died in custody in early 2015 from complications related to liver surgery, having contracted hepatitis C prior to his capture.[51]

One reason for the preference for killing suspected terrorists over taking them captive was that detention of terrorists presented its own challenges. Starting in the Obama administration, Guantanamo Bay was ruled out in terms of accepting new detainees, and the process of trying suspected terrorists in US civilian courts remains fraught from a domestic politics standpoint, with members of Congress from the president's own party resisting trials in their own state or district. Against this backdrop of having few palatable options for dealing with suspected terrorists, killing rather than capturing became the centerpiece of the counterterrorism strategy of the United States.[52]

Perhaps more importantly, arresting militants in the war zones and unstable areas where they are found is far riskier than killing via an unmanned drone. A pair of attacks in Somalia in October 2013 illustrates the difference. In early October, the same weekend as a Delta Force raid captured al-Liby, SEAL Team Six landed in Somalia with the intention of capturing Abdulkadir Mohamed Abdulkadir (known as Ikrima), an Al-Shabab leader. The assault ended in failure, with the Special Forces encountering stiff resistance as well as women and children, leading them to withdraw after a firefight. Later that month, the United States returned to target Al-Shabab leaders with drones, killing Ibrahim Ali Abdi, a senior commander, and his friend in the attack. Ideally, the United States would have captured their targets, but when facing the prospect of enemy fire and with a lack of adequate information, such as high-fidelity intelligence provided by a drone, it failed in the first (manned) raid. Conversely, the low-risk proposition of an unmanned raid killed the suspected terrorist in the latter (unmanned) case.

With this perceived utility of the drone in mind, during the first Trump administration, regulations on drone strikes became more decentralized, permitting operators in the field to decide whether or not to target suspects. Officials now say that the first Trump administration's standards for drone strikes permitted a lower standard of reasonable certainty when it came to men of a certain age or demographic, leading to more strikes and more civilian deaths.[53] Once the Biden administration came into power, however, they were quick to tighten these rules and essentially bring back the original Obama-era standards on when a strike could be authorized.[54] Discussions about reverting these restrictions have arisen once again with the second Trump administration in power from 2025. Overall, therefore, despite the controversies, it is clear to see how the historical American experience with drone warfare, the ease of deadly force, and the politically malleable rules of engagement, have become appealing for nation-states, leading to a world where drones are increasingly prevalent in war.

Could terrorists carry out a strike with drones in the United States or against US allies?

On the one hand, terrorists already have a number of tools at their disposal for killing large numbers of individuals, including the rudimentary but quite lethal AK-47 that the alleged terrorist on the high-speed train from Amsterdam to Paris had planned to use to kill scores of people in 2015. These weapons are already available and can potentially be devastating. On the other hand, drones – sometimes referred to as the AK-47s of the skies – are quicky becoming established as the perfect tools for terrorists. There are several features of drones that make them conducive to terrorism.[55]

First, they offer flexibility in terms of launch sites, since individual drones can be launched easily without any sophisticated tools. Similarly, their ability to loiter and wait for the appropriate time to strike offers strategic value in terms of maximizing damage, essentially acting as airborne IEDs that can seek out specific high-value targets instead of hoping that those targets will be in proximity to a stationary explosive device.[56] Senator Dianne Feinstein (D-CA) observed that, "in some respects, it's a perfect assassination weapon… it is very precise, it can knock out a room in a building if it's armed, it's a very dangerous weapon."[57] Even low-cost commercial drones could be used in a one-way attack (OWA) style to target an individual or, if equipped with a biological or a chemical agent, be quite disruptive.

Second, many air-defense systems that could target larger aircraft are likely to be unsuccessful against smaller drones. A good example is the North Korean drone, which had a five- to six-foot wingspan and was programmed to run surveillance over South Korea. Its mission to test whether or not South Korean air defenses could detect such small objects was cut short when several of the test drones ran out of fuel and subsequently crashed. During the disassembly of one of the four crashed drones, South Korean investigators found images of the Demilitarized Zone and the South Korean president's office and residence. While that particular drone was fairly benign, it suggests how these systems could be used to penetrate air-defense systems meant to easily detect larger aircraft. As Van Jackson put it in *Foreign Policy*, "it's the low-performance qualities of North Korea's drones that enable them to evade South Korean defenses, which are optimized for more traditional threats from bigger, faster, higher-altitude aircraft."[58]

Third, while these small drones might not be able to carry large explosive payloads, they would certainly have an important psychological impact, which is exactly the objective of terrorism. Indeed, in the case of the North Korean drone, the fact that even a small system could penetrate air defenses multiple times jarred the population. One Air Force colonel in Korea explained that this threat by North Korea took on high political salience for South Korean politicians who were trying to cultivate images as leaders who were attentive to the populace's security concerns. Last, since individuals can buy commercial drones inexpensively and easily online, the issue of ownership and attribution could be extremely difficult, making retaliation difficult and therefore doing little to deter an attack in the first place. Although today drone owners are required to register their aircraft, individuals can still assemble their own drones that are not only not registered but also not bound by the type of "geofencing" that manufacturers have placed on some drones to prevent the drone from going near airports, for example. Nation-states could also plausibly deny involvement in a drone-related terrorist incident given that there would be no pilot implicated and the type of drone used might well not bear any markings or radio signature that identifies the sponsor.

Of particular concern has been the prospect of lone wolf terror attack with drone. The type of lone wolves that carried out the Boston Marathon bombing in April 2013 or the 2017 Las Vegas Shooting could find a drone well-suited to a terrorist attack, insofar as the aggressor could fly the drone remotely into a crowded area, maximizing damage, or at least maximizing psychological terror. For example, in recent years, the misuse of commercial drones by violent individuals has exposed critical vulnerabilities in drone detection and defense.[59] In 2015, Japanese anti-nuclear activist Yasuo Yamamoto flew a DJI Phantom 2 drone carrying radioactive sand from the contaminated Fukushima region onto the roof of the Prime Minister's office in Tokyo.[60] The drone remained undetected for nearly two weeks, highlighting significant security lapses. Yamamoto, who referred to himself as an 'environmental terrorist', intended the act as a protest against Japan's reopening of nuclear power plants following the Fukushima nuclear disaster in 2011. This incident prompted Japan to implement stricter drone regulations, including bans near government buildings and in densely populated areas.

A more recent and high-profile case occurred in July, 2024, when 20-year-old Thomas Matthew Crooks attempted to assassinate President Donald Trump at a rally in Butler, Pennsylvania. Crooks conducted pre-attack surveillance by flying a drone over the rally site for approximately 11 minutes, capturing live footage to assess security measures and identify vantage points.[61] Despite being spotted by law enforcement prior to the attack, Crooks managed to access a rooftop adjacent to the rally venue, from which he fired eight shots, injuring Trump and killing a bystander. The Secret Service faced criticism for declining offers from local law enforcement to utilize drone surveillance, a decision that has since led to calls for enhanced protective measures and the integration of drone technology in security protocols.[62]

These incidents underscore a troubling trend: the democratization of aerial surveillance and attack capabilities through readily available drone technology. They highlight the urgent need for governments to adapt counter-unmanned aerial systems (UAS) capabilities, enforce robust regulatory frameworks, and develop deterrence strategies to address the evolving threats posed by the misuse of drones in both civilian and political contexts.[63] Put simply, there can be little doubt that the use of drones in terrorist attacks in a growing concern, one without quick solutions.

Would further proliferation of drones present security risks?

The nature of any future proliferation concern would depend on the type of drones in question, the regime deploying the drones, and the volatility of the region in which the drones are deployed. For instance, one concern related to increased proliferation is that drones could be seen as an easy and low risk way to coerce, pressure, or respond to a rival actor. The worry is that while drones may appear to be a low escalation option, they are still a serious step up the escalatory ladder of military action, which can lead to miscalculation and unintended consequences. As the UN Special Rapporteur for extrajudicial, summary, or arbitrary executions noted over a decade ago, “drones make it not only physically easier to dispatch long-distance and targeted armed force, but the proliferation of drones may lower social barriers in society against the deployment of lethal force and result in attempts to weaken the relevant legal standards.”[64] The report proved prophetic, as it claimed that because the use of drones does not introduce casualties on the side using them, they will be used more readily and subject to less public scrutiny.

If drones do lower the threshold for using force, then the countries that acquire them will be more willing to use or threaten force than they might otherwise. They might take more cross-border, interstate actions with fewer reservations, which would be particularly destabilizing in areas that are already prone to distrust, such as the East and South China Seas. Similarly, the CIA reports that there are more than 400 bilateral maritime boundaries that are not governed by formal agreements. These boundaries, where the rules governing them are ambiguous, would be more susceptible to the use of armed drones, since nation-states could literally “test the waters” with less risk than would be incurred with a manned equivalent.

A useful window for looking into possible future proliferation concerns/tensions comes from their use by RussiaRussia to launch incursions into NATO airspace in the Baltic and Black Sea regions. NATO members Romania and Latvia have cited incidents of Russian drones entering their protected airspace in 2024, with hundreds of occurrences already being registered since 2014.[65] Needless to say, the incursion spikes over the last decade are directly connected with Moscow's soured relationship with the West and its war against Ukraine. In September 2024, for instance, Romania reported a Russian drone incursion during a night attack on Ukrainian port infrastructure across the Danube. F-16s were scrambled, local alerts issued, and fragments of the drone were later found inside Romanian territory[66]. Around the same time, a Russian military drone entered Latvian airspace from Belarus before crashing near the town of Rezekne, sparking renewed concerns about NATO's eastern air defenses[67]. There have also been direct tensions between the US and Russia as a result of suspected drone incursions. In March 2023, a U.S. MQ-9 Reaper drone was downed over the Black Sea after a Russian Su-27 fighter collided with its propeller during a series of aggressive intercept maneuvers. The incident, which saw Russian jets dumping fuel and flying dangerously close to the drone for nearly 40 minutes, marked the first direct military contact between the U.S. and Russia since the Cold War.[68] While the U.S. insisted the drone was conducting routine surveillance in international airspace, Russia accused it of operating near Crimea in violation of restricted zones. As such, all three of these examples underscore how the growing use of drones in contested regions can escalate tensions between rival states, risking miscalculation, diplomatic crises, or even open conflict in already volatile regions.

Similarly, tensions have been spiking around the India-Pakistan border in regard to drone operations from both sides infiltrating the Line of Control in Kashmir.[69] In May 2025, for instance, India and Pakistan experienced their most serious military clash in decades, with drones at the center of a fast-escalating conflict. It began on April 22 when a terrorist attack in Pahalgam killed 26 Indian tourists, an incident India blamed on Pakistan-based militants.[70] In retaliation, India launched "Operation Sindoor," striking alleged terrorist camps in Pakistan. Pakistan responded by unleashing a deluge of drones, hundreds of quadcopter and OWA drone supplied by China and Turkey, against Indian military and civilian targets.[71] In a rapid and sustained defense operation, India's air defense forces shot down the majority of the drones and hit back with deep strikes, utilizing Israeli supplied OWA drones to target air defense and military infrastructure in Pakistani cities like Lahore and Karachi. As the world wondered if these drones strike would be the start of a broader war, a ceasefire was brokered by the US, pausing hostilities.[72] Nevertheless, the episode marked the first large-scale escalating drone war between two nuclear-armed states and signaled just how quickly drone can be turned to by rival nations in moments of severe tensions – even when both sides are armed with nuclear weapons.

The potentially destabilizing, or catastrophic, consequences of drone facilitated escalation are worrying to say the least. The international relations scholar Robert Jervis highlighted how a number of examples about decision-making under conditions of uncertainty explain how "people draw inferences from ambiguous evidence and, in turn, help explain many seemingly incomprehensible policies. They show how, when, and why highly intelligent and conscientious statesmen misperceive their environments in specific ways and reach inappropriate decisions."[73] Indeed, beyond the context of changing how nations calculate escalation, scholars have expressed concern that armed drones could change the way states calculate the use force at the intrastate level as well. For some of the same reasons that states find drones attractive in an interstate setting—primarily that they come at lower risk and cost—they might be inclined to use them against perceived domestic enemies. Many of the countries that have or are pursuing armed drones, such as Russia, China, and Turkey, have opposition movements that have challenged leaders' rule in these countries. Drones provide attractive answers to such rebellious movements.

The Assad regime in Syria used drones to conduct surveillance and carry out airstrikes against opposition forces and civilian populations during the civil war in Syria (2011-2024). The Turkish government has used armed drones against Kurdish separatist groups within Turkey and across the border in Iraq and Syria. Iran has reportedly used drones to monitor and suppress dissent, while also supplying drones to partners and proxies who do their bidding for them. In addition, there have been troubling instances of mass killing via drone in Nigeria and Burkina Faso. In December 2023, for instance, the Nigerian Army conducted a "military drone strike on a religious festival in the country's Kaduna State."[74] In what President Bola Ahmed Tinubu of Nigeria called a "mishap," civilians had gathered to observe a Muslim holiday celebrating the birthday of Prophet Muhammad when the two sets of strikes hit the communities gathered for the religious celebration.[75] There were 156 casualties, including children, the elderly, men, and women. In Burkina Faso, three military drone strikes (that the government claimed targeted Islamist fighters) killed at least 60 civilians at two crowded markets and a funeral since August 2023.[76] This trend of targeting civilians ethnic/religious groups deemed disruptive to the state has grown through 2024, with similar strikes in Sudan, Myanmar, and Indonesia (which will be explore further in Chapter 4).[77]

Finally, next-generation drone technologies, such as autonomous and swarming systems, will pose a myriad set of dangers as they proliferate into the hands of state and nonstate actors. If AI-powered true swarms are achieved, for example, they may be able to evade existing air defense in a "smart" manner, as opposed to simply overwhelming with a saturation attack. Mechanical engineer Vijay Kumar characterized a "true swarm" in the following way: "these devices take hundreds of measurements each second, calculating their position in relation to each other, working cooperatively toward particular missions, and just as important, avoiding each other despite moving quickly and in tight formations."[78] Flying multiples (even hundreds) of drones in formation would require sophisticated hardware, software, and data bandwidth that would be out of reach for many countries, but possible and quite harmful for those who can acquire it. Some drone experts, such as Zachary Kallenborn, take this concern one step further by arguing that "[a]rmed, fully-autonomous drone swarms are future weapons of mass destruction."[79] As Kallenborn explains, "drone swarms combine two properties unique to traditional weapons of mass destruction: mass harm and a lack of control to ensure the weapons do not harm civilians."[80] Such concerns are of course bookended by the 1980s worries about drones carrying nuclear weapons, and more recent concerns about a next-generation threat that could come from "dirty drones" armed with chemical, biological, or radioactive agents. Are there defenses against drones?

Although drone strikes have received the most attention because they do the targeting and cause the impact, drone defenses have also begun to receive attention as a way to guard against these attacks. These attacks do present challenges for traditional air-defense systems that are oriented toward larger, high-altitude, and fast-moving airborne objects. As touched upon earlier in the chapter, Houthi rebels, aligned with Iran and against Saudi Arabia, claimed responsibility for a series of drone strikes on two major Saudi Aramco oil facilities in 2019. The drone attacks caused considerable damage to infrastructure and disrupted production, revealing vulnerability to drone attacks. In Saudi Arabia's case, defending against drone attacks was difficult because Houthi/Iranian drones were often deliberately flying "below the radar" at low altitudes, had a low electronic signature, and flew slowly to reduce the chances of being picked up by air defenses. Nevertheless, countries have begun to develop systems that can guard against such attacks, with varying degrees of effectiveness or ability to scale.

Some early attempts to counter drones, especially in terms of stopping commercial quadcopters, bordered on the bizarre. For example, one option considered was trained eagles that could attack incoming quadcopter drones, but the approach seemed almost like a gimmick, as it was neither humane nor practicable at scale.[81] Similarly, drone nets that could be deployed to capture drones mid-air, launched from ground-based systems, handheld devices, or other drones equipped with net-capturing mechanisms, are difficult to scale. One company, Maverick Drone Systems, describes a mechanism in which an individual shoots a projectile that is a tethered web that wraps around the drone’s propellers and grounds the aircraft.[82] Although useful against one or two drones, this means of defense would be easily overwhelmed by any larger number of drone deployments, not to mention the fact that a net leaves little control over where the drone (armed with unknown substances) may land. However, as the threat from drones, military and commercial in origin, grew through the 2020s, more serious, although sometimes surprisingly rudimentary, attempts were made to defend against and counter drones.

The war in Ukraine, for instance, saw a rise in the use of passive drone defense in the form of add-on armor on tanks, referred to pejoratively as “cope cages.” These metal cages and nets were welded to tanks and armored vehicles in an attempt to defend against drone attacks by causing OWA drones or dropped explosives to detonate further away than intended. The effectiveness of drone warfare in Ukraine is a likely reason why the Russian nuclear submarine *Tula* was spotted in 2024 with similar ‘cope cage’ slat armor protecting its conning tower.[83] Although these cages were initially more crudely designed, they have improved throughout the conflict; experts such as Mark Cancian, a senior adviser for the Center for Strategic and International Studies, believe that these types of defenses are “absolutely here to stay.”[84]

Other approaches would involve drone detection systems that use radar, radio frequency (RF) sensors, acoustic sensors, or electro-optical/infrared (EO/IR) cameras to detect and track drones in the airspace. In September 2024, a lab in China even reported analyzing disruptions of communications to Starlink satellites, detecting drones based on the forward scattering of the electromagnetic waves caused by a drone crossing between the antenna and the satellite.[85] Once detected, defense could enact appropriate time sensitive countermeasures. This type of counter system has potential where drones can fly autonomously, or with a tethered fiberoptic wire, meaning there is no control frequency to jam or spoof.

Taking down attacking drones with smaller defensive ones, such as the RTX Coyote 2C Interceptor, is another counter-drone option (although one with a $125,000 price tag). In addition, in Ukraine, the practice of using cheaper FPV drones as interceptors against larger fixed-wing drones has grown in popularity for both sides. Although less effective than their purpose-made counterparts, the $500 price tag provides a compelling reason to attempt these maneuvers.

Drone detection at the individual level has also proven important in Ukraine, where handheld detectors can alert soldiers by listening to RF signals and give them pre-warning to attempt to jam incoming FPV drones or run to cover.[86] Another method of electronic warfare, called spoofing, involves sending a false GPS signal to the drone to deceive it about its location or intended flight path. During an Iranian drone and missile attack on April 13, 2024, analysts believe that Israel spoofed the position of ships to create a "ball of confusion" over Eilat in order to protect it.[87] Yet, while jamming and spoofing can be effective countermeasures, they also can produce unintended effects. In April 2024, for example, severe GPS jamming attributed to Russia forced two Finnair flights to Estonia to turn back. According to researchers at the University of Texas at Austin, around 50,000 commercial flights were affected by spoofed signals in the Middle East in 2024.[88]

A newer method of electronic warfare being produced by D-Fend Solutions is called "cyber take-over." It focuses on listening for RF frequencies and identifies the model of drone to hack it to land the drone safely without disrupting communications around it.[89] Yet this is not the only novel, outside-the-box approach. In 2015, for instance, the US Navy was developing a laser-based system to eliminate drones by literally burning them from the sky. As one laser scientist pointed out, however, "the path to laser weapons is littered with dead lasers" and the technology is always just over the horizon.[90] Nevertheless a decade later, in 2024, in response to North Korea's drone attacks, South Korea was reportedly ready to mass-produce a laser that could shoot down drones. The technology "directly irradiates and neutralizes the light source laser generated from optical fibers on the target," according to the South Korean military.[91] While the cost for the weapon is unreleased, officials are saying that each shot would only cost about $1.50,[92] more cost-effective than Israel's Dome defense system or the $480,000 per unit ground-to-air Stinger. Other directed-energy weapons, such as high-power microwave weapons, which use radio and microwave frequencies, are also being tested the US Navy as a method of disabling the motors of unmanned surface vessels.[93] In April 2024, defense contractor BlueHalo revealed that a laser weapon it developed was deployed abroad with the US Army beginning in 2022; however, the US Army has declined to confirm if the system has successfully taken down any drones.[94]

The quest for drone defenses is robust and extends to industry, government, and private researchers, especially as the drone threat grows. One system developed in Greg Falco's Aerospace Adversary Lab at Cornell University is intended to act in a surveillance and then defense capacity to defend against drones (see Figure 3.3). Falco's research group has invested approximately $700 in commercial off-the-shelf computer and sensing components to upgrade a $250 UAV kit into a fully autonomous defense system. The drone is equipped with a light detection and radar (LiDAR)/optical camera sensor, a basic flight controller, and a nano graphic processing unit (GPU), allowing it to process sensor data and dynamically develop new flight plans. Engineered for adversary avoidance, the drone can first detect unwanted assets and then autonomously adjust its flight path to steer clear, all without deviating from its primary mission objectives. For instance, if it encounters an adversarial drone, it leverages data from its camera—processed by the nano GPU—to calculate a new trajectory that avoids the threat. This may be useful to avoid drone hunting drones in future, highlighting how drones can be innovated to counter the counter-systems.

Figure 3.3 Adversarial Drone Detection System

Source: Author’s visit to Professor Greg Falco’s Aerospace Adversary Lab on October 1, 2024.

Overall, a large number of projects have intended to counter the expansive and ever-changing threat of military and weaponized commercial drone systems. Yet, here lies the problem: the drone threat is constantly changing as the software, hardware, command and control systems, and strategies of use are innovated, altered, and upgraded. It is a cat-and-mouse game, one that will not be won by a single “panacea” counter-technology. Instead, drones will be a perennial offensive threat and will only increase in range, power, precision, mass, and yield in the years to come. It is only through arms control, supply chain interception, andincreased investment in air defense that the drone threat will be mitigated.

4
DEBATES ABOUT THE USE OF ARMED DRONES

As the preceding chapters suggest, the United States mainstreamed the use of drones in combat but a number of nation state and nonstate actors have followed suit. The increasing prevalence of the drone has not come without controversy. Long standing debates about international and domestic law, ethics, democratic checks and balances, and effectiveness have continued alongside new patterns of use. This chapter examines those historic debates, highlighting their perennial relevance to today's drone world. It should be noted that there is no legal prohibition against the use of armed drones. Although there are movements to ban weaponized drones through an anti-drone treaty, which will be discussed in subsequent sections, international institutions have generally regarded drones in the spirit of saying that 'drones don't kill people, people kill people.' Just as a F-35 fighter jet is legal as long as it is used in accordance with international law, so too is a drone.

The international legal questions that arise with drones are not focused so much on the technologybut more on howthe technology is used. Such questions about how armed drones are used have been raised most prominently in the context of the United States, which is reasonable given that it has been the country to use armed drones most frequently over the past twenty-five years. Insofar as one country's practice set precedents for how new actors use drones,[1] examining US cases of armed drone strikes in terms of international legal compliance is quite useful. It helps us to see what issues might dominate future drone controversies and helps us cast light on current controversies. Indeed, former CIA director John Brennan remarked in 2012 about how US principles could lay the foundation for how other nations use drones. He said that the administration's use of drones was "establishing precedents that other nations may follow, and not all of them will be nations that share our interests … If we want other nations to use these technologies responsibly, we must use them responsibly. We cannot expect of others what we will not do ourselves."[2] With Brennan's thoughts in mind, we open this chapter with a focus on the legal debates around the US use of drones, which remain pertinent and help us better understand the practices of new drone actors in the 2020s.

Is the use of armed drones legal under international law?

Critics have raised a number of legal questions about the use of armed drones in combat by the United States. One set of questions deals with whether drone strikes comply with the recourse to force under international law (*jus ad bellum*, which means "right to war"). Indeed, the *jus ad bellum* concerns are about "the parameters of the war in which they're being used"—that is whether the United States is authorized to engage in armed attacks at all—rather than the technology itself.[3] Once a nation has resorted to force, the vehicle through which states use force is less relevant than whether that force is proportional and distinguishes between civilian and combatant.

Under the UN Charter, there are two main circumstances under which countries can use force: under Article 51, which is the right to collective or individual self-defense, and with a UN Security Council authorization. Otherwise, Article 2 (4) of the UN Charter prohibits intervention in other nation-states' territories.

One view of drone strikes suggests that they were legal in active battlefields such as Afghanistan, Iraq, and Libya but also in places such as Pakistan, Yemen, and Somalia. This view has suggested that the United States is in fact engaged in a non-international armed conflict (NIAC) with the Taliban, al-Qaeda, and its associates, and can target these forces where they exist. This supportive view also points to drone strikes as consistent with the principle of anticipatory self-defense, which customary international law interprets as a threat that is "instant, overwhelming, and leaving no choice of means, and no moment of deliberation."[4] In its 2011 white paper on targeting suspected terrorists, the United States pointed to the imminent threats outside of "hot battlefields."[5]

Defending its *jus ad bellum* position at a time when the policy was under fire in 2012, Eric Holder (who was then attorney general) outlined the legal basis for using lethal force in counterterrorism operations abroad, saying that the operations would be consistent with law of war principles.[6] Holder spoke to the questions of sovereignty, arguing that "because the United States is in an armed conflict, we are authorized to take action against enemy belligerents under international law … and international law recognizes the inherent right of national self-defense. None of this is changed by the fact that we are not in a conventional war." [7] He thus outlined arguments both about being in a NIAC and also relating to self-defense in terms of striking individuals outside places such as Afghanistan. It was from such legal justifications that the Global War on Terror (GWOT) was born, a conflict that continued with its legacy 'forever wars' – including with US drone strikes in Yemen and Somalia – for over 24 years (at time of writing in 2025) and into the mid-2020s.[8]

A more restrictive and critical view of this self-defense claim would say that the use of drones for targeting suspected terrorists outside "hot" battlefields such as Afghanistan violates the *jus ad bellum* principle of international law. Legal scholars such as Mary Ellen O'Connell disputed that the United States was engaged in an armed conflict with Pakistan, Yemen, and Somalia insofar as the hostilities are sporadic rather than a case of ongoing conflict, which would rule out the legality of drone strikes in these countries even if those countries consent.[9] In this context, questions can also be raised about whether the targets under fire are even compatible with anticipatory self-defense and the initial post-9/11 GWOT justifications. Many of the targets during the early 2010s were lower-level foot soldiers who were "neither presently aggressing nor temporally about to aggress"; just 2 percent were "high-level targets."[10]

In a related point about targeting, a one additional line of critiquefocuses on *jus in bello* principles, which pertain to the use of force *in* war. In particular, scholars have debated whether combat drones are compatible with the principles of *distinction* and *proportionality*. The origins of both principles come from the just war tradition, which provided a set of philosophical and ethical guidelines for how actors would conduct themselves in conflict. These guidelines were later codified into the protocols that form the basis of international humanitarian law (IHL), which expects actors to discriminate between civilians and combatants, targeting the latter for military advantage and minimizing the damage to the former.[11]

The principle of distinction first requires separating combatants from civilians and requires that parties to a conflict only engage combatants and spare civilians. It also requires parties to a conflict to distinguish between civilian objects (such as homes, schools, hospitals, and cultural sites) and military objectives (such as military bases, weapons depots, and command centers), taking all feasible precautions to avoid causing harm to the former. Further, parties to a conflict must avoid indiscriminate attacks. The principle is proportionality, on the other hand, involves taking into account the anticipated military advantage and ensuring that it exceeds civilian harm. Neither of these principles say that civilian casualties constitute a war crime but that parties to a conflict must take care to distinguish between combatants and civilians and ensure that the military advantage is greater than the damage to civilians.

According to the principle of distinction, actors are prohibited from directing their attacks against civilians. As stated in Article 48 of the Protocol Additional to the Geneva Convention (AP I), "In order to ensure respect for and protection of the civilian population and civilian objects, the

Parties to the conflict shall at all times distinguish between the civilian population and combatants and between civilian objects and military objectives and accordingly shall direct their operations only against military objectives."[12] Beyond this provision, Article 57 (5) (a) of AP I requires that countries "take all feasible precautions in the choice of means and methods of attack with a view to avoiding or in any event minimizing incidental loss of civilian life, injury to civilians and damage to civilian objects."[13]

Building on the principle of distinction, the principle of proportionality suggests that the anticipated military gain of a strike must exceed the anticipated damage to civilians and their property. Article 51 (5) (b) of AP I prohibits "an attack which may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive in relation to the concrete and direct military advantage anticipated."[14] As the former prosecutor of the International Criminal Court, Luis Moreno-Ocampo, suggested, "the death of civilians… does not in itself constitute a war crime."[15] It must be intentional and must exceed the anticipated military advantage.

Members of the policy and legal community have debated at length whether drone strikes meet the principles of distinction and proportionality under *jus in bello*. As with the discussion of *jus ad bellum*, much of the debate focused on the United States because of its prolific use of drones. Some scholars highlight the virtue of the drone to be both proportionate and discriminate. In regard to the American counterterrorism case, Max Boot observed, "[t]he US military operates a bewildering array of sensors to cut through the fog of war."[16] Military documents themselves point to the way that technology facilitates the kind of awareness that would help comply with international legal principles. The military's Joint Vision 2010 noted, for instance, that "in all operations technological advances … allow [the warfighters] to make better decisions."[17] The precision capabilities of an armed Predator or Reaper that can loiter over targets and carry precision munitions are therefore seen asan improvement over earlier alternatives such as carpet-bombing. Indeed, drones may also be an improvement over alternatives, such as the use of ground forces, long-range missile strikes, or manned air strikes. In his collection of data from drone strikes, Avery Plaw suggests that civilian fatalities from the use of drones are comparatively lower than either non-drone US operations or Pakistani ground operations in Federally Administered Tribal Areas (FATA), suggesting that drone strikes are more proportional than the alternatives, or at least less disproportional. He concludes that "a fair-minded evaluation of the best data we have available suggests that the drone program compares favorably with similar operations and contemporary armed conflict more generally."[18]

Other accounts of American targeting have been less charitable in terms of compliance with IHL. It was John Brennan (who was then CIA director), who claimed that "one of the things President Obama has insisted on is that we're exceptionally precise and surgical in terms of addressing the terrorist threat."[19] The implication is that if a strike is undertaken with 'surgical precision' it naturally fulfills the principles of distinction and proportionality, hitting the terrorists and sparing damage to others. The trouble is, this also implies that precision alone can serve as the ultimate authority in assessing context and identity and striking the correct person. This is not the case. In reality all *precision* really means is guaranteed death and destruction for whoever is on the receiving end, even if the intelligence is wrong and person is a civilian.[20] Put simply, a precision drone strike without accurate intelligence may well end in jus in bello violations, no matter how technically *precise* and *surgical* the strike is. Inherent in these judgments is the often-subjective distinction between a combatant (a legal target) and a civilian (not a legal or legitimate target). As earlier sections highlight, drone strikes have indeed killed a number of civilians, but the reported percentages vary widely (see Chapter 2, *When did nation-states start using drone strikes and for what purposes?*). One of the reasons why these accounts and percentages vary widely is because of fluid interpretations of who is defined as a civilianand who is defined as a legal combatant target. Part of the problem resides in the ambiguity of Article 4 of the Geneva Conventions, which designates an individual as a combatant in part by "having a fixed distinctive sign recognizable at a distance."[21] The

1977 AP I states that “civilians shall enjoy the protection afforded by this section, unless and for such time as they take a direct part in hostilities.”[22]

Conventional wars such as World War II made these criteria quite clear, since combatants were generally wearing uniforms. Modern unconventional conflict creates situations where combatants are not clearly identifiable based on emblems, and are often oscillating between direct and indirect participant and civilian. The commingling makes it difficult to discern legitimate combatants from protected civilians.[23] Applying the standard to counterterrorist situations is therefore quite fraught. The International Committee of the Red Cross has sought to offer clear guidance on the difference between direct and indirect participation, but even their legal experts have had challenges coming to a consensus. As the Israeli High Court of Justice’s Judgment on Targeted Killings reported, “the notion of direct participation in hostilities is complex, emotive, and still inadequately resolved.”[24] Its own view is that the “direct” character of the part taken should not be narrowed merely to the person committing the physical act of attack but should also include people in the business of intelligence and transportation of those who do carry out those attacks. By this measure, almost anyone in a community could wittingly or unwittingly be in a position to be considered as having a direct involvement in hostilities.[25]

That the definition can be quite subjective explains, in part, the wide variation among accounts of civilian casualties, as discussed earlier. For example, many cases of individuals killed are ambiguous, with press reports referring to “people killed” as opposed to assigning a designation, such as “civilian,” to aid identification and data gathering. Indeed, this is one reason a government can claim zero civilian casualties but have that position be disputed by studies involving interviews of individuals on the ground near the attacks, where people might have a different understanding of the role the target had played in hostilities.

During his administration, President Obama defended his drone strike policy not just on the recourse to force side—going after targets considered to be “a continuing and imminent threat to the American people,” in areas where “there are no other governments capable of effectively addressing the threat"[26]—but also the *jus in bello* aspect of civilian harm. He noted that the United States would only conduct strikes where there was "near-certainty that no civilians will be killed or injured."[27]

In 2013, when President Obama gave several speeches about drone strikes being consistent with international law, few observers would have agreed that the United States was taking sufficient care to avoid civilian harm. Nongovernmental organizations such as Amnesty International and international organizations such as the UN expressed concern that the United States targeted individuals in ways that it deemed extrajudicial or at least pushing the boundaries of international law. In 2021, Amnesty International USA submitted a statement on "20 years of US drone strikes," suggesting that the United States had not taken sufficient precautions to avoid civilian harm.[28] It also commended the United States for admitting that its infamous August 2021 drone strike during the fraught withdrawal from Afghanistan had inadvertently killed 10 people. As the Pentagon admitted in November 2021, the United States had struck a Toyota Corolla on August 29 of that year, believing that the car was operated by an Islamic State leader who had planned to target evacuees at the international airport in Afghanistan.[29] They believed that the attack was a legal defensive action and did not see that children were in the area. As the example suggests, the technology itself does not make a strike inherently more or less legal. Indeed, the experience of the United States suggests that having a platform that can loiter over its target for long periods to ascertain combatant status plus precision-guided munitions does not alone create compatibility with the laws of armed conflict. That combination of features is helpful, but as the United States has shown on a number of occasions, militaries also need good intelligence. Drone can circle over a target for many hours, days, or even weeks, then strike the target with precision—but hit the wrong person if it has been tracking the wrong person to begin with.

Is the use of armed drones ethical?

The use of armed drones has provoked considerable ethical debate. One view suggests that if a nation-state uses force as part of its counterterrorism policy, then the most humane, ethical way to carry it out is through the use of drone strikes. As Dan Byman has pointed out, drone strikes are more ethical than some alternative approaches to counterterrorism, such as those conducted by nations who have a history of torturing detainees and indiscriminately bombing civilian areas.[30]

Bradley Strawser has also defended the use of drones on ethical and moral grounds, suggesting that drones are more accurate in terms of reducing casualties on the ground and do not bring a pilot into the line of fire. As he and others have suggested, drones are not novel in terms of their ability to engage targets lethally and if anything are a more appropriate vehicle than predecessors or existing alternatives. Strawser suggests that if a country is going to engage in conflict, drones are the most humane, legal way to do it. Indeed, "using such technology is, in fact, obligatory."[31] The combination of capabilities that can surveil and engage targets is preferable to "dumb bombs" with no loitering or precision capabilities.

On the other side of the debate are philosophers who have raised the question about whether drones introduce a moral hazard for the use of force.[32] Moral hazards involve situations whereby avoiding cost has the perverse incentive of causing one actor to engage in risks that they would not otherwise take. Consider, for instance, that in 2014, 70 percent of skiers reported wearing helmets—triple the number from 2003. Still the number of head injuries did not decline. The hunch is that helmets give individuals license to take more risks, exposing them to injuries that even helmets cannot protect against.[33]

This everyday example of costs and risks applies in the context of drones, as drones present no costs to the user. The drone operators are not at risk, and the domestic populace does not see body bags coming home from war. The result, backed by comments of many former leaders (including former secretaries of defense Gates and Panetta), is that the use of drones has allowed the United States to take liberties with using force precisely because the technology is relatively antiseptic and low-cost.[34] According to this formulation, the problem is not so much with how a particular side uses force, but that it *is* using force. The counterfactual question it raises is whether that actor would have engaged in force in the absence of the enabling technology. The argument is not germane to cases like Ukraine where a ground invasion launched the war and drones later followed and became ubiquitous. But the fact that the United States has engaged in armed drone strikes with the frequency it did, and to the near-exclusion of manned alternatives in certain context, suggests a counterfactual world with lower levels of military force.

It is on this side of the philosophical debate that theorists such as Michael Walzer come down. Walzer worries that to those equipped with a hammer, everything will look like a nail, and in the case of having armed drones, everything will look like a viable, legitimate target. He notes that “here is the difficulty: the technology is so good that the criteria for using it are likely to be steadily relaxed,” causing an “overuse of drones” and tendency to use drones as a blunt instrument rather than as a vehicle for precise, targeted killing. He concludes that using drones in this way is not “morally right,” and implies that bearing some risk ourselves could help create a more circumspect and moral targeting strategy.[35] Such guidance, of course, runs counter to one key reason why leaders have found drones to be attractive, which is that they minimize risk to one’s own side.

Do countries target their own citizens with drones?

Historically, countries have rarely targeted their own citizens with drones. Yet this has begun to change. Some states target citizens who join distant terror organization on foreign soil; others use drones in apparent attempts at domestic control, striking elements of their own population. Both ‘strategies’ raise highly relevant, hotly debated, and important questions about the legality and ethics of such actions.

For years after the 9/11 terrorist attack, the United States identified, located, and captured such individuals, bringing them to Guantanamo Bay. The problem, however, was that Guantanamo Bay became stigmatized as a place where due process was lacking. In 2013, Daniel Klaidman wrote a book *Kill or Capture* based on hundreds of interviews with officials of the Obama administration who acknowledged that drone strikes became a way to remove suspected terrorists without the dilemma about where to house and then try the suspected terrorists.[36]

An even more acute dilemma arose when those suspected terrorists were US citizens. In 2011, the United States carried out a strike in Yemen that killed Anwar Al-Awlaki, suspected of being an al-Qaeda recruiter and promoter of radical thought. He maintained a blog, a YouTube channel, and a magazine, named *Inspire*, which was the first online jihadi magazine in English writing in "a comfortable American vernacular," as *The New York Times* described it.[37] Both were often cited as inspiration for terrorist attacks. At the time, he was central in organizing al-Qaeda's foreign operations.[38] Eric Holder (who was then attorney general) wrote that, of the four US citizens killed in Yemen, only Al-Awlaki was deliberately targeted.[39]

While the others killed in Yemen were not deliberate targets, most had some suspected ties to terrorism. Al-Awlaki's son, Abdulrahman, who was born in Denver, Colorado, was killed on October 11, 2011. By all accounts, the strike was not targeting Abdulrahman; many US officials, including Barack Obama, were allegedly "surprised and upset" that Abdulrahman was killed.[40] Al-Awkali's son had no known ties to terrorism and was apparently out looking for his father, with the actual target supposedly being an Egyptian named Ibrahim al-Banna, who was suspected of being a senior operative in Yemen's al-Qaeda affiliate, al-Qaeda in the Arabian Peninsula.[41]

Samir Khan, on the other hand, who was killed in the same attack as Anwar Al-Awlaki, appeared to be somewhat more closely tied to terrorist activities. Khan, who was born in Riyadh, Saudi Arabia, had been raised in Queens, New York, later to move with his family to Charlotte, North

Carolina. He had been maintaining a jihadist blog in his parents' basement when he moved to Yemen in 2009. There he became involved in the radical *Inspire* magazine. For example, one passage attributed to him declared that "it doesn't take a rocket scientist to figure out that I [am] Al Qaeda to the core."[42] Although not directly targeted in the strike that killed Al-Awlaki, Khan would certainly have been on the radar of American counterterrorism officials.

In his memoir, Leon Panetta (Former United States Secretary of Defense) addressed at least the intentional killing of Americans, specifically that of Awlaki. He wrote without remorse that Awlaki "actively and repeatedly took action to kill Americans and instill fear. He did not just exercise his rights of speech, but rather worked directly to plant bombs on planes and in cars, specifically intending those to detonate on or above American soil. He devoted his adult life to murdering his fellow citizens, and he was continuing that work at the time of his death."[43]

There were two instances in which Americans were deliberately killed in Pakistani drone strikes. The first was on November 16, 2011, which killed Jude Kenan Mohammed. Mohammed was the son of an American mother and Pakistani father and grew up in North Carolina. In 2008, a few weeks before his twentieth birthday, Mohammed left the United States to visit his father in Pakistan. He then disappeared in Pakistan, likely to join and train with al-Qaeda. In 2009, Mohammed was placed on the FBI's Most Wanted list for providing material support to terrorists. The government reported that he was not specifically targeted, but clearly was considered to be of interest to the US counterterrorism officials.[44]

In other cases, the United States inadvertently killed its own citizens with drone strikes. In April 2015, the United States reported that it had accidentally killed an American and an Italian aid workers who were being held hostage. The United States reported that it "had 'no reason to believe either hostage was present'" during the operation, which intended to target two suspected American al-Qaeda leaders who were thought to be in the compound. Despite near-continuous surveillance, the United States had not seen the hostages brought into the compound, thus inadvertently putting the two innocent individuals in the crosshairs.[45]

The same strike that killed the aid workers also killed Adam Gadahn, known as the American mouthpiece of al-Qaeda for speaking against the country and in support of the terrorist organization. The US government reported that Gadahn was not a specific target but was in the al-Qaeda compound that had been housing the aid workers who were also killed. A separate strike in April 2015 killed another American suspected of being an al-Qaeda militant, named Ahmed Farouq, although he too was not specifically targeted.[46]

In February 2013, a white paper seeking to clarify and institutionalize the general conditions for striking Americans was leaked to NBC News. That Department of Justice white paper sought to provide the legal reasoning behind targeting American citizens with drones. The memo pointed to legal circumstances based on the belief that an individual is a "senior operational leader" of al-Qaeda or "an associated force." Belief does not require specific intelligence about a plot to attack the United States. Indeed, the memo states that the United States does not need "clear evidence that a specific attack on US persons and interests will take place in the immediate future." The conceptualization was therefore thought to present "a more expansive definition of self-defense or imminent attack" than had been stated in public speeches.[47]

It was this question of targeting Americans that Senator Rand Paul used as the fulcrum for his filibuster of John Brennan's nomination as director of the CIA in 2013. In one of the longest filibusters in recent Senate history, nearly 13 hours long, Senator Paul raised the specter that drones were a threat to US citizens on US soil.[48] "No American should be killed by a drone on American soil without first being charged with a crime, without first being found guilty of a crime by a court," Paul said. "How can you kill someone without going to a judge, or a jury?"[49] When the filibuster ended, the vote to confirm Brennan proceeded and he became the next CIA director.

Less than a year later, news outlets reported that the US counterterrorism community was tracking an American working for al-Qaeda and debating whether to target this individual. Although President Obama was due to make the final decision on targeting Abdullah al-Shami, translated as “Abdullah the Syrian,” some members of Congress were allegedly informed. As Mazzetti and Schmitt put it, Abdullah al-Shami’s “nom de guerre masks a reality: He was born in the United States” before becoming a militant and fighting with al-Qaeda in Pakistan.[50] The United States also moved aggressively to find Jehad Serwan Mostafa, another US citizen, thought to be involved with Al-Shabab in Somalia. The Justice Department offered a $5 million reward for information leading to his capture or conviction. Based on US policy, the killing would be justified if the alternative of capture was not feasible or if he was considered an imminent threat.

Overall, therefore, it’s clear to see how the U.S did not shy away from targeting its citizens who had travelled abroad to join terror organizations. These strikes were not without controversy and set the legal basis under which the US government could kill a US citizen without due process. This disquieting prospect is only tempered by the fact that this extreme measure was used rarely and not without great scrutiny. In the 2020s, however, as drones proliferate, such practices appear to be becoming increasingly common.

In recent years, many countries have targeted their own civilians with drones during similar counterterrorism activities. In 2021, the Indonesian military allegedly utilized drones and helicopters to drop modified mortar rounds on Indigenous villages in the Indonesian province of Papua in an attempt to quell armed resistance from the West Papua National Liberation Army. While no civilians were killed in these strikes, they destroyed numerous homes and places of worship displacing villagers to hide in the jungle.[51] Witness testimonies to Human Rights Monitor also indicated that drones were used to spy on the villages to assist ground forces during raids.[52] In other instances, countries have framed the targeting of civilians as erroneous targeting. In January of 2023, the Nigerian Army killed 39 civilian cattle herders; although the government apologized in June, the Fulani herders believe that they are being intentionally targeted as the government has often called them bandits.[53] As mentioned in Chapter 3, later that year in December, the Nigerian Army accidentally targeted and killed at least 88 civilians and injured 68 more while they were taking part in a religious festival, adding to the at least 300 civilians accidentally killed by air strike in Nigeria.[54] Similarly, the Burkina Faso military claimed to strike Islamic fighters but deployed the drones in crowded markets, killing at least 60 civilians and injuring at least 55. Ilaria Allegrozzi, a senior researcher for Human Rights Watch, argued that these strikes were violations of the laws of war.[55] Drones also appear to have assisted the Burkina Faso Rapid Intervention Battalion in the execution of 223 civilians in February 2024. A report published by state media described aerial drones being used to track fighters and then being called off, which Human Rights Watch argued could mean a desire to prevent the crimes from being recorded. Supporting the idea of malicious targeting, the US Commission on International Religious Freedom also issued an update in 2023 documenting abuses by Burkina Faso and Nigeria against Fulani Muslims.[56]

China has used unarmed drones to surveil and repress ethnic minorities such as the Uyghur people in Xinjiang Province, using DJI (a prominent Chinese drone manufacturer) for “stability maintenance, counter-terrorism, and conservation purposes.”[57] DJI has in turn come under international condemnation for facilitating repression, including by the United States under the Countering CCP Drones Act for posing “an unacceptable risk to U.S. national security.”[58] The risk is that DJI presents a violation of American values in acts abroad, such as the repression of an ethnic group; the fear is also that the drones will be used for espionage via the data that drones could report back to servers in China. Current US law prohibits the use of federal funding for the purchase of DJI drones.[59]

How does the use of drones affect democratic checks and balances?

Immanuel Kant famously argued that what makes democracies different from non-democracies is that their citizens directly bear the burdens of war. Because it's the people who fight, suffer, and pay the costs, their consent for war depends on whether they believe the conflict is justified. When the public no longer sees the war as worth the sacrifice, they're more likely to pressure the government to end it.[60]

International relations scholars have followed up in this vein and suggested that since a democratic populace will "ultimately pay the price of war in higher taxes and bloodshed," they will "sue for peace" when the costs mount, creating shorter wars at lower cost.[61] The accountability mechanism underlying this logic hinges on the public bearing some burden of war. With drones, however, the public can be woefully out of touch with the consequences; indeed, insofar as all politics is local and one's family and friends are not coming home in body bags, then the incentive to pressure leaders to end wars diminishes. It is not surprising that the domestic public perception of drones in the United States was favorable, with support for drone deployment rarely falling below 50 percent for polls taken between 2011 and 2014 (while the first strike was in 2002, polls did not begin until 2011) and the modal support levels reaching around 65 percent[62]. A survey of Americans in 2021 found that respondents generally found drone strikes legitimate, with an average of 6.2 on a scale of 1–10, with 10 being the most morally legitimate.[63]

By contrast, Americans were overwhelmingly concerned about drone use domestically, especially when it came to their own privacy. Sixty-four percent of Americans indicated that they would be very or somewhat concerned if law enforcement used drones for surveillance, and 67 percent were opposed to drones being used for routine policing.[64] Americans also expressed skepticism about the use of drones for commercial purposes by a 2–1 margin in opposition, with only 21 percent in favor—the remaining 35 percent neither supportive nor opposed. However, a 2021 national survey from the University of North Dakota found that while 89 percent of respondents were worried about the improper use of drones by the government and private companies, when asked about specific tasks such as surveillance, surveying, research, delivery, and filming, participants on average believed that the benefits of using drones outweigh the risks.[65] Attitudes may have shifted, or these data may suggest that attitudes vary across different regions within a country.

American support for the foreign use of drones, however, created a favorable backdrop for Congress to abdicate a constitutional responsibility of overseeing the use of force abroad. In the United States, the responsibility for authorizing military force resides with Congress, yet the relationship between the use of drones and congressional checks in wartime is uneasy at best.

Most significantly, Congress has not specifically authorized the use of drone strikes outside active battlefields. In 2001 it passed the Authorization for the Use of Military Force (AUMF), which authorized the president to "use all necessary and appropriate force against those nations, organizations, or persons he determines planned, authorized, committed, or aided the terrorist attacks that occurred on September 11, 2001, or harbored such organizations or persons, in order to prevent any future acts of international terrorism against the United States by such nations, organizations or persons."[66] While President Bush and President Obama have implicitly used the AUMF to legitimize drone strikes in places such as Pakistan, Yemen, and Somalia, a legal debate has evolved dealing with whether the 2001 AUMF intended to be open-ended in both time and space. Does Al-Shabab in Somalia, for example, qualify under the AUMF? The group was not present at the time of 9/11 but ostensibly has been placed within the al-Qaeda network since its inception. Ryan Goodman pointed out as much after the September 2014 strike against the leader of Al-Shabab, Ahmed Abdi Godane, by questioning whether or not the group is an "associated force" of al-Qaeda. The answer to this question provides or denies the United States the legal authority to target members of Al-Shabab.

Despite the unclear ground upon which the United States is making attacks against Al-Shabab, there has been little congressional opposition to strikes against them on these grounds.[67] While President Obama himself urged the repeal of the AUMF, stating that he "look[s] forward to engaging Congress and the American people in efforts to refine, and ultimately repeal, the AUMF's mandate"[68] he did not identify a replacement that would authorize the type of strikes that have been allegedly carried out with this authorization. As a result, President Obama ended up making the most of AUMF during his tenure.

For example, during the Libya intervention (2011), the Obama administration claimed that it did not have to seek authorization for military force because it was only using drones, thereby exempting it from the 1973 War Powers Resolution, which would require congressional authorization if troops were deployed for more than 60 days. It stated that "U.S. operations do not involve sustained fighting or active exchanges of fire with hostile forces, nor do they involve U.S. ground troops" and do not obligate the United States to seek specific authorization.[69] In addition, in the 2014 strikes against Islamic State (IS) in Iraq and Syria, the Obama administration appeared to act on the basis of Article II of the US Constitution, which grants commander-in-chief privileges to the president. Harold Koh, former legal advisor to the president, suggested that the government has relied on the "splinter theory" that allows it to use force based on the "associated forces" part of the AUMF. The basic argument suggested that the AUMF authorized the president to engage in an armed counterterrorism campaign, and that since the 9/11 attacks, the original al-Qaeda group has splintered into other groups, some of which may have had different objectives, but bore enough resemblance to the parent group to be culpable and subject to being targeted under the original AUMF.[70]

Consistent with this logic, the executive branch continued to engage in strikes against organizations that are new since 9/11, such as IS, al-Qaeda in the Arabian Peninsula (AQAP), and al-Qaeda in the Islamic Maghreb (AQIM), and that remain unchecked by the legislative branch. Congress has been loathed to restrict the president's autonomy when it comes to using armed drones for counterterrorism. Some individuals, such as Congressman Adam Schiff (D-CA), proposed a sunset clause for the AUMF, but these measures gained little traction. Congress has little incentive to introduce meaningful restrictions. While it is unlikely to get credit for foreign policy successes, it would be blamed if it introduced restrictions and a terrorist attack took place. Its incentives then are to grant the executive branch considerable latitude when it comes to counterterrorism policy, especially since the status quo comes at no real cost to the constituents represented by the members of Congress.

The 2002 AUMF against Iraq has also been used for justification of drone strikes. Most notably, the first Trump administration cited it as legal justification for its strike against Iranian general Qassem Soleimani in 2020. After this strike, a bipartisan joint resolution S.J. 68 passed in the 116th Congress, stating that actions against Iran did not qualify under the 2001 and the 2002 AUMF. However, after being vetoed by the first Trump administration, the resolution could not garner enough votes to overturn the veto and failed to become law.

Under the Biden administration, a bill to revoke the Iraq AUMF passed the Senate but did not receive large amounts of support, as the House Foreign Affairs Committee Chair Michael McCaul (R-TX) favored a different bill that would repeal the 2002 AUMF and replace it with a more limited authorization.[71]

Overall, the 2001 and 2002 AUMFs dramatically expanded the President's ability to wage war with limited, if any, sustained oversight from Congress. The rise of drone warfare has only deepened this dynamic. Because drones lower the immediate costs of war—politically, financially, and in terms of American lives—they allow military action to continue on the margins of public attention and congressional scrutiny. In effect, the combination of broad, open-ended war authorizations and remote, low-visibility weapons systems like drones has weakened traditional democratic checks and balances on the use of force, making it easier for presidents to wage perpetual, undeclared wars with little meaningful debate or public accountability.

Where is public opinion on drone strikes?

As the use of armed drones grew in frequency between 2005 and 2010, a number of groups began forming an anti-drone coalition in protest. What unified this movement was a commitment to nonviolence in the service of, at the most extreme, banning all drones through an international treaty, and, more modestly, reducing reliance on drones and creating more accountability. The movement gained international attention, with 75,000 individuals having signed a petition that would take a number of actions against the use of drones, including an international ban on the use or sale of weaponized drones, but also international action under the International Criminal Court to investigate those who carried out drone attacks.

The international movement had national-level followings as well. In the United States, one of the most visible groups in the movement was the Global Drones Watch run by Code Pink Women for Peace, which described itself as a grassroots organization working to end US-funded wars. The group organized a 2013 summit in Washington, DC, with delegates from Yemen, Afghanistan, and Germany and sought to highlight the casualties that have resulted from American drone strikes. More recently, the group has primarily focused on Palestinian liberation and human rights abuses, but still assists in co-sponsoring counter drone protests. Other groups in the United States have joined the anti-drone movement. In May 2023, for example, Veterans for Peace, Ban Killer Drones, and Code Pink organized a protest outside of Holloman Air Force Base, culminating in the arrest of three veterans.[72]

Although the use of drones is generally popular among American legislators, isolated members of Congress have voiced concerns about it, generally in the context of the homeland. As mentioned in the section above, Senator Rand Paul's (R-KY) filibuster of President Obama's 2013 nomination of John Brennan for the director of the CIA focused primarily on targeting Americans and primarily with force (though also through surveillance), but had little to say about the appropriateness of using armed drones abroad. Some members of Congress, such as Congressman Adam

Schiff (D-CA), questioned the CIA's dominant role in conducting the armed drone strikes in places like Yemen and Pakistan, asking whether there was adequate oversight compared to the Joint Special Operations Command; nevertheless, the CIA remained the government agency responsible for most strikes over the long-term. In short, opposition to the executive's drone policy has largely been silent in the legislative branch.

The anti-drone movement had local roots, often at locations proximate to drone bases. For example, groups in upstate New York, many of which have connections with Catholic pacifist groups, near Hancock Airfield outside Syracuse have protested the use of this base to carry out attacks in Afghanistan. Several acts of civil disobedience have landed many of the protesters in local jails. One prominent example that made national headlines featured Mary Anne Grady Flores, a grandmother of four living in Ithaca, NY, who was sentenced to jail for a year for participating in a protest outside Hancock Airfield after being instructed by the local courts to desist. However, many of these anti-drone movements became more muted over time as drones proliferated, strikes normalized, and the frequency of American counterterrorism strikes declined.

Uproar about US counterterrorism strikes was not infrequent, especially in visible cases like the August 2021 botched strike in Afghanistan or the January 2020 strike against Iranian general Qasem Soleimani in Iraq. But for what has become the model drone usage—in the context of interstate conflicts, such as between Ukraine and Russia or Armenia and Azerbaijan—global opposition is limited. The reason is that in these contexts, drones are used like any other tool in the toolkit and have not raised the same type of international legal concerns about sovereignty, distinction, or proportionality as the US counterterrorism strikes.

Do drone strikes "work" for counterterrorism?

One of the important debates in the context of counterterrorism strikes is whether these strikes are an effective counterterrorism tool. The prevalent use of drones by the United States suggests that at least some high-level individuals think that these strikes are effective in addressing the terrorist threat. The Obama administration repeatedly defended its use of drone strikes as "narrowly targeting our action against those who want to kill us,"[73] and even critics acknowledge that the use of armed drones has been successful in eliminating members of al-Qaeda.[74] Perhaps the more vexing question, though, is not the tactical question whether drone strikes have killed a number of suspected terrorists—a point on which most sides can agree—but the strategic question whether this is an effective longer-term strategy. In other words, are drone strikes creating more terrorists than they kill?

The reasoning behind this question is as follows: Drone strikes taking place in areas such as Pakistan could be seen by some individuals in those countries as a violation of sovereignty. The strikes also occasionally kill civilians, and the drones themselves are terrifying—imagine hearing the constant buzz of a drone overhead. As one individual told *New Yorker* writer Steve Coll in 2014, "drones may kill relatively few but they terrify many more. They turned the people into psychiatric patients. The F-16s might be less accurate but they come and go."[75] According to this account, drones alienated large numbers of the populace, causing some individuals to take up arms against the perpetrators, in this case the United States. Drones then, based on this argument, create a backlash effect, killing some terrorists in the short term but creating far more in the long term.

There is much anecdotal evidence to this effect. In a 2012 tweet, a Yemeni lawyer wrote: "Dear Obama, when a US drone missile kills a child in Yemen, the father will go to war with you, guaranteed. Nothing to do with Al Qaeda."[76] This view suggests that *revenge* drives individuals to become militant, not the ideology surrounding extremist Muslim groups. Another piece of evidence in this vein is the uptick in AQAP numbers, which spiked in the years after drone strikes. AQAP consisted of a few hundred members in 2009, with no regional influence. By 2012, it had thousands of members and had control of some territory in Yemen.[77] Greg Johnsen, who spent a considerable amount of time in Yemen, concluded that drone strikes helped recruitment of AQAP—they are the reason why the United States "lost Yemen." With a large number of strikes and a local base for training militants, Yemen became a breeding ground for future terrorists.[78] The 2014 Nobel Peace Prize co-recipient Malala Yousafzai met with President Obama at the White House and expressed skepticism about the effectiveness of drone strikes, arguing that a more effective long-term strategy is to send books, not drones.

While this line of thinking is certainly compelling, critics have countered that some threats are so imminent and potentially destructive that not eliminating them is more catastrophic than conducting a strike that might trigger a backlash over the longer term.[79] Others suggest that locals actually see these strikes as more benign than alternatives, such as the ground forces (whether of the target country or of the United States), which would likely displace large parts of the local population and destroy infrastructure.[80] This also seems to be a sustainable position. In fact, the two accounts could be fully compatible with each other if it means that in the short term, militants are killed but in the longer term, more militants are created. Leaders in a democracy might still have incentives to stop tomorrow's attack and then deal with the possibility of future attacks as they arise.

Investigating these two perspectives systematically is important since it bears on the types of counterterrorism and counter-radicalization efforts that would be needed alongside the drone strikes, and on the overall wisdom of the current policy. However, the question is a difficult one to evaluate empirically, the reason being that the location of strikes is not randomly distributed. They occur where there are militants, so looking at militant activity after a strike would not be independent of the reason why there were strikes in the first place. Saying that there was more militant activity in Waziristan after a strike compared to Switzerland after no strike is not meaningful since the reason for the initial strike is that Waziristan was a region of active terrorist activity. Data on drone strikes present challenges for this sort of comparison.

Some scholars suggest that they can match an area with a strike against one without a strike and attribute differences in militant activity to the cause of the drone strike. These studies have found that drone strikes lower the incidence and lethality of terrorist attacks. This being said, the studies cannot vouch for the long-term consequences, which would be important given that a blowback effect would be a longer-term proposition of recruitment, training, and planning a terrorist attack.[81] The finding directly challenges other studies that have shown removing a terrorist leader does not lead to organizational decline.[82]

Although the empirical question whether drone strikes create more terrorists than they kill is a difficult one to answer, there is certainly a plausible theoretical linkage between drone strikes and blowback, as well as persuasive qualitative evidence to this effect.[83] It is in this spirit of a precautionary strategy guarding radicalization that President Obama concluded that "the use of force must be seen as part of a larger discussion we need to have about a comprehensive counterterrorism strategy,"[84] including the role of foreign assistance. More recent conflicts, such as the Israel-Hamas war, have revived these discussions. For instance, H.A. Hellyer, a geopolitics researcher for the Carnegie Endowment for International Peace, argues that civilian casualties will likely increase recruitment to Hamas as civilians wish to defend themselves from Israeli attacks.[85] Thus, the use of drone strikes in the absence of broader strategic goals matched by resources might have short-term tactical gains without having longer-term strategic advantages.

5
DRONES FOR THE GROUND AND SEA

Up until now, the discussion has largely focused on drones as an *aerial* technology. This is consistent with how the term "drone" has been conventionally used. It is also consistent with the way many countries have channeled their unmanned resources. The US funding of unmanned systems shows that the vast majority of resources have historically been dedicated to aerial systems. As Table 5.1 shows, almost 91 percent of the US budget for unmanned systems for the years 2014–2018 was allocated for aerial systems. Nevertheless, this has begun to change, with demand growing for drones in other domains.

Table 5.1 US Department of Defense Unmanned Systems Funding ($ Million)

Year	Air	Ground	Sea	Total
2014	3775.9	13.0	330.3	4119.1
2015	4819.4	47.0	409.8	5276.2
2016	4467.6	44.3	408.6	4920.5
2017	4217.0	52.7	429.7	4700.4
2018	4419.3	66.0	381.8	4867.1
Total across years	21,699.1	223.9	1960.2	23,883.2

Source: Unmanned Systems Integrated Roadmap FY2013–2038.

Take the Unmanned Ground Vehicle (UGV) as a key example. UGVs are far from new, as this section will show, with the origins of these "ground drones" traced back to before World War I. Yet, with their proven utility in explosive ordnance disposal during the War on Terror, their growing use in the commercial sector for deliveries, their military application as offensive weapons by Russia in Ukraine, and the parallel advances taking place in the self-driving car sector (such as with Tesla and Waymo), demand for these systems has grown once again. Currently valued at $3.07 billion, the global UGV market (excluding the automotive industry) is projected to achieve a compound annual growth rate of 8.6 percent over the next decade, growing "to $6.35 billion by 2032."[1]

There are also Unmanned Maritime Vehicles (UMVs), otherwise known as maritime drones, which have increasingly defined asymmetric naval warfare in the 2020s. These drones can be subdivided into Unmanned Surface Vessels (USVs), sometimes known as 'drone boats' that operate on the surface of the water—and Unmanned Underwater Vehicles (UUVs), also known as underwater drones, which operate under the surface of the water as uncrewed submarines. These UUVs can be subdivided into two classes: Remotely Operated Vehicles (ROVs) and Autonomous Vehicles (AVs). Again, all these systems have long histories that can be traced back to the to the 1890s and into the first decade of the twentieth century. In terms of USVs, the recent success of Ukraine in blunting the impact of Russia's Black Sea fleet with rudimentary drone boats has led to renewed military interest in the systems. According to GlobalData's latest projection, the USV market is set to grow at an annual rate of 6.7 percent, from $1.1 billion in 2024 to $2.5 billion by 2034.[2] In addition, the UUV market is set to achieve similar rates of growth. Due to threats to underwater infrastructure, renewed strategic nuclear tensions, and burgeoning scientific demand, the UUV market is expected to increase from "$379m in 2023 to $965m in 2033."[3]

With all of this in mind, and the projected growing impact of UGVs and UMVs in conflict and civilian life, it is important we look at the past, present, and future of these systems in both the commercial and military domains. This includes the use of Unmanned Aerial Vehicles (UAVs) at sea and integrated within UUV and UGV systems.

What types of unmanned technologies exist for ground environments?

UGVs first emerged around the same time as early experimentation with wireless control in the late 1890s and early 1900s. To be specific, it was Leonardo Torres Quevedo, a Spanish engineer, inventor, and mathematician, who developed (between 1901 and 1902) the Telekino. This was a novel remote-control system that sent signals transmitted by radiotelegraph to fulfill complex "mechanical movement at a distance."[4] The Telekino would be applied to a range of machines across all domains, but the first "UGV" was a "three-wheeled self-propelled carriage" that, in 1904, was successfully deployed and controlled over a range of 30 meters.[5] Of course, Torres Quevedo was not the only inventor working on such wireless technologies at the time; Ernest Wilson and C.J. Evans in the United Kingdom, Nikola Tesla in the United States, and later Hedy Lamarr, who innovated with frequency hopping, also experimented (among many others) with wireless innovations across air, land, and sea.[6]

As is often the case with advances in civilian technologies, it would only be a matter of time before they were developed and applied in the military domain. Described as a vehicle that was "technically flawed but full of promise," the Soviet TT-26 Teletank, armed with a maneuverable flamethrower, was developed during the 1930s and was one of the first truly wireless tanks.[7] Controlled by an operator located in a tank further back from the front-line action (up to 1.5 miles away, but within visual line of sight), the Teletank was controlled by a twenty-button control panel, with command functions in rows of four. As the historian Ian Johnson has documented,

> [i]n the first row there were fire control buttons: the first activated fire control, the second fired the flamethrower, the fourth caused the Teletank to emit a smoke screen. The next row controlled engine start-up and gear shifting, which by 1939 included up to four gears as well as reverse. In the final row were the tank's navigational controls: turning right, turning left, and turning the turret. In addition, the operator had the ability to switch the radio channels by which the vehicle was controlled, lest the enemy find a way of interfering with the frequency.[8]

As such, it is clear to see how advanced and intricate these Soviet systems were for their time. Teletanks saw their first combat deployment during the Winter War against Finland, where they were used to target enemy bunkers. Although it is fair to say that their performance was mixed, they did achieve some level of success. As a report by General Kombrig Yermakov of the 100th Rifle Division explained, despite struggling with a “large number of depression and potholes,” the drones destroy two heavily reinforced defenses, “pillboxes No. 39 and No.35.”[9] Yet despite elements of success, the Teletanks were reportedly “deployed improperly, proved difficult to maneuver in heavy snows, and frequently ran afoul of Finnish mines.”[10] Unfortunately for the Red Army, by the end of that Winter War, the Teletank battalion had lost the vast majority of its vehicles. As a result, by 1941 the project was effectively abandoned. However, this did not mark the end of remote-controlled UGVs during World War II.

Standing at one foot tall and four feet long, the ironically named “Goliath” is another important example of one of the first remote-controlled “tanks” (see Figure 5.1). First deployed in 1942, this one-way disposable tracked vehicle could “carry 60kg (130lbs) of explosives and was steered remotely using a joystick control box” before being detonated.[11] This joystick was attached to the “tank” by a “2,145-foot triple-strand control cable,” allowing for acceleration, maneuver, and detonation.[12] Although foiled by rough terrain and enemy soldiers cutting the connection where possible, the Goliath was deployed in combat during World War II, but was soon found to be too expensive and vulnerable to have any major tactical or strategic effect. Despite these shortfalls during the war, however, the Goliath has gone down in history as one of the main influences behind modern radio-controlled robotic vehicles.[13]

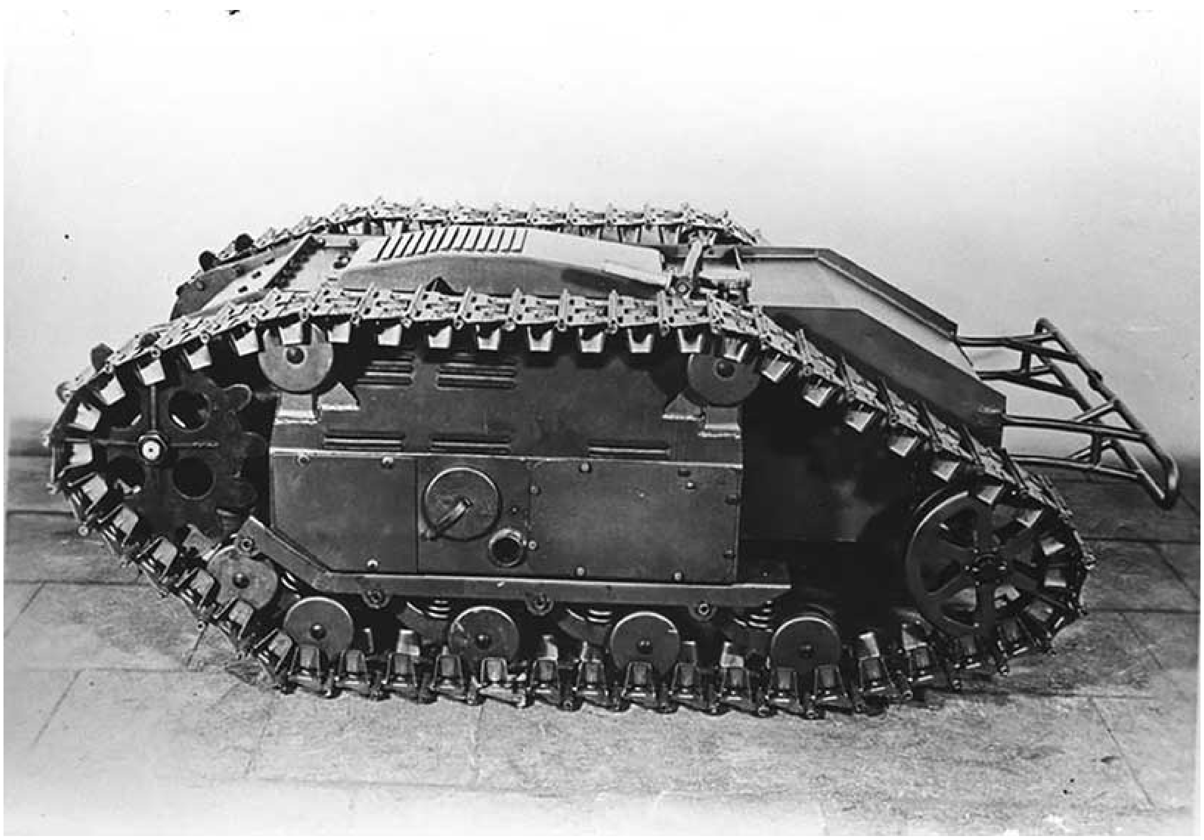

Figure 5.1 World War II German Sprengpanzer Explosive Tracked Mine Named "Goliath"

Source: Bundesarchiv, Bild 146–1980-053-53/CC-BY-SA 3.0.

Indeed, since the end of World War II, there have been many iterations of UGVs. The DARPA Autonomous Land Vehicle (ALV), developed from the 1960s to the 1980s, was a "12-foot tall, eight-wheeled robot with multiple sensors, tasked to go from point A to point B without human intervention in the hills outside of Denver."[14] During this period, planned military uses focused on deploying the UGVs in chemical, biological, radiological, and nuclear (CBRN) environments or carrying out tasks that would expose human operators to excessive levels of risk.[15] Although the project would not result in a specific deployable system, the research was integral to future US Army and DARPA projects as part of the US Army Tank-Automotive Command (TACOM) and DARPA Advanced Ground Vehicle Technology program.[16] More recently, Lockheed Martin and the US Army

Tank-Automotive Research, Development, and Engineering Center have partnered together in an attempt to develop self-driving technology that can be installed in the military's existing vehicles. This would allow large logistical supply vehicles to be operated remotely, reducing the likelihood of casualties from ambushes.

Another example comes from the British Morfax Wheelbarrow, developed during the 1970s. This UGV was specifically developed in reaction to the Irish Republican Army's (IRA's) bombing of both military and civilian targets and was aimed at helping with bomb disposal. As drone experts Dan Gettinger and Arthur Holland Michel have explained, the "Wheelbarrow laid the basic template for EOD robots, which are the most prolific unmanned ground vehicles in modern militaries."[17] Indeed, it is here that we can turn to what is perhaps the most common use of UGVs today, namely for explosive ordnance disposal, a practice that grew in prevalence during the Global War on Terror with the introduction of new UGV technologies.

Between 2003 and 2007, ambushes killed more than 3,000 American soldiers in Iraq and Afghanistan. While aerial-based surveillance and reconnaissance platforms proved particularly helpful in identifying these threats, one UGV, the PackBot, which is about the size of a small suitcase, worked alongside soldiers to conduct vital surveillance on the ground (see Figure 5.2). In a military setting, the purpose was for the vehicle to identify and dispose of explosives, and to check for the use of chemical agents. In a civilian context, however, the PackBot can patrol public settings, using real-time video, audio, and sensor data to assess potential public threats.[18] Versatile systems, PackBots were used in this manner during the 2014 World Cup in Brazil to ensure the public's safety throughout the event.[19] Most recently, 127 of the newest PackBot 525s were acquired by Germany, bringing the total number of nations owning and deploying PackBots up to 57.[20]

Figure 5.2 PackBot Used in Explosive Ordnance Disposal Training with US and Saudi Arabian Forces in 2021

Source:
https://en.wikipedia.org/wiki/PackBot#/media/File:U.S._and_Saudi_Arabia_explosive_ordnance_disposal_technicians_train_in_Saudi_Arabia._(50921885603).jpg

UGVs are now routinely used for identifying and defusing improvised explosive devices (IEDs), either by law enforcement or the military. As Lieutenant Colonel Arnald Thomas has noted, UGVs "avoid human endurance constraints." Humans need rest and have limited attention, two limitations that do not arise in the context of an unmanned vehicle.[21] To serve these functions, today's modern UGVs often have instruments designed to observe the environment, and use the information gathered to make decisions independently, or relay the data collected to a human operator who controls the vehicle remotely. In some cases, they can be armed.

One of the most widely used UGVs has been the Tactical Adaptable Light Ordnance Neutralization (TALON) family of robotic systems. Their main purpose has been bomb disposal, but they are also used for surveillance of enemy territory, which helps anticipate and avoid ambushes or explosions. As stated by the manufacturer, QinetiQ, “from Ground Zero after the 2001 World Trade Center attack, to Iraq and Afghanistan, searching for the Boston Marathon bombing suspect and assisting with security during major sporting events” the TALON has been deployed around the world.[22] The latest iteration is the TALON 6, which was exhibited for the first time in 2022, and is set for adoption by the UK Ministry of Defense and the US Army, which have both long maintained active and updated fleets of TALON.[23]

The TALON systems have a history of service that stretches back over two decades. TALON was first involved in combat operations in Bosnia in 2000, and, as already mentioned, through Afghanistan and Iraq during the War on Terror. It is reported to be remarkably hardy, being all-weather, capable of operating day and night, and amphibious up to a 100-foot depth. QinetiQ North American advertises the robustness of the technology by reporting that a TALON was “blown off the roof of a Humvee in Iraq while the Humvee was crossing a bridge over a river. TALON flew off the bridge and plunged into the river below. Soldiers later used its operator control unit to drive the robot back out of the river and up onto the bank so they could retrieve it.”[24] Variations of TALON include the TALON HAZMAT, which uses sensors to test for chemicals, gas, and radiological threats. TALON HAZMAT sends that information back to its controller in real time. It is ideal for scouting out situations in a potentially hazardous environment. While these technologies are characterized by a primarily defensive or supportive role, other TALON technologies can carry a lethal strike capacity.

The SWORDS TALON (pictured in Figure 5.3) builds on the idea of the TALON in that it is remotely operated and durable in water, but is also equipped with several types of weapons. These include a grenade launcher or machine gun, specifically an “M249, which fires 5.56-millimeter rounds at a rate of 750 per minute, or the M240, which can fire about 700 to 1,000 7.62-millimeter rounds per minute.”[25] *Time* magazine reported in 2004 that

SWORDS was one of the world's most amazing inventions. In 2007, three SWORDS TALON units, each armed with a machine gun, were deployed to Iraq. Although their weapons were never used, their deployment marked the first time that robots carried guns into battle (albeit without firing a shot). Rumors swirled about why the SWORDS system did not use its lethal capacity, and after speculation that the system had shot errant bullets, the contractor suggested that the Army preemptively decided not to use the system. An Army program manager's explanation for the SWORDS's removal—"once you've done something that's really bad, it can take 10 to 20 years to try it again"—suggests that the military was being cautious with the deployment of the new technology, seeking to avoid a public relations debacle that could set the technology back decades.[26]

Figure 5.3 The SWORDS System

Note: “The SWORDS system allows soldiers to fire small arms weapons by remote control from as far as over 3,937 feet (1,200 meters) away. This example is fitted with an M249 SAW” (para.1).

Source: https://en.wikipedia.org/wiki/Foster-Miller_TALON#/media/File:SWORDS_robot.jpg

Yet despite the early hesitation with the SWORDS system, the US Army did not abandoned the idea of having a lightly armed tracked UGV ready for deployment on the battlefield. The Tracked Hybrid Modular Infantry System (THeMIS) is a key example of this ambition (see Figure 5.4).[27] Developed by an Estonia company Milrem Robotics with support from the United Arab Emirates, this modular UGV, with an optional armed capacity, was tested in 2024 during the Expeditionary Warrior Experiment conducted by the US Army. This exercise specifically sought to test state-of-the-art solutions that can “increase warfighter lethality through 2040.”[28] With this in mind, systems like the THeMIS, as legacies of the SWORDS, may well have an active future in the US military. With a 20-kilometer max speed and the ability to carry a 750-kilogram additional payload, these UGVs are seen as versatile ground drones that can be used for everything from logistics, through to front-line combat roles.[29] This certainly seems to be the case in practice with THeMIS being tested around the world, including in zones of active conflict like Ukraine. Here they have been used for intelligence-gathering, route clearance, casualty evacuation, or in an armed capacity with 14 THeMIS unmanned vehicles supplied for use in the war.[30]

Figure 5.4 The THeMIS UGV 5th Generation, Logistics Variant

Source: CC-BY-SA-4.0.
https://es.m.wikipedia.org/wiki/Archivo:THeMIS_5th_generation_UGV.jpg

An interesting point to note here, however, is that Russia has since offered a one million ruble -prize to anyone who captures one. This will allow Russia to research vulnerabilities in the ground drones, including sensitive metadata, potentially highlighting the growing role and importance of these UGVs.[31] In fact, according to the manufacturer, the reputation of THeMIS is growing, with successful deployments as part of Operation Barkhane in the Sahel for logistical support and observation. Since this time, "16 countries, 8 of which are members of NATO," have acquired the systems.[32] As of 2024, the company has announced plans to produce 500 THeMIS units per year, indicating this growing international demand.[33]

Yet despite these recent advancements in smaller UGVs, the move to develop a larger, tank-size, unmanned ground combat vehicle has proven to be challenging. As reported by NBC in 2020 "[t]he Army decided to replace Bradley Fighting Vehicles 17 years and $22b ago. They still don't have a prototype."[34] There can be little doubt that the decision is an important one; the Bradley is "a 33-ton tank-like workhorse used to carry troops into battle and provide fire support with its rapid-fire cannon and anti-tank missiles."[35] Nevertheless, the system was designed in the 1960s and has been in operation since the 1980s, and so a replacement is long overdue. This is especially the case as the Army looks to become leaner, meaner, and more cost-efficient, which likely means adopting unmanned technologies that could allow it to reduce combat teams and rely more on robotics. With this goal in mind, the Army issued a document that emphasized a "blue-sky" approach to spark big thinking about the future.[36]

Such thinking is paying dividends, with growing research and development in the private and government sectors. The XM30 Mechanized Infantry Combat Vehicle is now set to replace the Bradley. Although still in the design phase, a $1.6 billion contract was awarded in 2023 for an "optionally manned system" that will ensure "a next-generation, tracked, armored fighting vehicle designed to address the critical challenges of the future battlefield."[37] In this context, optionally manned means it will "have the capability to conduct remotely controlled operations while a crew is not in the vehicle."[38] Although there is still no prototype available at the time of writing, there are high hopes for the large UGV. As General James Rainey, commanding general of Army Futures Command, stated, the "announcement for XM30 demonstrates we are on a sustainable path to equip today's Soldiers with modern equipment while we invest in the technologies and systems necessary to build the Army of 2030."[39] So, despite there being a long way to go, it is clear to see that the US Army continues to hope its large ground drone program may pay off, providing a viable unmanned future for front-line operations. This being said, quicker progress is being made in autonomous UGV systems.

As we have noted, DARPA and the US Army have long worked to develop an unmanned transport system that is essentially an unmanned convoy. In 2014, in a demonstration that foreshadowed the driverless technology commonplace today, the Army operated driverless vehicles that navigated both rural and urban courses, various traffic patterns, and pedestrians, all while keeping to its pre-programmed itinerary. As the head of science and technology at the Army Capabilities Integration Center indicated, "[w]e're not looking to replace soldiers with robots. It's about augmenting and increasing capability," including the giant logistics tail that can be vulnerable to attack.[40] This effort is ongoing. As outlined in the *U.S. Army Robotics and Autonomous Systems Strategy* (issued in 2017), by 2030 the US military aims to have fully "automated convoy operations and unmanned combat vehicles improving maneuver."[41] However, it is not just autonomous convoys that are being developed at DARPA; faster, more tactical systems are also in development.

DARPA'S *Robotic Autonomy in Complex Environments with Resiliency (RACER)* program is but one pertinent example. Successfully tested in 2023 and 2024, the RACER Heavy Platform (RHP) are "12-ton, 20-foot-long, skid-steer tracked vehicles" powered by a bespoke RACER algorithm and similar in size/function to manned armed combat vehicles.[42] Far from just being remote-controlled, these systems will allow for "[e]xtreme speed off-road ground autonomy at any scale in any terrain."[43] This is the future the US military is "racing" toward, with the US Army and the Department of Defense's Defense Innovation Unit (DIU) set to launch its Ground Vehicle Autonomous Pathways (GVAP) project. Also announced in 2024, this project has seen eight private companies commissioned "to develop software capable of controlling military vehicles on the ground."[44] As Kevin O'Brien, technical director for the DIU's Autonomy Portfolio, stated, "[t]here has been a revolution in the techniques and capabilities of uncrewed ground vehicles … We're eager to bring these matured technologies back into the Department of Defense."[45] Put simply, although largely still in the testing stage, with the growing maturity of AI, the 2020s are seeing a rapid growth in UGV capabilities, with fully autonomous systems prioritized as future force multipliers.

What is the state of proliferation in terms of unmanned ground technologies?

Countries are increasingly recognizing advantages in terms of troop safety, such as for surveillance, reconnaissance, or logistics, but they are also seeing the utility of UGVs for offensive purposes.[46] The United States is the largest user of UGVs, owning roughly 40 percent of the UGVs in the world in 2022.[47] Yet, the United Kingdom, Canada, France, and Germany are the next biggest users, operating around 15 percent of existing UGVs. Israel, Australia, Switzerland, Spain, and Sweden also own approximately 15 percent of the UGVs in the world. The rest of the countries command roughly 30 percent of the world's UGV market—including Russia, which is increasingly interested in combat robots for deployment against Ukraine.[48] In fact, it should be stated that Russia's growing investment into armed UGVs has been a major catalyst for widespread renewed interest in unmanned ground systems. Armed systems, such as the Uran-9, are fitted with a 7.62-mm machine gun, a 30-mm automatic cannon, four anti-tank missiles, and are designed to provide combat units with remote surveillance and fire support.[49] Such developments caused major alarm among NATO allies when news emerged that they were deployed and tested in "combat conditions" in Syria in 2015. Indeed, Russia has spent many years developing such systems. *Popular Mechanics* put it succinctly over a decade ago when it reported that Russia wants "fighting robots, and lots of them."[50] The versions in development over the last 10 years have been semi-autonomous; however, more recently Russia has been working on autonomous versions. One older semi-autonomous system is a mobile shock-reconnaissance robot that was tested and approved in April 2014. The system was deployed to secure Russian missile sites and operated remotely through a wireless connection. Russia's future goals, however, include an autonomous system that could be pre-programmed to carry out a wide range of activities, from patrol and reconnaissance missions, to the destruction of targets and providing security for those individuals protecting the missile sites.

Russia also anticipates using one robot to replace what today requires five to 10 soldiers. One version of this technology is the "Armored Frog," which is about the size of a Jeep, is amphibious, and can fire at targets with dual machine guns. Russia also has the Strelok (translated at "Sharpshooter"), which knocks down doors, climbs stairs, and is armed with a Kalashnikov; and the Metalliste, which is a six-wheeler with a silenced submachine gun.[51] Thus, over the last decade Russia has increasingly focused on building and expanding its varied capacity in UGVs.

The closest Russia has come to achieving its autonomous robotic future, however, is through the "Marker." This UGV has gone from testing to active deployment across an accelerated timeframe (likely due to the demands of Russia's war against Ukraine). This is a three-ton five-wheeled system, which can "mount anti-tank missiles, heavy machine guns, grenade launchers, unmanned aerial vehicle (UAV) launch modules, jammers, or other weapons."[52] It is designed as an anti-tank robot that can "offer technical vision, communication, navigation, autonomous movement, and group control."[53] The UGV reportedly has a "modular multi-spectral vision system, which uses neural network algorithms for data processing" and autonomous decision-making.[54] The Marker is said to be able to identify various targets through this algorithm, including unauthorized personnel, UAVs, and motor vehicles—although, as is often the case with Russian defense technologies, such claims are to be met with some skepticism.

For example, building on its initial reports of success in Syria in 2015, Russia ha been experimenting with its new UGVs in Ukraine (since 2022). In 2023, to prove its capabilities, Russia declared a "baptism of fire" for the Marker by deploying them in the Donbas.[55] However, the continued exposure of their UGV technologies to the harsh realities of war has led to less than impressive results. This was most evident in 2024 when Russia sent its armed UGVs as part of an assault in Berdychi, eastern Ukraine. The Russian propaganda reports of this attack bear careful reading, especially when compared to the actual end result. As Russian commentator, Boris Rozhin, declared,

> [a]s part of the combat mission, a group of assault drones took part in supporting the assault operations, ensuring the suppression of enemy positions in the village using the installed AGS-17 modules, firing several hundred grenades … During combat use, drones showed good results … The drones were able to continue operating even in conditions where losses of personnel and expensive equipment from enemy fire would have been inevitable.[56]

If true, such an attack would have marked one of the greatest successes of offensive autonomous UGV deployment anywhere in the world. However, as drone expert David Axe reported for *Forbes*, the reality was quite different.

As Axe explained, "the Ukrainian army's 47th Mechanized Brigade either jammed or damaged at least two of the robots—and then sortied tiny first-person-view unmanned aerial vehicles to blow them up."[57] This conclusion was supported by another leading drone expert, Samuel Bendett, who argued "[r]ight now, anything that moves on the battlefield is seen and hit with a drone."[58] Indeed, as mentioned in the section on counter drones (Chapter 4), the modern battlefield is not a safe place for tanks and armored vehicles, as evidenced by the growing use of reinforced cages above turrets. With this in mind, it is likely that when faced with an advanced state military, such UGVs with lighter armor and a susceptibility to being jammed or attacked by First-Person View (FPV) drones will find it hard to function in future conventional warfare.

With these vulnerabilities in mind, how has the West developed UGVs? As UGV experts Zachary Kallenborn and Marcel Plichta found when they inventoried and characterized 32 Western UGV models, there are major developments taking place across all ranges of ground robotics:

> [t]he UGVs came in a broad range of sizes from MacroUSA's Beetle N-UGV weighing in at 1 kg to Milrem and EDGE Group's Type X at a whopping 12,000 kg. Of the identified UGVs, two were classified as micro using the U.S. Army's classification (less than 4.5 kg), 11 as small (4.5 to 91 kg), 11 as medium (91 to 1,361 kg), and eight as large (above 1,361 kg).[59]

Their results also highlighted how the Spanish Ministry of Defense has developed an "automation kit" designed to convert manned armed vehicles into UGVs; a growing trend in state development.[60] In fact, such "retrofitting" has also proved useful to Israel, which has already deployed such systems in combat.

As with aerial drones, Israel has also very much been at the vanguard of UGVs, using them for reconnaissance, remote-controlled weapons, IED detection/disposal, and border surveillance. The Israeli Defense Force (IDF) justifies its investment in the technology in the following way: "Major threats are evolving on Israel's borders every day … Among its finest tools are UGVs, which could redefine Israel's capabilities in the near future."[61]

One of their primary systems is the Guardium, whose development began as an initiative in 2008—a partnership between Israel Aerospace Industries and Elbit Industries. Originally meant to carry out reconnaissance and weapons operation, it became "one of the first regularly operating unmanned security vehicles in the world."[62] The Guardium MK III is fully autonomous, reportedly "creates deterrence by rapid closure of the sensor-to-shooter loop, identifies and classifies hostile activity, gives advance warning to military forces, and provides a threat response—all without endangering personnel."[63]

With autonomous technology developing so quickly, Israel has most recently (2022) unveiled the Medium Robotic Combat Vehicle (M-RCV). According to the Directorate of Defense Research and Development, the ground drone incorporates a "number of cutting-edge technologies including advanced maneuvering capabilities, the ability to carry heavy and varied mission loads [including a machine gun and anti-tank missile launcher], and a built-in system for transporting and receiving UAVs."[64] This last characteristic is important to note, as it means the UGV can deploy its own aerial drone for reconnaissance missions. This is a feature the United States has also been working on, with General Dynamics Land Systems in test with the TRX-tracked UGV that can carry 50 Switchblade one-way suicide drones.[65] Such developments likely mark the beginning of a new trend in UGV–UAV teaming.

Finally, as we have alluded to, it is important to note that after the October 7 attacks by Hamas in 2023, the IDF have experimented with integrating their more hi-tech capabilities into older armored personnel carriers. Although deemed too vulnerable to carry troops due to the threat of more modern anti-tank weapons, these older systems have been deemed useful in an unmanned capacity when fitted with the latest remote-control and automated technologies. The seemingly obsolete M113, for example, dates back to the 1960s, but has now become a UGV that, according to *The Jerusalem Post*, has "played a key role in the battle for the Philadelphi corridor in Rafah, the area that runs for seven miles along the border of Gaza and Egypt."[66] While some reports suggest these systems can be packed full of explosives and used as a one-way suicide UGV, or armed with mortars, others report the M113 is mainly "designed to transport supplies to front-line positions and support various military tasks without endangering personnel."[67] Of course, the deployment of such technologies in urban environments is not without controversy, raising questions about what safeguards are in place for the protection of civilians caught in the ensuing conflict. Such questions are discussed in Chapter 7 when we turn to analyze the future of drones.

Beyond the West and its allies, or the warring parties in Europe, India has also developed cutting edge UGVs. Daksh, an electrically powered, remote-controlled unmanned ground robot, is intended to identify and defuse all types of hazardous objects, primarily IEDs. It can also climb stairs, carry relatively heavy hazardous objects, and operate for three hours on a full charge. The first delivery of five Dakshs took place in December 2011 and was India's first indigenously developed robot, beating out the British equivalent that the Indian Army also tested. A newer version was developed in 2015 and was three times faster than the previous model. This UGV also has the ability to survey areas contaminated by nuclear, biological, or chemical exposure, and to mount a weapon.[68] India is also looking into unmanned ground combat vehicles that could perform counterinsurgency operations, recover hostages, or disrupt indoor hostage situations, which otherwise would put soldiers at risk, while also mounting a light machine gun or grenade launcher. In short, India has been moving forward in developing homegrown UGVs.

This mission took one forward in 2023 when Indian Defense Minister Rajnath Singh unveiled a new Enhanced Collaborative Autonomous Rover System (ECARS) for patrolling contested border regions. It was no accident that the announcement was made at the Indian Institute of Technology located in Jammu in the disputed Kashmir region. Such fully autonomous UGV developments indicate that this specially designed ECARS, with “cutting-edge 4×4 multi-terrain” operational ability and “enhanced collision avoidance system”, will be the future of Indian border patrols.[69]

Finally, in terms of India’s future development, it should be noted that the AI & Robotics Technology Park (ARTPARK), a unique not-for-profit foundation set up by the Indian Institute of Science, was established with support from the Department of Science & Technology in 2020. Since then, ARTPARK has established the ARTPARK Innovation Program bringing together startups in AI and robotics from across India. This has resulted in projects like the STOCH-3 Legged Robot, CIRAKSHAKBOT tactical UGV, and VARAHA THROWBOT, a “throwable micro-robot platform that enables operators to obtain instantaneous video and audio reconnaissance within indoor or outdoor environments” (among many others).[70] Each system, however, is largely focused toward surveillance, reconnaissance, and bomb disposal, again highlighting the current priorities for India.

Unsurprisingly, China is also venturing into the development of UGVs but has traditionally been estimated to be about five years behind the United States, Israel, and European countries. Nevertheless, around 10 years ago, China firmly identified unmanned ground technologies as key elements of its future force posture, making a number of major pronouncements in 2014 about future plans. According to an officer in the People’s Liberation Army (PLA), “unmanned ground vehicles will play a very important role in future ground combat. Realizing that, we have begun to explore how to refit our armored vehicles into unmanned ones.”[71] Another officer, the president of the PLA Academy of Armored Forces Engineering in Beijing, said that “though we have yet to develop unmanned tanks, I think it is an irreversible trend that computers will gradually replace humans to control those fighting machines.”[72] In June 2014, China North Industries Group, a major defense firm, created China's first research center for developing UGVs.[73] The deputy director of the center cited the success of United States with UGVs in Iraq and Afghanistan in EOD roles as a motivation behind developing their own systems that can carry out tasks more safely and remotely.[74]

Over the last decade, China has made progress in developing systems similar to many of those we have discussed. Indeed, far from leading in the field, China has developed familiar looking machine-gun-mounted remote-control UGVs, like the Calvary Chinese Tracked UGV. Manufactured in 2018, this remote-controlled UGV is designed to "provide close-range fire support against hostile infantry and light vehicles."[75] In addition, just like Israel and Spain, the PLA has also experimented with turning older tanks and armored vehicles into functional ground drones. With President Xi's promise to provide a "world-class military by 2049" in mind, and quick fixes needed, Type 59 Soviet-era tanks from the 1950s were converted for remote-control unmanned deployment.[76] As Liu Qingshan, the chief editor of Tank and Armoured Vehicle, stated to Reuters, "[a] large number of due-to-retire Type 59 tanks can be converted into unmanned vehicles if equipped with artificial intelligence."[77] Again, far from revolutionary, such efforts show China's continued mission to keep up, or indeed catch up, with the competition.

One of the more recent developments, however, was a smaller machine gun-armed autonomous UGV system called the Sharp Claw I, which entered service in 2020. Although similar to other systems discussed, what is interesting and unique about this UGV is that it does not operate alone. Instead, it is partnered to the larger Sharp Claw II UGV, "a 6×6 wheeled unmanned ground vehicle that was designed to carry out battlefield reconnaissance, patrolling, assault and transport missions."[78] In essence, the Sharp Claw II is the "mothership" to the Sharp Claw I, with the smaller autonomous UGV stored in the cargo bay until required.[79]

Although none of these systems make China stand out in terms of UGV development, it should be noted that China's advantage comes from its investment in AI and autonomous technologies more broadly. As Thomas

Corbett and Peter W. Singer revealed in 2024, the Shanghai Institute of Microsystems and Information Technology (SIMIT) of the Chinese Academy of Sciences claimed to have made “two new breakthroughs toward overcoming one of the most crucial speedbumps: autonomous vehicles’ ability to perceive their surrounding environment and track movements.”[80] Such advances are complemented by Chinese advancements in LiDAR (Light Detection and Ranging) which are effectively the eyes of many UGVs and autonomous vehicles, feeding information to the onboard computer. Although the United States has traditionally been the leader in this area, large subsidies have been provided to Chinese industry and, according to Corbett and Singer, “the Chinese government is also allocating resources to acquire foreign IP, encourage foreign manufacturers to establish factories in China, and push for the promotion of Chinese standards on the market.”[81] While this has led to concerns about Chinese data-gathering and data-transmission technologies entering the US market, raising risks about covert intelligence-gathering through civilian applications, it also shows how China is seeking to bridge that long-held gap between the West and the rest in UGV capabilities.

Of course, a number of other countries are also developing technologies similar to those we have described. Although we cannot cover them all in this volume, the examples documented in this chapter highlight the main categories and trends in UGV development into the mid-2020s. For example, in 2024, the Japanese military purchased three of the previously discussed THeMIS UGVs from Milrem Robotics for supply transportation and intelligence missions. Although these drones are designed for more tactical use, at the time of writing the Japanese military plans to fit them with an Intelligent Functions Kit (MIFIK) allowing them to “take on- and off-road operations independently.”[82] In addition, in 2024 the United Arab Emirates signed what has become one of the world’s largest UGV orders with Milrem Robotics, which committed to supply 20 tracked robotic combat vehicles (RCVs) and 40 THeMIS UGVs.[83] Thus, numerous examples exist to track on a global scale.

Yet, what this section has shown is that UGV use is increasing in terms of function and performance. From more traditional UGVs to aid in bomb disposal, logistics, or border patrol, through to modern UGVs that can deploy UAVs or mount fully autonomous attacks on enemy positions, it is clear that UGVs are cementing their place on the battlefield in a way that looked less likely a decade ago. While still a much smaller market than aerial drones, a key indicator of this growing utility and interest is the extent to which the manufacturers and sales of these systems have spread globally, with ground drones of all shapes and sizes being built and deployed all around the world. Of course, this is not to say UGVs will replace all crewed tanks and armored vehicles any time soon. There is still a lot of work to be done to make these systems versatile and reliable. Nevertheless, with the documented pressures on the usefulness of the manned tank in future war, UGVs may well be seen as a lower-risk and cheaper alternative to more vulnerable big-ticket items, while also continuing to be deployed as more specialist systems.

Are unmanned ground technologies likely to be game changers?

Although particular UGVs are indispensable in terms of IED detonation, the previous section shows that many others still have operational limitations and require continued research and development. For example, the ground is typically densely populated with obstacles that confound the unmanned system's ability to navigate, let alone survive against enemy fire. Although some of the most modern advanced UGVs can travel quickly in tests, the truth is most vehicles, especially autonomous ones, would be slow moving in the realities of a wartime situation, making them vulnerable to attack. Additionally, the more offensively minded they are, the larger, more lumbering, more visible, and therefore more vulnerable they are vis-à-vis the adversary. Indoor settings are also difficult because hallways often block radio signals, meaning unmanned vehicles are unable to move easily within walled structures. This limitation makes them better suited to confirm the security of outside spaces, such as a courtyard. While increased levels of autonomy will help address these issues, as the previous section highlighted, the technology still has a way to go before becoming resilient and robust enough to be fully relied upon for mission success in a sensitive or crucial wartime situation.

Indeed, another related limitation is the set of trade-offs involving sensors, space, and weight such that improvements along one parameter limit the advantages along another. Any useful unmanned device would require not only night vision but also infrared for seeing through smoke. These sensors, however, would add weight and necessitate a large battery. The added capabilities carry a trade-off in terms of making the vehicle more sizable, limiting its range (portability), again making it more visible.[84]

Even so, UGVs have significantly changed the explosive ordnance disposal missions conducted by national armed forces by limiting risks for one of the most dangerous components of the military. UGVs are particularly well-positioned to have an important impact in certain regions with heavily militarized borders—such as the Korean Peninsula, Indian subcontinent, and the Middle East. Put simply, as we look to the future of UGV use in war, it is clear that for the time being at least the technology will continue to occupy more specific and tailored roles, as opposed to mass front-line deployments.

What is the status of unmanned technology for the maritime domain?

Naval systems have evolved in similar ways to ground and aerial systems, starting with surveillance and reconnaissance missions and evolving to technologies that can detect mines, conduct strikes, and carry out autonomous missions. The technology is divided into UUVs, UAVs that are integrated into aircraft carrier operations, and USVs. This section examines these categories of naval systems, focusing mostly on the use of UUVs and

UAVs for maritime purposes since the development of USVs has been relatively slow by comparison. Two notable exceptions are the use of USVs by Ukraine against Russia and the growing use of USVs by the Houthi terrorist group based out of Yemen, both of which will be outlined in this chapter. Overall, however, the number of maritime drones is extensive and growing, so while a comprehensive survey is not possible, this section, like the previous one, speaks to illustrative examples of how such systems are being developed.

Mines have long been the bane of navy ships; mines have damaged or sunk US Navy ships at four times the rate of any other form of attack. They have been a major threat in every major conflict since the US Civil War. Mines tend to be a popular instrument of war since a $10,000 sea mine can sink a ship worth more than $1 billion, not to mention the human casualties that can result in the process.[85] Against the backdrop of this asymmetric threat, the prospect of UUVs is an attractive way to defend against the potential for destructive mines. Indeed, some early versions of unmanned naval systems were platforms dedicated to demining. As US Navy Explosive Ordnance Disposal (EOD) personnel note about unmanned undersea vehicles' utility in Operation Iraqi Freedom, these "gadgets were the main workhorses of the mine clearing effort … if one got blown up in the process, the relatively cheap price meant it would be no big deal."[86] Military analysts have observed that such technologies could also defang Iran's efforts to mine the Strait of Hormuz as a way to prevent oil tankers from transporting oil, thus driving up prices. Its undeclared mining of the strait in the 1980s would therefore have been less plausible in an era of UUVs. In 2012, the United States sent several SeaFox vehicles to do just that: detect and destroy any mines that would help Iran close the strait. At 1.3 meters long and 41 kilograms in weight, the SeaFox, pictured in Figure 5.5, is a portable "semi-autonomous wire-guided mine disposal vehicle developed by Atlas Elektronik."[87]

Figure 5.5 Seafox Combat Round

Note: A Seafox Combat Round is maneuvered into its launch position by a member of HMS Bangor's Mine Disposal Crew. HMS Bangor destroyed two underwater bombs during operations off Libya in 2011.

Source: https://commons.wikimedia.org/wiki/File:Seafox_Mine_Disposal_System_Onboard_HMS_Bangor_off_Libya_MOD_45153320.jpg

Launched from helicopters or rubber boats, the SeaFox is "on what amounts to a suicide mission" when it destroys a mine, in that it too is destroyed. This also implies that it shreds the $100,000 investment in each vehicle as well, yet this is the purpose behind these "disposable" UUVs, intentionally sacrificed to reduce the threat to large crewed surface vessels.[88]

There are also uses for UUVs beyond demining, which have a history that goes back to the 1950s and 1960s, when self-propelled underwater research vehicles were used in oceanography in the Arctic. They could go places too dangerous or too deep for human submariners. Small-hulled

UUVs are better able to withstand pressure than large-hulled craft (such as crewed submarines) and have thus become useful for missions at greater and greater depths. The militarization of the subaquatic domain during the Cold War increased the need for UUVs.[89]

With this in mind, UUVs also have utility in intelligence, surveillance, and reconnaissance. One line of development seeks to mimic the movements of sea creatures in ways that could be useful for stealthy surveillance. The US Navy pioneered a line of underwater drones, the GhostSwimmer, which could mimic jellyfish, eels, and the dorsal fin of a shark. The program was part of a larger program called Silent Nemo in the 2010s that sought to bring new technologies into military platforms. At five feet long and around 100 pounds, the underwater drone used its tail to power and steer, and could dive down to depths of 300 feet. With a 500-foot wired connection, it could be controlled remotely, or "swim independently, periodically returning to the surface to communicate."[90]

Most recently, the idea to mimic the natural features of sea creatures was taken to a new level through the development of the Northrop Grumman Manta Ray (for DARPA), which began in 2020 and launched its first at-sea tests in 2024.[91]

Pictured in Figure 5.6, the Manta Ray is part of a burgeoning "XL Class" of UUVs, meaning at 12 meters long it is an extra-large uncrewed underwater vehicle.[92] This advanced glider-type UUV is specifically engineered to operate autonomously for extended durations and over considerable distances (over 6000 miles), eliminating the necessity for human intervention during its missions.[93] The design emphasizes hydrodynamic efficiency, enabling the Manta Ray to traverse vast underwater expanses while maintaining a low acoustic profile. Equipped with state-of-the-art sensors, it can conduct a variety of tasks ranging from environmental monitoring to reconnaissance, making it a versatile asset in both military and scientific applications. In addition to its size and striking design, two other features make this UUV stand out from the crowd. First, the Manta Ray is autonomous, meaning it can glide, turn, hover, and anchor without direct human oversight and control. In essence, the UUV could be sent on a pre-set long-distance mission around the world for weeks, if not months, on end. Second, and perhaps most useful for both military and scientific applications, the Manta Ray is modular and can be rapidly assembled in the field. As Dr. Kyle Woerner, DARPA program manager for Manta Ray, explained, "[t]he combination of cross-country modular transportation, in-field assembly, and subsequent deployment demonstrates a first-of-kind capability for an extra-large UUV."[94]

Figure 5.6 Manta Ray Drone at Naval Surface Warfare Center, Port Hueneme, California

Source: Google Earth

The Manta Ray is not alone in this class of UUV, with American defense manufacturer Anduril (set up in 2017) developing the autonomous Ghost Shark XL UUV powered by its advanced Lattice artificial intelligence-enabled autonomy software.[95] Like the Manta Ray, it is modular by design allowing for rapid customization and ease of deployment (it can even fit in the back of an C-17 military transport plane). Although many of the details about this underwater drone remain unknown, according to the manufacturer it is designed to support "subsea maritime missions globally" and has "multi-purpose capability that can adapt to mission requirements, serving as an agile force multiplier" including for "maintaining strategic deterrence."[96]

While it is not certain if the system will be armed, reports have suggested Ghost Shark could well be configured to "launch torpedoes or missiles, as well as loitering munitions, or lay mines." It could also be capable of launching "non-kinetic attacks, such as electronic warfare jammers" or as a "drone mothership," launching other UUVs or UAVs, just as the UGVs are being designed to do.[97] Needless to say, more information will be released in time, but the Ghost Shark is already in demand. Tests are underway with the Royal Australian Navy (RAN), who have an active procurement and in-country production contract for the UUV, and numerous other national militaries and commercial entities are interested in harnessing the technology. As the Chief of the RAN, Vice Admiral Mark Hammond, stated, "[w]e are a nation girt by sea, and the Ghost Shark is one of the tools we are developing for the Navy to patrol and protect our oceans and our connection to the world."[98]

In terms of USVs, developments have been slower due to the increased need for collision avoidance and to maintain control in rough conditions.[99] The US developed the Spartan Scout USV as a concept demonstration in 2002, and is a sensor and weapons system mounted onto an inflatable boat and used for demining or firing against small boats.[100] Its main virtue is to provide a way of patrolling the seas without necessarily needing to put humans in harm's way, or to run into the limitations imposed by the need for rest. Singapore's Navy, which played a role in the initial development of the Scout, launched their own fleet of the USVs in 2005, primarily as a way to battle maritime piracy.[101]

By the 2010s, more developments were underway, with companies like Zyvex Marine developing the Piranha USV. The Piranha is made of nano-enhanced carbon fiber which is lighter than either fiberglass or aluminum, leading to fuel savings of 75 percent compared to traditional vessels. At 8,000 pounds in weight, the manufacturer boasts that the drone boat is capable of carrying a "15000-pound payload a distance of 2,500 miles

(4,000 km).”[102] Increased payload with low fuel use and long-range are all eye-catching assets for a nation’s military. Indeed, as the manufacturer stated in almost prophetic terms back in 2012, “[i]f the U.S. Air Force and the Royal Air Force can control attack aircraft flying over Afghanistan from cubicles in Nevada, there is little reason why the U.S. Navy and Coast Guard cannot accomplish many of their missions with a fully remotely operated patrol vessel.”[103] In the 2020s, we are seeing such ambitions reaching maturity, although with some way still to go.

The USVs—Sea Hunter, Sea Hawk, Mariner, and Ranger—are key examples of such unmanned surface systems.[104] Tantamount to full-size manned ships, these retrofitted USVs originate from both a DARPA project and the Strategic Capabilities Office’s Overlord program. Overlord began as a partnership between the US Department of Defense and the US Navy to speed up the “Navy’s adoption of autonomous and unmanned systems” by converting large, commercially available vessels into autonomous operation.[105] This resulted in the four vessels that are deemed to be the future of the Fleet, which, according to Navy Vice Admiral Stephen T. Koehler, will allow for a “formidable manned and unmanned team … [w]here unmanned systems work in concert with, and enable enhanced capability of manned platforms; driving to an even more distributed and more lethal force.”[106] In an impressive display of capability, 2024 saw the four prototypes “sail a combined 46,651 nautical miles” and “visit ports in Japan and Australia.”[107] In addition, according to Commander Jeremiah Daley, the head of Unmanned Surface Vessel Division One, “each operated for as much as 50 days at sea at a time ‘almost exclusively’ in autonomous mode.”[108] Such vessels will likely not only be useful for logistics and resupply, but also as potential decoys, surveillance assets, and vital force multipliers if deployed in an armed capacity.

Another type of USV that is growing in popularity is offensive one-way attack “drone boats” that can be used individually or in en masse deployments. As will be explained in the section on UMV proliferation, this popularity stems from the successful deployment of these systems by

Ukraine and the Houthi terrorist group. However, these systems do have a longer history. One purpose for such UUVs is to engage larger military vessels, much like when two suicide bomber drove a small boat packed with explosives into the USS *Cole* in 2000, killing 17 sailors. Today, however, these suicide attacks can be conducted without the need for humans onboard. In one test of such technologies in a rudimentary swarm, a simulated enemy boat approached a convoy and the human controller ordered five of the USVs to saturate the enemy vessel, leaving the other eight to continue escorting the manned ship. After the order, the five USVs, using a combination of sensor data and planned routes, each plotted their own course to the enemy ship, sharing information with each other and coordinating along the way.[109] Once the USVs had simultaneously engaged the "enemy" vessel, the simulation was stopped, yet the utility of the drones in this defensive maritime capacity was clear to see.

The next step in development is to program the ships with rules of engagement, so that they autonomously target enemy combatants, ensuring that they avoid targeting allies or noncombatant ships. This is particularly important because in a war zone enemies often attempt to jam transmissions between the ships and their operators. A single operator would be in charge of orchestrating up to 30 USVs, unlike Predator pilots, who operate in a one-to-one ratio. The biggest obstacle may be the logistics of aiming and firing the weapons on each USV. A single operator could not possibly aim and fire machine guns from 30 different USVs, requiring the targeting and firing processes to be automated.

Overall, therefore, the Navy sees unmanned systems as the way of the future, not only because of the upside in terms of capability and risk avoidance, but also because they could be cost-effective in tight fiscal environments. Taken together, the prospect for cost savings may be considerable, and the Navy is pushing for more unmanned systems for the future

How are aerial drones deployed in the maritime domain?

In terms of combat-deployed unmanned naval aviation, one of the breakthrough moments came with the development of the RQ-2A Pioneer. Launched by rocket-assisted takeoff or pneumatic rails, the Pioneer was later recovered at sea or in a landing field. The Navy, the Marines, and the Army have flown Pioneers in every military intervention since 1986, including more than 300 combat reconnaissance missions in the 1991 Gulf War, in which some Iraqis allegedly surrendered on the basis of the buzzing "vultures" overhead.[110]

More advanced carrier-based aerial systems have been tested, but due to disagreements about the role they should play (stealth or long-range intelligence, surveillance, target acquisition, and reconnaissance, ISTAR) have failed to reach active deployment. For instance, in July 2013, the US Navy made history by landing a drone on the deck of a carrier, the USS *George HW Bush*, off Virginia. The aircraft was the X-47B, the Unmanned Combat Air System (UCAS), which is an experimental vehicle that has a range of 2,000 nautical miles and can fly at 40,000 feet.[111] It was the first pilotless aircraft to land on a carrier. About a year later, in August 2014, the UCAS landed within 90 seconds of the F/A-18E Super Hornet. The two aircraft achieved the Navy's goal of taking off and landing in close succession. Nevertheless, funding was halted in 2016, and in 2022 it was announced that the historic X-47B would be heading to its final resting place in a museum.[112] This is also because the United States has the highly advanced F-35 manned aircraft to fulfill a deployable combat role from aircraft carriers. However, as will be touched upon toward the end of the chapter, both China and Turkey are forging the way with full stocked "drone carriers," which are likely to aid in and define their future force deployment.[113]

As an alternative for carrier-based aerial drones, however, US defense manufacturers have sought to utilize their existing long-range drones, such as the Reapers and Global Hawks, for maritime surveillance. With a range of 22,000 kilometers, and 40+ hour flight time, the Global Hawk has been used to patrol off the coast of Alaska and the entry point of the Northern Sea Route.[114] In addition, Sky Guardians (modern Predator/Reaper style drones), tested in Arctic conditions, have quickly become the go-to systems for nation-states with vast maritime regions in need of Intelligence, surveillance and reconnaissance (ISR) overwatch. As of 2023, Canada, the United Kingdom, Denmark, and Norway were all confirmed, or in advanced discussions for the systems.

What is the state of proliferation in terms of unmanned technologies related to maritime environments?

Given that unmanned systems confer a number of advantages, including sidestepping human endurance limitations, it is not surprising that other countries are trying to buy into the unmanned industry. As mentioned in the opening to the chapter, the USV market is set to grow at an annual rate of 6.7 percent, from $1.1 billion in 2024 to $2.5 billion by 2034.[115] In addition, the UUV market is set to achieve similar rates of growth from "$379m in 2023 to $965m in 2033."[116]

Similar to UGV proliferation, the United Kingdom and Israel remain at the forefront of unmanned technologies related to maritime environments. As with unmanned aerial and ground vehicles, Israel has long been a leader in unmanned underwater and surface vehicles. As one observer has suggested, Israel has been "more agile in its thinking about how to deploy unmanned systems than were larger nations' militaries."[117]

Israel cannot support the cost of a large standing force, but its small military has major mission requirements and must maximize how it uses unmanned systems. Much as it was at the forefront of unmanned systems in the 1970s and 1980s, it was an early developer of many Protector vessels that approaches suspicious vessels as the initial contact rather than a ship that is manned. The Protector has a number of sensors and cameras to this end, and newer systems have sensors that can reorient in response additional incoming vessels. Other variants are involved in demining activities, providing intelligence, and lethal engagements.

In addition, Israel has long sought underwater drones, especially to aid in de-mining. As Israel's aeronautics director for the next generation of weaponry stated back in 2013, the task of demining is tantamount to "looking for a needle in a haystack. These are sophisticated mines, which activate themselves and explode at the acoustic signal of the engines of a ship passing overhead, changes in water pressure when a ship passes overhead, or magnetic mines, which attach to any metal ship."[118]

With this threat in mind, the Caesaron (or Little Caesar) autonomous underwater vehicle was revealed by the Israeli Navy in 2017, providing an unmanned system that can address the issue without risking an onboard crew.[119] Although there has been a lot of secrecy around this UUV, with few public appearances, some details are known. For example, they UUV is said to have "a long cylindrical hull with [a] simple two-blade screw [propeller] on the end of a long conical tail."[120] In terms of its role and capacity, it is reported to have a "large telescopic optronic mast" with multiple cameras and sensors allowing it to fulfill roles in intelligence, surveillance, reconnaissance, and electronic warfare monitoring.[121] In addition, the Caesaron is said to have side-scan sonar for mapping and detecting mines. Upon detection, the UUV can itself send out "four smaller kill-UUVs, such as the SeaFox," which are expendable mine disposal drones used to detonate the mine.[122] This capacity means that the Caesaron can act as a UUV drone "mothership," like some UAVs and UGVs can today. With such versatility, it is not surprising that Israel has taken some of its leading experience and expertise in the world of UUVs and applied them to an exportable version.

The BlueWhale, developed by the state-owned Israel Aerospace Industries, is a commercial submarine drone, released in 2023, which is essentially a "a commercialized version of the Caesaron."[123] Reports show that the BlueWhale is around "11 meters (36 feet) long and just over 1 meter (3.2 feet) in diameter" and weighs 5.5 tons with a top speed of seven knots.[124] Like the Caesaron, this is an autonomous system that has "sonar to gather intelligence and detect mines, with enough power to submerge for up to 4 weeks."[125] With underwater threats growing, exemplified by the destruction of the Nordstream II pipeline in 2022, this capacity has already attracted widespread attention. Both Italy and Germany have expressed interest in the drone, with Italy considering a $270 million acquisition program due to run until 2035.[126] As such, Israel is quickly positioning itself as a future leading exporter of underwater drones and certainly one of the world's most advanced autonomous UUV powers.

The British have also long been using UUVs. In particular, the Royal Navy has used underwater drones to prevent Iran from introducing mines in areas like the Strait of Hormuz, an important shipping lane, and has considered whether to use these vessels for antipiracy missions in the Horn of Africa. The United Kingdom's Ministry of Defence has looked favorably upon these successes and has asked the defense industry to develop drones that can "provide greater support to maritime operations such as mine countermeasures, anti-submarine warfare, and missile defence … [which] will make it possible for UK armed forces to continue to use the sea with security and persistence."[127] These systems include the UUVs, USVs, and unmanned air vehicles launched from ships.

As stated in the United Kingdom's latest "Defense Drone Strategy" (2024), the "vision is for the UK to be world-leading in uncrewed defence systems," with the Royal Navy already having "developed the use of Remus 100 and 300 Uncrewed Underwater Vehicles (UUVs) for mine detection, and M500 underwater Remote operated vehicles for seabed operations."[128] In terms of the latter deep-sea role, the Royal Navy ordered a series of new fully autonomous systems, including "three Iver 4 580 model underwater vehicles [with a] 300-metre (980ft) depth survey system" and two larger "Gavia underwater drones that can reach depths of 1000m (3,300 feet)" for deep-sea mapping.[129]

These were purchased as part of Project Hecla established to "optimise the Navy's ability to collect and exploit hydrographic and oceanographic information."[130] As security expert, George Allison has argued, these have been purchased by the Royal Navy to allow for continuous autonomous operation in high-threat areas and "to provide a persistent and accurate situational awareness of the underwater battlespace."[131] With the previously mentioned threats to underwater assets, and increasingly contested waters, such systems are vital for an island nation and its global navy.

Following suit, Russia has been seeking to develop numerous underwater drones. Among the most notable of these innovations is the Poseidon, also referred to as the doomsday drone.[132] First unveiled as a concept in 2015, although not commissioned until 2023, this nuclear-powered autonomous underwater vehicle is designed for strategic missions, including delivering nuclear payloads to enemy ports (or coastal enemy cities). Although primarily an underwater platform, it represents Russia's ambition to leverage unmanned systems for enhanced deterrence and warfare capabilities, with Russian state TV airing claims it could cause a tsunami that would "plunge the British Isles into the depths of the sea" and turn the country into a radioactive desert.[133]

Another important UUV in Russia's arsenal is the Sarma-D, Russia's latest attempt at a XL UUV. With Russia' aging submarine fleet, and infamous breakdowns or deadly incidents like the Kursk in August 2000, such UUVs would promise an impressive 8,000–10,000-kilometer range, and many of the key features of a full-size submarine. As maritime drone expert H.I. Sutton explained, although often promoted by Russia for civilian tasks, including "repairing undersea cables, prospecting work for oil/gas, tracking oil leaks in underwater pipelines, transporting cargo, survey and operating undersea equipment. Its naval potential is clear."[134] Here of course, Sutton is pointing to the drone's ability to tamper with such cables, a growing worry, especially in the North Atlantic. What can be repaired at depth, can be removed at depth. Thus, these are just two examples of the resources and investment Russia is placing in more offensive UUV systems. However, it is with Russia's wartime enemy, Ukraine that we see perhaps the greatest innovation in maritime drones.

Although Ukraine has experimented with both UUVs and USVs, it is with the latter that it has had the most success.[135] Commonly referred to as drone boats, these weapons have provided a potent response to the Russian Black Sea Fleet since the onset of the war in 2022. The adoption of these vessels, which started as retrofitted jet skis and motor boats, marks a significant shift in asymmetric naval warfare, leveraging modern commercial technology to enhance a smaller state's capabilities against a traditionally stronger naval force.[136]

Although Ukraine may have preferred to rely on more conventional naval assets to counter Russian aggression, much of the Ukrainian fleet was captured or scuttled in the 2014 invasion.[137] As such, the Russian Navy demonstrated its dominance in the Black Sea, particularly following the annexation of Crimea, and so Ukraine recognized the need to innovate its maritime strategy. By mid-2022, Ukraine had begun to experiment with the USVs.[138] These small, agile vessels could evade detection and launch surprise attacks on Russian ships, making them an attractive option for a country with limited naval resources.

Among the most notable USVs employed by Ukraine is the "Sea Baby," a small, fast, and remotely operated vessel designed for precision strikes against larger ships (see Figure 5.7). One of the first significant uses of such USVs occurred in August 2022 when Ukrainian forces targeted the Russian frigate Admiral Makarov, one of the flagship vessels of the Black Sea Fleet.[139] This attack marked a turning point, showcasing the potential of USVs in striking high-value maritime targets. Following this initial success, the Ukrainian Navy and its allies ramped up efforts to develop and deploy USVs. Reports indicate that Ukrainian engineers collaborated with various Western defense companies to enhance the capabilities of these drone boats. By 2023, the USVs had become a vital part of Ukraine's naval operations, conducting multiple strikes against Russian supply ships and landing craft in the Black Sea. For instance, in July 2023, a series of coordinated drone boat attacks successfully damaged Russian logistics vessels, disrupting supply chains and logistics routes vital to the Black Sea Fleet's operations. In one attack, the Russian warship Olenogorsky Gornyak was hit and seen listing in the Black Sea after a Ukrainian sea drone attack on a major base in the port of Novorossiysk.[140] To counter this threat, Russia sent Mi-8 helicopters to search for the USVs. In a world first, however, Ukraine responded by arming the drone boats with guided R-73 air-to-air missiles, which ultimately secured the "first aerial kill by an unmanned surface vehicle, and [was seen as] a harbinger of a new era in naval warfare".[141]

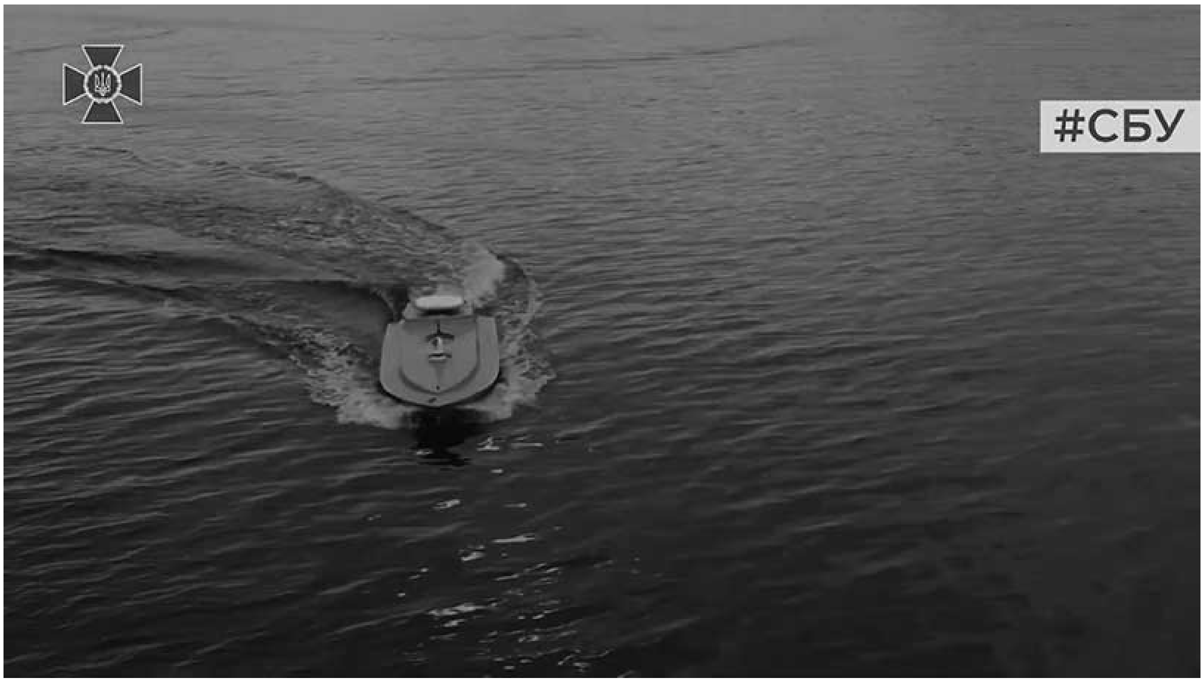

Figure 5.7 Footage of a Sea Baby USV Undertaking Sea Trials in January 2024

Source: Security Service of Ukraine (2020). All content is available under the Creative Commons Attribution 4.0 International license—ssu.gov.ua.

Overall, the strategic deployment of USVs has transformed Ukraine's approach to naval warfare, allowing it to project power in an area where it was previously weak and vulnerable. These armed unmanned vessels have enabled Ukrainian forces to engage the Russian fleet from a distance while minimizing risk to personnel. The ongoing development of such technology reflects a broader trend in modern warfare, where nations seek to leverage unmanned systems, including commercial elements, to achieve strategic advantages against more powerful adversaries.

Both China and India are also developing USVs mostly for surveillance. As US Navy Captain Carl Schuster suggested in response to these developments, "the innovations promise to add new strategic dimensions to global maritime hot spots, including simmering tensions in the South China Sea."[142] The United States has been developing a number of unmanned units that it would intend to use for demining, anti-submarine warfare, and antipiracy, so it is not surprising that China would be developing its own systems. Indeed, China has been rapidly developing and deploying USVs for military purposes, particularly since the mid-2010s, as part of its broader strategy to enhance maritime dominance and security. One of the most notable platforms is the JARI USV, unveiled in 2018 by the China Shipbuilding Industry Corporation (CSIC).[143] This multirole USV is capable of conducting anti-submarine, anti-surface, and air defense missions, and can be equipped with various weapons, including torpedoes and missiles.

Another significant development is the Haiyi (Sea Wing) USV, which has been operational since around 2017. It is primarily used for oceanographic data collection but has potential military applications, such as deep-sea reconnaissance and intelligence-gathering.[144] Similarly, the Marine Lizard, a stealthy amphibious USV launched by China in 2019, is designed to participate in amphibious assault missions.[145] In a novel function, it can transition from sea to land, carrying payloads like missiles, or perhaps UAVs, and can be remotely controlled for coastal and offshore defense. In theory, therefore, this USV could offer an all in one 'full spectrum drone warfare' capacity, allowing for function across all domains.[146]

India's interest in USVs, on the other hand, is primarily for antipiracy, in particular being able to deploy unmanned vesssels to conduct reconnaissance in potentially hostile waters. The hope is to develop unmanned ships that can loiter in "the exact area where pirates wait for an assault. This would add power to the first strike capability."[147] The Indian Navy seeks to build on what they view as a success of US and Israeli navies when it comes to unmanned vessels.[148] However, more recently, India has been inspired by how Ukraine has deployed sea drones against Russia. Specifically, in 2024, Sagar Defence Engineering, an Indian startup, unveiled the Bali USV. This drone boat is “equipped with radar, an object-tracking system, and swarm capabilities”. In addition, reports suggest “Indian firms may soon develop drones capable of carrying explosives.”[149]

In short, many of the same players in the development of aerial and ground unmanned vehicles are also interested in and developing maritime systems. Whereas the aerial drones have an international regime dedicated to stemming their proliferation, albeit one with major limitations, unmanned systems in the maritime environment would face no such proliferation impediments, meaning that those countries seeking to acquire the technology likely can. This has raised questions about whether there are hazards to such proliferation. Indeed, an important example to conclude with is the pertinent case of how a violent nonstate actor is making the most of access to such technologies.

The Houthi movement, officially known as Ansar Allah, has increasingly employed maritime drones as part of their asymmetric warfare strategy in Yemen, particularly targeting the strategic shipping lanes of the Red Sea and out into the Indian Ocean. These USVs have been used in terrorist attacks against both military and commercial vessels, raising security concerns over freedom of navigation in one of the world’s most vital maritime corridors, which leads through to the Suez Canal. The Houthis’ adoption of this technology represents a significant shift in their capabilities, allowing them to strike distant targets with precision while minimizing their own risk.

Houthi maritime drone attacks first gained international attention in 2017, when they began deploying explosive-laden USVs against Saudi-led coalition warships and other vessels supporting the Yemeni government.[150] These attacks involved remote-controlled boats filled with explosives, designed to target ships by ramming them at high speeds. One notable incident occurred in January 2017, when a Houthi drone boat attacked the Saudi frigate Al Madinah near the port of Hodeidah.[151] The attack, which was caught on video, resulted in significant damage to the ship and the deaths of two crew members, showcasing the destructive potential of these maritime drones.

The technology behind these maritime drones appears to be a mix of locally modified vessels and foreign-supplied components, with evidence suggesting that Iran has provided material and technical support to the Houthis in developing their drone capabilities.[152] The maritime drones are typically equipped with GPS systems for navigation and explosives designed to detonate on impact. These drones are often launched from small boats or from coastal areas under Houthi control, allowing them to target vessels passing through the Red Sea, including commercial oil tankers, cargo ships, and naval vessels.

The use of maritime drones by the Houthis poses a significant threat to global shipping, particularly in the Bab-el-Mandeb Strait, a critical chokepoint for oil and goods traveling between Europe, Asia, and the Middle East. The Houthis have periodically targeted oil tankers, aiming to disrupt Saudi oil exports and create instability in global energy markets. For instance, in July 2018, two Saudi oil tankers were attacked by Houthi maritime drones in the Red Sea, prompting Saudi Arabia to temporarily halt oil shipments through the Bab-el-Mandeb. Although the tankers did not sink, the attacks underscored the vulnerabilities faced by commercial shipping in the region.

Beyond the immediate physical damage caused by these drone attacks, the psychological and economic impacts are profound. The Houthis' use of maritime drones creates a constant sense of insecurity for vessels transiting the region, raising insurance costs, and forcing ships to reroute or enhance security measures. The threat of such attacks, combined with the Houthis' use of sea mines, UAVs, and missile strikes, contributes to an environment of heightened tension and uncertainty in the Red Sea. This has drawn international concern, particularly from the United States, European nations, and maritime organizations, who have called for stronger measures to protect freedom of navigation.

Efforts to counter the Houthi maritime drone threat have involved increased naval patrols and intelligence-sharing among the Saudi-led coalition, the United States, and other regional and international partners. However, the persistent nature of the threat, combined with the relative ease of deploying these drones, means that Houthi attacks remain a significant challenge, with 130 attacks taking place in the Red Sea alone between October 2023 and October 2024.[153]

Are unmanned maritime systems likely to be game changers?

As the state of proliferation suggests, as long as unmanned technologies can circumvent the limitations and risks faced by humans, they will be attractive to nation-states. This includes aerial systems but also underwater or surface systems. Some of the security consequences are therefore analogous across the different types of drones. To the extent that using drones reduces the costs of incursion, countries will be tempted and even emboldened to use force across boundaries. Reports of Russian military vessels entering NATO waters or intimidating NATO members have, for instance, increased since the start of its war in Ukraine.[154] To the extent that the costs of these incursions drop when the technology is unmanned, we might expect more such incursions. If the rules of engagement are unclear when the vehicle is manned, they are even murkier with unmanned systems. Can countries send USVs across boundaries without paying any consequences? Or will the other side consider this an incursion that requires a response? These questions remain ever present and relevant, but the indeterminate rules of engagement raise the prospect of miscalculation.

One martime drone aspect that is often overlooked is how aerial drones launched from aircraft carriers have the potential to be game changers in ways similar to those launched from land. In some ways, however, that effect can be magnified by the enormous range of ships. To be sure, ships cannot reach far-flung destinations as quickly as aircraft, but they could essentially provide a forward operating base from which combat operations could be launched. Although the United States chose not to pursue this path, Turkey and other nations, like China, are in later stage production of dedicated “drone aircraft carriers.”[155] When other countries possess such technologies, they too could deploy combat drones from a ship. One scenario could include China deploying a naval ship to the Western Hemisphere and putting a new type of aircraft (or indeed UUV or USV) in range of the United States, which could seem attractive to countries that do not have forward operating bases in the hemisphere.

One of the most significant game changers, however, is the development of autonomy in naval drone technology. In this context, autonomy would relate to the ability to set a destination and for the underwater drone to reach the destination without human operation, which can mean guiding its course based on attributes along the sea floor, through bridges, or other features of the underwater environment. With recent increases in attacks on submarine critical infrastructure, there are worries about the threat such technologies could pose in the future.[156] There is also the possibility that such systems could help guard against such action over longer ranges and in international waters. Autonomy is important for maritime environments since they can free underwater vehicles from the umbilical cable. Otherwise, this cable is required for power and data from the mother vessel, which then needs to be in the vicinity. Autonomous unmanned alternatives allow for a greater range and maneuverability.

Unmanned technologies offer a world of lower-risk options for a range of activities, from antipiracy to exploration of areas that would otherwise be off limits because of ice or cold, such as Antarctica. For now, however, the technology continues to evolve, which is made more difficult by technological impediments presented by the difficulty of navigating the complex maritime environment, including everything from boat traffic to unpredictable currents, to debris on the ocean floor or deep sea connectivity.

Are there nonmilitary applications of unmanned maritime or ground technologies?

As with aerial drones, unmanned underwater vehicles (UUVs) have steadily gained traction for nonmilitary purposes. In 2012, National Defense magazine noted a growing trend: defense firms like Boeing and Lockheed Martin began marketing their underwater drone technologies to commercial sectors. This shift was driven in part by declining defense budgets, which encouraged firms to seek new markets.[157] At the same time, industries such as oil and gas, having already tapped into easily accessible resources, were being pushed toward new frontiers — in remote polar regions and deep waters — where manned operations were risky, expensive, and impractical. UUVs offered a safer and more cost-effective alternative for these challenging environments. Indeed, the most lucrative application of unmanned maritime systems is certainly in the service of the oil and gas industry, where these unmanned vehicles have been used for deep-sea surveys that allow companies to make maps before investing in infrastructure.

Unmanned underwater vehicles are also valued for their ability to explore parts of the ocean that are too remote, dangerous, or inhospitable for humans. One example is their use in studying the underside of Arctic and Antarctic sea ice. These regions are too cold and difficult for human divers to access safely, but underwater drones can operate beneath the ice to map features like algae blooms, which are crucial for understanding polar food chains. Shaped like small torpedoes, the drones are deployed through holes drilled in the ice using oil burners and steam drills. Once launched, the drones travel beneath the ice, collecting data and measurements that help scientists estimate the distribution and abundance of algae across wider areas — a task previously limited to what could be observed by marine animals or a handful of highly trained divers.[158]

Unmanned underwater vehicles are also used in search and rescue. For instance, they were tasked with aspects of the search for Malaysian Airlines Flight 370, which proved vexing in part because of the enormous area that the search spanned. The Bluefin-21 was able to produce high-resolution, 3E mapping of the sea floor and go to an area that Australian Air Chief Marshal designated as “new to man.”[159]

Beyond these applications, there are also recreational uses of UUVs. Given the sophistication required to operate in the open seas, and the comparatively limited expertise of hobbyists, these unmanned vehicles tend not to go too far afield; nevertheless, this wider interest in UUVs is demonstrated by groups such as the Personal Submersibles Organization, whose members use the internet to compare notes on how best to design, build, and operate personal underwater vehicles, both manned and unmanned, in their capacity as hobbyists.

UGVs, on the other hand, have evolved from military origins into an array of commercial applications, leveraging automation, robotics, and AI. Their commercial use began with early applications centered around agriculture and mining, where they assisted in hazardous or repetitive tasks. In agriculture, autonomous tractors and harvesters emerged as early UGVs, reducing labor needs and increasing precision in farming operations.[160] Similarly, mining industries deployed UGVs for transporting heavy materials and performing inspections in dangerous environments like tunnels, helping to prevent accidents.[161]

More recently, the integration of advanced sensors, GPS, and machine learning has allowed UGVs to flourish across various sectors. Key examples include autonomous delivery robots, which companies like Amazon, Starship Technologies, and Nuro have pioneered. Amazon Scout, for instance, is a small, self-driving delivery UGV that delivers packages directly to customers in urban areas.[162] Starship's delivery robots operate similarly, with over six million deliveries complete as of 2024, handling small deliveries autonomously on sidewalks (see Figure 5.8).[163] These UGVs utilize GPS, cameras, and obstacle avoidance technologies to navigate complex urban environments.

Figure 5.8 Delivery Robot from Starship Technologies at Oregon State University

Source: Photos by Blake Brown, marketing manager. October 18, 2020. CC-BY-SA-2.0.

The construction industry has also seen a surge in UGV deployment, particularly with autonomous bulldozers and excavators. Caterpillar's Command technology allows for the remote operation of construction machinery, reportedly enhancing safety and efficiency.[164] Komatsu has developed a similar solution, with its Autonomous Haulage System (AHS) allowing driverless trucks to transport materials in mining operations.[165] These UGVs improve efficiency by operating 24/7 and reduce the risk of human injury in hazardous environments.

Additionally, UGVs are making an impact in logistics. Automated Guided Vehicles (AGVs) have become essential in warehouses for material handling, with companies like Kiva Systems (acquired by Amazon) creating robots that move inventory within fulfillment centers.[166] These robots are programmed to pick up and transport goods within large warehouse spaces, streamlining operations and reducing reliance on human labor for repetitive tasks.

The utility and power sectors have also embraced UGVs for maintenance and inspection, particularly in environments unsuitable for humans, such as nuclear plants, pipelines, and electrical substations. Boston Dynamics' Spot, a versatile "legged UGV," is an example of this. Spot is capable of navigating rough terrain and is used for inspections in industrial environments, equipped with sensors, cameras, and machine-learning capabilities to autonomously detect issues like gas leaks or mechanical faults.[167]

As UGV technology continues to advance, therefore, it is becoming more integrated into smart cities, agriculture, logistics, and many more commercial domains. The adoption of UGVs is driven by the ability to operate in environments that are either dangerous, remote, or where precision and efficiency are paramount, showing the commercial sector's increasing reliance on automation for greater safety and productivity.

Finally, when it comes to commercial USV, it is safe to say they are also challenging the established role of manned systems. Take environmental monitoring as a key example. Here USVs find a role in projects that require consistent and large-scale data collection over long periods. Saildrone, a leading USV company, has developed wind-powered USVs equipped with solar panels to support a wide range of oceanic studies (see Figure 5.9).[168] Saildrone's vessels collect data on ocean temperatures, salinity, and carbon dioxide levels, which are critical for climate science and fisheries management. These USVs can operate for months at a time, covering vast areas of the ocean without human intervention, and have been used in major projects by National Oceanic and Atmospheric Administration (NOAA) to study marine life and oceanic carbon cycles.[169]

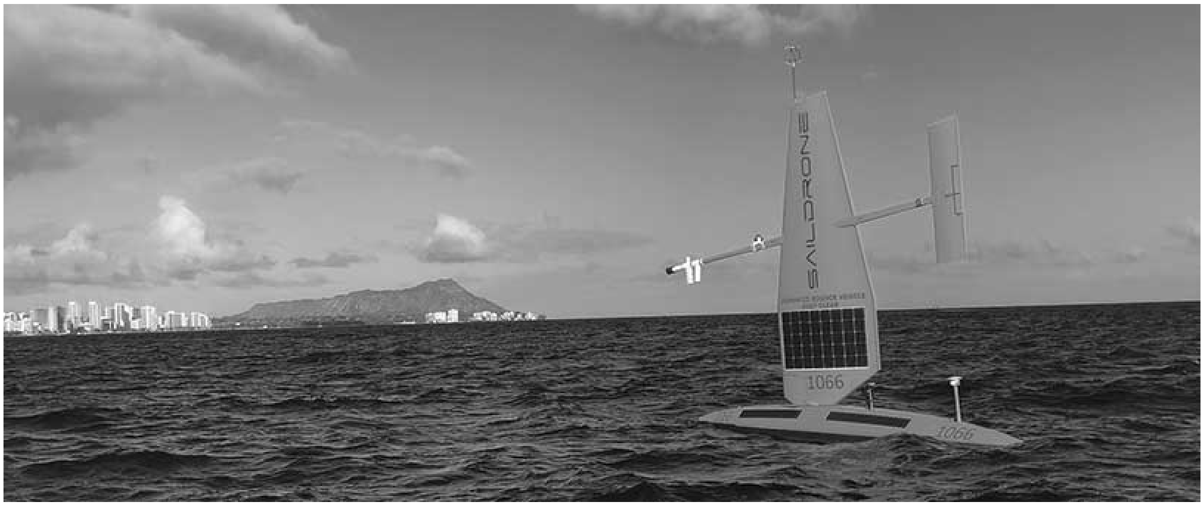

Figure 5.9 Saildrone

Note: The saildrone is said to have sailed over 1.3 million nautical miles and spent almost 45,000 days at sea.

Source: National Oceanic and Atmospheric Administration (US Department of Commerce). Retrieved from https://www.pmel.noaa.gov/ocs/saildrone

Maritime security and traffic monitoring is another area where USVs are proving valuable. In ports and busy waterways, USVs like the Sea-Kit X are employed for "subsea asset monitoring, maritime logistics, ocean science, environmental management, marine inspection and efficient survey of the sea floor."[170] The company is also developing a luxury line of USVs billed as "change superyacht operations, embracing new and innovative technologies to provide an unparalleled leisure experience for yacht owners, their guests and crews while substantially decreasing the environmental impact of superyachts."[171] These vessels are equipped with radar, Automatic Identification Systems (AIS), and communication tools to interact with manned ships and port authorities. They offer real-time situational awareness, improving security while reducing the need for human-operated patrols.

In the realm of maritime surveying, USVs are now extensively used to map oceans, lakes, and harbors. One notable example is the Seafloor Systems EchoBoat-240, a small, highly mobile USV designed for hydrographic surveys. It can autonomously navigate waterways using GPS and sonar systems to create detailed maps of underwater environments, often used by governments and private entities for coastal management and dredging projects.[172] This USV reduces the cost and risk associated with traditional manned survey vessels, making surveying more accessible, especially in remote or difficult-to-navigate regions.

In the offshore energy sector, USVs are playing a pivotal role in the inspection and maintenance of offshore wind farms. The XOCEAN XO-450 is a prime example, a USV designed for offshore wind farm surveying. The XO-450 collects data for environmental impact assessments, seabed mapping, and cable route surveys using multi-beam echo sounders, environmental sensors, and data-transmission systems. What sets XOCEAN apart is its fully autonomous operation, capable of running 24/7 with remote monitoring from shore. This level of automation significantly reduces the need for crewed vessels, cutting both operational costs and risks to human workers in challenging offshore environments.[173]

In addition, USVs are increasingly used in maritime security and surveillance. The ACV Global's Marine Monitor (M2) USV is a system designed to autonomously patrol harbors, coastlines, and marine protected areas. Equipped with radar, cameras, and AIS, the Marine Monitor can help detect illegal activities such as smuggling, piracy, and illegal fishing. The vessel transmits real-time data to command centers, enabling authorities to respond quickly to any detected threats. It is particularly useful for border and port security, allowing continuous monitoring without the expense of human-operated patrol boats.[174]

Finally, in the field of shipping and logistics, USVs are being tested as autonomous cargo carriers. One of the more ambitious examples is the Yara Birkeland, which is set to be "the world's first fully electric and autonomous container ship with zero carbon emissions."[175] While larger than most USVs, this vessel will operate autonomously on surface routes, carrying goods between ports along the Norwegian coast. Once fully operational, the Yara Birkeland is expected to revolutionize short-sea shipping by reducing human labor, fuel costs, and carbon emissions, demonstrating the growing role of USV technology in logistics.

Overall, therefore, it is clear to see how it is not just the military domain that has expanded in its use of USV, UUV, and UGV systems. If anything, today we are seeing a closer relationship between the development of commercial systems and military technologies, allowing for rapid innovation—especially in autonomous systems—but also rapid proliferation. As such, the future looks to be unmanned/uncrewed, if not fully autonomous, across all domains.

6
NON-COMBAT DRONES

The use of drones for armed conflict has tended to draw considerable attention, scrutiny, and indeed criticism. Yet, drones also have far-ranging nonmilitary applications, from the simple recreational, to commercial, and governmental uses. This chapter evaluates the role of remote technology for these nonlethal purposes, exploring diverse use cases from humanitarian crisis response to law enforcement commercial deliveries.

How are drones being used by governments other than through the military?

While the military has been at the cutting edge of drone development, government agencies other than the military are increasingly looking to drones to carry out their work. For example, the largest drone fleet outside the Defense Department belongs to Customs and Border Protection (CBP), which uses two distinct types of aerial surveillance operations. On the one hand, CBP employs a small drones program of anywhere between 145 and 460 rotary and fixed-wing drones. These are used for small-scale operations and employed in conjunction with a trained operator, but can be left autonomous for up to 30 minutes if given specific coordinates for a mission. They have most often been used for apprehending small-scale migration or narcotic operations.[1] This program offered CBP a way to monitor borders without expending resources such as their Air & Marine Operations'

Unmanned Aircraft System, which has nine MQ-9 Predators and Guardians for both air and land missions.[2] A 2022 award of nearly $530 million from CBP to General Atomics is meant to upgrade and expand the fleet.[3]

The use of these Predators and Guardians, unarmed versions of those used in conflict, has not come without controversy. The civil liberties group Electronic Frontier Foundation filed a lawsuit that uncovered information showing that CBP flew 700 surveillance missions between 2010 and 2012 for other agencies that were not authorized to use drones for patrol purposes, like the Drug Enforcement Agency.[4]

Questions also arose as to the relative effectiveness of using drones for border control. In 2022, CBP credited the small drones program for leading agents to apprehend 51,248 illegal immigrants crossing US borders.[5] The Air and Marine Operations (AMO) MQ-9 Program detected 104,755 cross-border illegal activity.[6] Considering the 2.2 million estimated illegal border crossings in 2022, these numbers only equate to about 7 percent of incidents.[7]

Even more, a 2014 audit showed that operating the AMO drones costs $12,225 per hour, and in the 2022 fiscal year, the total of 11,386 logged flight hours amounted to nearly $140 million. A spokesperson from the agency defended the use of drones, suggesting that the data were misleading insofar as drones are used for the "big-picture" issues of identifying hot spots rather than tracking individual violators, although the audit concluded by recommending against the agency's proposal of spending an additional $443 million to buy 14 new drones.[8]

Despite the critics, however, the CBP agency's defense suggests, drones look increasingly appealing for law enforcement, and a number of state and local agencies share the sentiment. As of 2023, over 1,400 police departments use drones, including the Seattle Police Department.[9]

Initially, police use of drones met with public approval and has periodically elicited concerns. In the early 2010s, Seattle's Police Department had acquired two drones only to have them decommissioned and transferred to the Los Angeles Police Department (LAPD) without having been used. The LAPD, in turn, then faced public outcry over the question of how the drones would be used and put a moratorium on their use. In California, however, the Chula Vista Police department used 29 drones to respond to over 16,000 calls between 2018 and 2023, arriving on scenes to assess safety and seriousness before human personnel arrive. While most of Chula Vista drone missions are used to assess issues like substance abuse and theft, violent incidents and traffic collisions were also responded to. In these cases, the drone allowed for a rapid response time of under two minutes.[10] The flying of drones around the city has led to worries from the public of being constantly surveilled, but requests to view the footage have often been denied on the grounds of the footage being investigative and thus concealed from the public. One resident filed a public records request to be able to assess potential violations of privacy; Chula Vista officials refused, leading to a lengthy legal fight pitting public right to privacy against law enforcement's mandate for public safety.[11]

The appeal of drones for policing is that they can serve similar functions as police helicopters but at a fraction of the cost: $22,000 for a police drone compared to between $500,000 and $3 million for a helicopter (not to mention pilot training, pay, and aircraft maintenance).[12] This highlights the importance of both small drone cameras and sensors (e.g., thermal sensors that can detect suspects via body heat emitted), and the drone's ability to capture photos and videos that can serve as important evidentiary information.

In April 2014, the city of Lloydminster became the first city in Canada to use drones for speed and traffic law enforcement, with the city citing lower costs than existing approaches.[13] That said, the city also recognized the potential anxiety that drones might create among a public that would not have the same predictability of knowing where drone photo enforcement units sit as they would with a physical camera.The possibilities are endless, and in many cases worryingly so, as the technologies become more advanced and readily available.

What are the commercial applications of drones?

Amazon made news in 2014 by announcing that it would deliver packages via drone, and in so doing joined what has become a growing tide of commercial drone interest. Up to May 2024 alone, the Federal Aviation Administration (FAA)—the US government agency responsible for ensuring the safety and efficiency of air travel—states that there were 383,000 registered commercial drones.[14]

The list of commercial applications for drones is extensive and includes almost any activity for which surveillance, monitoring, and data are useful and for which there are, as mentioned before, impediments to humans conducting a task that is 'dull, dirty, or dangerous.' In response to the increased demand for commercial drones, the FAA has been granting exemptions at increasing rate to drones that "do not pose a threat to national airspace users or national security."[15]

One of the earliest applications of drones for commercial activities was in the area of oil and gas in remote regions like Alaska. Launched by hand into the air, the drones used sensors to generate 3D images and "paint" maps of the ground. Drones are useful in this context in part because of the remoteness of the Prudhoe Bay, which is in the Northern Slope of Alaska and home to the largest oil fields in the United States. Similarly, the climate of the region means that many of the roads are impassable for many months, giving a great advantage to aerial drones. As former secretary of transportation Anthony Foxx stated when endorsing the move to use drones, "these surveys on Alaska's North Slope are another important step toward broader commercial use of unmanned aircraft. The technology is quickly changing, and the opportunities are growing."[16]

A second early mover in terms of commercial drones was in the construction industry. As *Architect* magazine put it in 2014, "interest in drones is on the rise among architecture and construction firms for the equipment's ability to access and scope out hard-to-reach or dangerous sites."[17] This industry is particularly interested in aerial imagery that can be used for surveying and logistical planning. Drones also help monitor progress and enable engineers to work in real time on the implementation of a construction project. As the CEO of drone startup Skycatch speculated about the drone's potential, "one job site could cost a company a few billion dollars. If you can shave a few days off their costs, it's huge."[18] In a round of FAA approvals announced in December 2014, Clayco Corp., a company able to monitor construction sites, was granted an exemption. The FAA still required that they fly under 400 feet, fly within sight of operators, and be under 55 pounds, a rule that applied more generally. The technology, it was argued at the time, would "help with topographic surveys, environmental site assessment, [and] job site safety."[19] Today, drone adoption in construction has accelerated, with firms increasingly relying on UAVs for tasks that improve project timelines and site safety. For instance, Turner Construction, one of the largest U.S. contractors, expanded its drone program (including ground robots) to conduct real-time site inspections and progress tracking across major hospital and infrastructure projects during the COVID-19 pandemic, when reducing on-site personnel became critical.[20] Similarly, *Skanska USA* uses drones equipped with photogrammetry software to produce 3D models for complex urban developments, such as the $1.6 billion LaGuardia Airport Terminal B reconstruction.[21]

A third prominent area for commercial drones has been in agriculture. When conducting their own research on the issue, the Association for Uncrewed Vehicle Systems International (AUVSI) "found that almost all respondents considered agriculture to be far and above the largest market."[22] According to *Aviation Week*, about 80 percent of future commercial applications of drones would likely involve agriculture.[23] One scholar working on agricultural drones suggested that "the application of these data drones is only limited by our imagination."[24] For less than $1,000 farmers could have a drone, typically a quadcopter or equivalent, that allows farmers to fly autonomously using a global positioning system

(GPS) and take images that are then incorporated into software. As Chris Anderson, formerly of *Wired* magazine, describes it, the imagery can be used in the service of visualizing patterns of soil variation and pest infestations; observing differences between crops that are healthy and those that are not through the infrared data captured; and creating time-series animations.[25] These tools allow any warning signs to pop up early so that farmers can address emerging problems with their crops, using the drone to assess crops, monitor the health of crops, and ensure resistance to pests, all of which are currently tasks that require a farmer to walk through the fields.[26]

The turn to drones meshes with what has become the trend of "increasingly data-driven" or "precision agriculture" aimed at becoming more efficient to service growing populations. This approach is based on observations of variation within and across crops through the use of imagery. The introduction of GPS made it possible to map terrain and then observe spatial variation on the basis of crop yield, hydration, and nutrient levels in ways that optimize decisions about where to plant, how to combat disease, and where to irrigate. One robotics engineer suggested, "it sounds trivial but those numbers really add up a lot. If we could save farms 1% on inputs like herbicide and pesticide and increase their yields by 1%, you are looking at multibillion dollar savings."[27]

Beyond farming, Internet giants were also keen to get in on the action. Facebook and Google both pursued drones to help provide more widespread internet access. Facebook, in particular, showed interest in buying solar-powered drones, which can stay airborne for up to five years and could act as wireless access points to provide internet in remote areas. In pursuing this interest, Facebook bought Ascenta, a UK-based company that makes solar-powered drones. Google also acquired a solar-powered drone company that Facebook had been trying to acquire, namely, Titan Aerospace. Such acquisitions were early signals that Google was becoming much more than just a search engine, but rather a holding company for everything, including its drone delivery business. Google conducted experiments in Australia that would use fixed-wing aircraft to deliver anything from chocolate to cattle vaccines. More recently, in the United States, Walmart has made drone delivery available to over 1.8 million households in the Dallas Fort-Worth region and now operates in six states through 31 delivery hubs.[28] These tests and early deliveries have not been without controversies and environmental impact, with researchers from the United Kingdom, the United States, Mexico, and Indonesia arguing that the use of drones for such purposes "is also associated with a range of potential harms to humans and wildlife," (including when used in conservation).[29] Yet the rollout continues at a pace. By the end of 2024, Amazon stated it would have delivery services to customers in the United States, as well as cities in Italy and the United Kingdom via MK20 Prime Air drones. They have already started testing these drones by delivering prescriptions to towns in Texas and California following their beyond visual line of sight (BVLOS) approval.[30]

The use of drones for deliveries is attractive because it means accessing areas that are too expensive to reach, too dangerous, or inaccessible via conventional delivery services. It is for this reason that DHL, the German logistics company, launched a service to use an autonomous quadcopter to deliver supplies to Germany's North Sea island of Juist, which is also car-free. According to *Deutsche Post*, which owns DHL, it had authorization from the German transport ministry to fly its 'parcelcopter' to Juist and not to fly over houses. DHL reports that it avoids air collisions by flying under 50 meters while checking in with a ground station. It also uses a container that is weatherproof to protect packages from potential damage.[31]

Yet despite these successful cases over the past 10 years, we still do not live in a world where drone delivery is ubiquitous. Indeed, some companies (like UPS and FedEx) appeared to be following suit in trying to develop drones for delivery services, but to no avail.

Despite the big promises, these companies under-delivered. Practical impediments emerged that have, thus far, been difficult to overcome, especially in cold weather and congested urban environments. Drones have a relatively short battery life.[32] They are subject to destruction in bad weather conditions. They require authorization in terms of airspace usage.

Nefarious actors can interfere with the deliveries, making theft from porches look like an easy problem to solve when compared to the problems of a rogue drone. As such, commercial industries with deliveries found more affordable and pragmatic options like gig delivery employees in automotive vehicles or on bikes. This is not to say that drones are redundant in this space. On the contrary, they will certainly continue to roll out and play a major role in our future delivery landscape, albeit when the challenges that persist are overcome.

Drones have, however, proven valuable for the film and journalism industries because many potential scenes or stories would fit under the 'dangerous' heading when it comes to human involvement or the 'cost-effective' heading. For Hollywood, several companies have used drones on closed sets not only as a cost-effective alternative for aerial shots normally performed by helicopters or planes, but as one that can capture something like an explosive action scene that might put a cameraman in danger.[33] The cable news network CNN also reported that it had brokered a deal with the FAA to incorporate drones into its reporting. "Our aim is to get beyond hobby-grade equipment and establish what options are available and workable to produce high-quality video journalism using various types of UAVs (drones) and camera setups," according to one senior vice president, who followed by saying that the drones would naturally have to operate safely.[34] Today, it is hard to spot a TV documentary or movie that does not use a drone in some way shape or form, highlighting just how effectively drones have integrated into the film industry.

The same could be said for sports and sports broadcasting. The sports network ESPN began using drones to cover sporting events such as the Winter X Games, with the provision that ESPN would keep drones within a "closed-set environment." This had been defined as not over spectators or near airports, but rather to track snowboards or snowmobiling activities in a set geographical environment. As ESPN's manager for the approval process stated, "any piece of technology we feel brings viewers closer to the event we're interested in."[35] Russia also approved the use of drones to capture snowboard and skiing events at the Sochi Olympics (2014), which allowed for some viewing angles that would be impossible with either a distant helicopter or an individual photographer from a more distant vantage point. Nevertheless, the use of drones in sports is not always so welcome.

In the 2024 Paris Olympics, the reigning gold medal champions in women's soccer, Canada, were penalized when they were caught using drones to spy on their opponents' practice. Their coach was suspended for a year and fined, with the Canadian team protesting that "all top 10 teams" scout out other teams and that drone surveillance was no different.[36] The soccer federation certainly begged to differ and reminded teams after the incident that it had banned spying by drone during the Olympics. This is not the only concern for drone use in the entertainment industry. It is important to recognize that drone use in these kinds of industries needs to be done sensitively. For instance, privacy concerns are an issue with members of the public identifiable and permissions difficult to obtain; also, different emotional reactions that people might have to drones and how animals can be impacted need to be considered (an issue discussed later in *What are the potential applications of drones for aid and relief operations?* below).[37]

What are the potential applications of drones for aid and relief operations?

Although much of the publicity about drones often highlights the concerns about security and privacy, drones also have the potential to be useful for nongovernmental activities that are neither commercial nor recreational. For example, UNICEF is using drones to address transport, connectivity, and emergency preparedness. Traditionally, the delivery of life-saving materials in both humanitarian and development contexts can face myriad challenges, such as complex geography. As a UNICEF report highlighted in June 2017, the government of Malawi and UNICEF launched an air corridor to test the potential humanitarian use of unmanned aerial vehicles (UAVs) the "test corridor is the world largest test area with over 5000 square km (2000 square miles)—and allowing operations up to 400 m (1300 feet) above ground level—which is specifically dedicated to the humanitarian and development uses for drones and the only dedicated unmanned flight testing space in the continent of Africa."[38] Put simply, drones can quite literally transcend traditional drawbacks and transport issues, delivering life-saving materials and generating incredible social benefits.

Indeed, UNICEF are not alone in this mission. The Silicon Valley startup Matternet has attempted to do something similar, asserting that "drone delivery technology should be first used in the developing world to deliver food, medicine, and other necessities to areas that are less accessible by car or truck."[39] The company has long argued that commercial technology usually diffuses from developed to developing countries, even though those who need the technology most are arguably people in developing countries who otherwise cannot access medicine or food because they live in remote areas with poor infrastructure. The idea behind Matternet was to build a network of drones that can cover a swath of land by transporting goods between ground stations, which will recharge batteries and load swap in ways that sidestep roads altogether. The group tested the network of octocopters in the Dominican Republic, Haiti, and Lesotho, where it transported material from clinics to hospital labs. Such pioneering deployments of drones have led to thousands of similar projects spreading across the world today.

Yet this is not the only way drones can be used for good. Wildlife researchers have been using drones carrying cameras and sensors to track and document wildlife, estimate population sizes, map terrain, and catch poachers in areas of Africa, South Asia, and more recently Latin America.[40] The potential negative impact of such drone use on animals and humans has been mentioned earlier in the chapter, but for practitioners, if these concerns are taken seriously and mitigated where possible, the drones still have incredible utility. For example, Mexico planned to use drones to detect illegal fishing of the critically endangered vaquita marina, the world's smallest porpoise, in the Sea of Cortez. Drones, it had been argued, would allow authorities "to have permanent aerial patrols in the area and be able to react much more efficiently and quickly" to protect the porpoises. This is incredibly important with the animals fewer than 100 in number and threatened by the same nets that fish for the totoaba, a fish that is highly sought after by chefs in China.[41]

A number of actors have sought to promote the idea further. Princess Aliyah Pandolfi of Kashmir-Robotics founded the Wildlife Conservation UAV (Drone) Challenge. The challenge—to design inexpensive drones capable of detecting and locating poachers—attracted close to 140 entries. The drones must also be able to be launched from the bush, operate for hours at a time, and communicate over existing commercial infrastructures.[42] Google gave the World Wildlife Fund $5 million for anti-poaching drones, which have conducted aerial surveillance in isolated areas of Africa and Asia, where poaching of endangered species is common.[43] These drones are often launched by hand and are equipped with night vision capabilities to see poachers in all levels of light. The visual information coming from the drones is then communicated to rangers, who can apprehend the poachers. More generally, drones could be useful for documenting wildlife that is difficult to reach otherwise, such as killer whales and osprey. They are able to conduct flyovers and document population size without disturbing the animals to the extent that a fixed-wing, manned aircraft would. Recognition technology that could differentiate between different species is also being developed. Take SnotBot as a pertinent example, a modified consumer drone that flies through a whale's spout, or blow (the water it ejects into the air) "collecting the biological data within." As the researchers at Ocean Alliance who run the drone state, it is by studying this biological sample that they can get insight into the "genetics/DNA, hormones and microbiomes of whales."[44]

Another potential positive application of drones under the heading of nongovernmental activities, is the use of drones for disaster relief. Drones have the virtue of being able to access areas of an earthquake relief zone that would be inaccessible to humans. For example, in the wake of the 7.8- and 7.6-magnitude earthquakes that struck the Turkey/Syria border in 2023, relief organizations were struggling to find people. More than 41,000 victims were pulled from ruins, but several remained stuck deeper under the debris and thus were difficult to pinpoint. However, thanks to drones equipped with NASA's FINDER (Finding Individuals for Disaster Emergency Response) device, emergency teams were able to retrieve several remaining survivors.[45] Further, drones could also use aerial mapping to create a picture of the areas in highest need and then focus assistance to those areas. In an area with a shortage of resources and poor infrastructure, being able to triage based on this drone footage could prove to be extremely helpful.

Drones for these purposes followed the example of the 2011 Japan Fukushima nuclear accident, in which drones were used to identify radiation levels so that individuals did not have to be exposed to potentially dangerous radiation levels themselves. A Japanese company has subsequently developed a drone that can fly into the Fukushima reactor autonomously, using lasers to avoid obstacles and recharging batteries without human intervention. One robotics company, Autonomous Control Systems Laboratory Ltd., created a one-meter-wide, six-propeller drone to collect dust for examination and measure radiation levels, producing data in real time.

Another emerging application suitable to aid and relief missions that are often too dangerous for manned equivalents is the use of drones to fight wildfires. In 2018, the Woolsey Fire ravished Southern California, destroying nearly 100,000 acres of land and causing the evacuation of 300,000 residents. A local company AeroVironment, in conjunction with the National Park Service Inventory and Monitoring Program, was able to deliver analytics based on aerial imagery to guide disaster and relief efforts.[46] Today, drones conduct nearly 75 percent of inspections on power lines, one of the leading causes of wildfires.[47]

Facebook founder, Mark Zuckerberg, has also sought to apply his technology to disaster relief. For instance, when he visited Pope Francis in the Vatican, he delivered him his own drone; a solar-powered drone similar to the one that Facebook had indicated it hoped would become available for bringing the internet to developing regions.[48] The meeting and drone gift came at a time when Italy was recovering from a devastating earthquake, and Zuckerberg had emphasized across his products the hope that technologies such as drones can provide a tool in the service of humanitarian relief. The Pope had previously received a drone from a school that had promised that drones represent “the values of technology in the service of man,” noting the helpful applications for earthquake relief after the big Nepal earthquake.[49] Nevertheless, the darker side of drones nearly reared its head against Pope Francis in September of 2021, when a rogue drone was prevented from threatening the safety of the Pope during a Mass in Slovakia.[50]

In terms of more relief focused organizations and their engagement with drones, the American Red Cross conducted a study to investigate how it might be able to use drones for disaster response., While it identified many potential opportunities, it also raised some enduring questions about restrictive regulations and the policy environment in which the drones would operate. For example, groups wanting to use drones for the Washington State mudslide relief effort back in 2014 were rebuffed by governmental officials concerned about how the drones might be used. A UN humanitarian affairs official who conducted a study on the use of drones for humanitarian responses concluded that the pendulum may have swung too far in the direction of restrictiveness: “It’s been interesting to see how fast we went from total Wild West to something where it’s rapidly shifting to the default is that you can’t do it without permission, but there’s not necessarily clear rules for how do you get permission.”[51] Added to this, of course, is the fact that there is no more complicated and chaotic environment than during times of disaster relief. Agencies deployed overseas in a regulatory (and socio-cultural) context different from their own need to navigate different rules and regulations in time-sensitive situations with in-country support limited due to said disaster.

What is the recreational potential for drones?

Like commercial drones, recreational drones (also referred to as consumer drones) are a growing industry, with drone manufacturers reporting revenue growth of three to five *hundred* percent per year. Between 2015 and 2019, the number of registered drones grew from 300,000 to 1.5 million (likely with far more that are unregistered).[52] The trend in recreational drone popularity can be exemplified with the Do-It-Yourself Drones community, which is composed of individuals who assemble their own drones or assemble those of premade kits they buy online. This community had 26,000 members as of 2012, yet their membership multiplied fourfold to nearly 95,000 by 2024.[53] These personal technologies include inexpensive toy drones marketed toward young teenagers. More advanced drones are also available for individual use for photography and videography. The most popular hobby drones have been from the Chinese-made DJI line with models ranging from $300 to $3,000. Their most expensive model, the DJI Mavic 4 Pro, has a mounted 6K camera device, 51 minutes of flight time, a LiDAR sensor, and omnidirectional vision sensors.[54]

Drones are appealing to individuals and hobbyists interested not just in new technologies in their own right but also in the instant and intimate documentation of their experiences. As tech writer Chris Anderson suggests,

> If you're a windsurfer and want a great YouTube video of your exploits, you're not going to get that from the shore, and hiring a manned helicopter and camera crew to follow you offshore isn't cheap. But if you've got a "Followme" box on your belt, you can just press a button and a quadcopter drone with a camera can take off from the shore, position itself 30 feet up and 30 feet away from you and automatically follow you as you skim the waves, camera trained on you the whole way.[55]

That technology then becomes smaller and lighter and can be placed on a soccer ball to follow youth sport, or can bring new meaning to "helicopter parenting" by tracking a son or daughter on his or her way to a bus stop or school. Of course, the growing allure of drones to civilians has its downsides as well, with similar technologies being used to stalk or attack former partners or associates. In extreme cases, drones have even been "weaponized by abusive exes," with one man in Pennsylvania allegedly using a drone to air-lift explosives onto his ex-girlfriend's property.[56] Such issues once again raise important questions about privacy, but also about women's rights and the gendered impact of drones.

In another case of drone misuse, an off-duty employee of the intelligence community, in a state of drunkenness, took his friend's quadcopter and was flying it near the White House, when he appears to have lost control and allowed the drone to land on the White House lawn. The "pilot" then read about the incident in the news and cooperated with security officials.[57] The incident reflects the perils of benign, if inexperienced uses of drones, but also highlights the possibility that malicious actors could use these vulnerabilities to inflict harm on civilians or high-level officials.

In December 2018, London Gatwick airport experienced significant disruptions after a Gatwick security official allegedly spotted drones in the restricted airspace. With an abundance of caution, and a deep concern about what the drone would do if it collided with a commercial airplane, the airport shut down for several days interrupting over 100,000 people as they attempted to travel over the holiday period. Officials were never able to ascertain the identity of the drone operator or even if a drone was actually flown above the airport. Yet, as one aviation expert concluded, "[i]t showed the serious risk of drone intrusion, and how quickly that could bring an airport to its knees."[58]

In a somewhat similar case, six years later, drone sighting were once again causing disruption, this time in the United States. Just before the holidays in 2024, thousands of drone sightings were reported in the tri-state area (New York, New Jersey, and Connecticut) leading to public panic. While federal agencies attempted to calm a concerned population, local politicians and lawmakers, under significant pressure from their electorate, called for an FBI investigation and federal assistance. Statements by Congressman Jeff Van Drew (R-NJ) added to the alarm by claiming, "high sources" had told him that the suspected drones were tied to Iran, and potentially from an Iranian mothership "off the East Coast of the United States of America" and therefore needed to be shot down.[59] As a precaution, the FAA placed temporary drone flight restrictions on 31 towns in New Jersey[60]

The validity of many of the drone sightings has since been questioned. Pentagon officials, and experts like Dr. Jamey Jacob of Oklahoma State University's Oklahoma Aerospace Institute for Research and Education, believe that the uptick in sightings was caused by the misidentification of manned aircraft.[61] Of the over 5,000 reports received by the FBI, only 100 had enough evidence to warrant further investigation.[62]

What are the potential safety risks of nonmilitary drone use?

The potential safety risks of using drones in ways that are non-compliant with regulations are considerable. A number of dangerous incidents involving drones have been reported as individuals have increasingly invested in drones. This was especially concerning in the earlier days of drone use, with Commissioner Ray Kelly of the New York Police Department (NYPD) arguing that the NYPD was still coming to terms with how to think about the use of individual drones because the technology had led the policy.[63] Indeed, over the last decade, a number of incidents in major cities across the United States have highlighted the potential for concern when it comes to unfettered drone use in densely populated pedestrian areas and airspace. Hardly a month passes where there is not some new report about a commercial airline having to maneuver to avoid colliding with drones in metropolitan areas.

In 2017, the FAA reported the first confirmed inflight collision between a drone and a piloted aircraft in the United States. A UH-60M Black Hawk Helicopter providing security for a meeting of the UN General Assembly collided with a DJI Phantom 4 quadrotor, a common consumer drone. While nobody was hurt and the drone was destroyed, it was a significant wake-up call as a civilian helicopter would have probably fared much worse compared to an army Black Hawk.[64]

In 2021, the first conviction was handed out for unsafe operation of an unmanned aircraft after a drone collided with an LAPD helicopter, forcing an emergency landing.[65] Drones have also drawn criticism in the context of wildfires; however, not the officially sanctioned ones, but the hobbyist aircraft that have interfered with wildfire management and caused firefighters to ground the planes they were using to fight the fires.[66] In fact, with more than 100 of these cases documented, the FAA has officially cautioned citizens, stating "[y]our photos and video footage of the wildfires are not worth the lives and crucial operations they jeopardize."[67]

The concerns about the proliferation of civilian drones are not limited to the United States and nor to proximity to manned aircraft. Concerns have also been raised about drone flights in proximity to sensitive infrastructure.[68] During October and November 2014, there were a number of sightings of small drones flying over French nuclear reactors. It is still not clear why the drones were flying over the reactors, although one hypothesis is that they were an "organized provocation" from an antinuclear group. Because the drones are so small and seem to have little more than photo or video capabilities, many do not see them as an immediate threat to the reactors. French officials did, however, take the matter seriously. Michael Sordi, a lawmaker from Haut-Rhin, warns, "It may be time to start shooting them down, to move to another level of security and sanctions against this behavior."[69] French law forbids flying an aircraft below 3,280 feet and within 3.1 miles of a nuclear plant. This violation is punishable by one year in prison and a fine of 75,000 euros. In France there are roughly 900 commercial operators and an unknown number of private operators of drones.[70]

John Large, a British nuclear expert, assessed the vulnerability in saying that "the flexible access of maneuverability of the drones" is such that they can transgress barriers that ground vehicles or even manned aircraft might have a difficult time transgressing.[71] To be sure, small drones would have trouble penetrating cement walls, but one view is that the drones could be used in reconnaissance to identify structural weaknesses that are then used to inform aerial attacks that then produce meltdown with widespread effects.

That drones enable entry and present aerial security challenges related to access is also echoed in other contexts. For example, prior to the first assassination attempt of Donald Trump, the shooter flew a drone around to scope out the site before the rally.[72] This clearly exposed the possible security concerns associated with drones that can transcend traditional barriers intended for road or foot traffic.

What are the potential privacy risks associated with domestic drones?

Drones could make many tasks such as delivering packages, conducting law enforcement, and surveying property cheaper and easier, which is why they have become more commonplace. The increasing prevalence of drones has drawn ire from privacy advocates, however, who worry about the ways that drones seem to present new and pernicious infringements of individual space when compared to traditional surveillance camera. What makes surveillance technologies potentially different is that drones, especially miniaturized ones, can hide in plain sight. One website advertises the Dragonfly drone as "a palm-sized robot that flies like a bird and hovers like an insect."[73] Because of the size, which is small, and the appearance, which mimics a dragonfly, when it comes to insects and drones, its increasingly difficult to tell the difference[74] The ability to fly without being noticed means that these drones can be more intrusive than other surveillance technologies without fear of being spotted. Yet it is not just the small drones that pose a problem. Large drones can also be used for the invasion of privacy, especially when deploy for government ends. In terms of privacy issues related to the government use of drones, even with the current technology, drones could be barely discernible in the sky but still allow the government to collect video or images with impressive resolution. Senator Rand Paul raised the rhetorical question of whether "unwarranted and constant surveillance by an aerial eye of Big Government" was the answer to crime. Senator Paul went on to state that he did not want a government drone monitoring his barbecues or "a nanny state watching over my every move."[75] He then wrote a series of letters to Robert Mueller, who was then director of the FBI. The first requested more information about how long the FBI had been using drones while not publicly outlining protection of privacy, whether it had planned to develop such protections, and the measures it was taking to protect Fourth Amendment rights, along with a litany of other concerns related to the FBI's use of drones, including whether it planned to arm them.[76] Another followed up on the earlier email, reiterating the importance of transparency and requesting that the FBI offer prompt responses to the queries. He then sent an additional letter asking for clarification about the FBI's claim that there had not been a need to seek a warrant to use drones in the past, seeking to understand the FBI's understanding of when individuals do or do not have reasonable expectations of privacy, the matter on which the Fourth Amendment turns.

The American Civil Liberties Union reported approvingly on Senator Paul's "dogged" efforts to gain clarity on what it means to have a "reasonable expectation of privacy."[77] The FBI responded to these requests stating that its agents had used drones to conduct surveillance over the United States 10 times between 2006 and 2013, using the drones to support operations related to kidnappings, search and rescue missions, drug interdictions, and support missions. It noted that it had conducted surveillance using drones for eight criminal and two national security cases. The FBI elaborated that it does not use armed drones over US soil and that it would acquire a warrant to obtain information that goes beyond a reasonable expectation of privacy. Otherwise though, the FBI concluded that there were no Fourth Amendment concerns surrounding its use of drones.[78] In a follow-up letter to members of Congress, the legislative affairs officer for the FBI noted that it was unable to disclose many of the FBI-specific drone practices, which are classified as 'Law Enforcement Sensitive' because of the security considerations with which they deal.[79]

Since 2013, when these issues first came into the public eye, there has been limited progress in addressing them. Despite growing public awareness and concern, the legal and regulatory landscape has struggled to keep pace with the rapid advancements in drone technology, leading to ongoing discussions about privacy, civil liberties, and the appropriate use of drones in law enforcement.

Given the fraught nature of the discussion about privacy, including surrounding the term "reasonable," it is not surprising that the United States has had a number of Supreme Court cases interpreting the scope of what is reasonable or not. In three major Supreme Court cases in the 1980s, the justices sided with the government. These cases very much foreshadowed the present debate surrounding the use of drones by law enforcement agencies. The first case in 1986, *California v. Ciraolo*, dealt with whether the government could constitutionally identify marijuana plants in an individual's backyard from an airplane at 1,000 feet. The Court stated that the "Fourth Amendment simply does not require the police traveling in the public airways at this altitude to obtain a warrant in order to observe what is visible to the naked eye."[80] In another case, *Dow Chemical Co. v. United States*, the use of government cameras to take aerial pictures of a Dow chemical facility were seen as constitutional in part because "the photographs here are not so revealing of intimate details as to raise constitutional concerns,"[81] as the Court put it. In other words, these rulings suggested that the mere involvement of technology did not itself constitute a violation of privacy under the Constitution since these technologies were not being used in superhuman ways but rather completely consistent with the human eye to view events not of an intimate nature. Thus, in some respects one could indeed be wary of the proliferation of drones from a privacy perspective.

Despite these concerns, however, others suggest that the proliferation of drones presents few risks even when it comes to questions of privacy. One argument suggests that the privacy horse had left the barn long before drones came onto the scene. As the Congressional Research Service's report on privacy and drones puts it, "in determining society's privacy expectations, a reviewing court might also take into consideration the proliferation of aerial mapping such as Google Maps and Google Earth conducted by private actors."[82] For that matter, do the technologies depart considerably from a closed-circuit surveillance camera strapped onto a lamppost instead of a drone? Are individuals simply responding differently because of the novelty of the technology but not because of any qualitative difference between the privacy they have already relinquished and that which they would stand to relinquish with drones? Drones, according to this logic, are if anything a difference of degree, not a difference of kind.

A different defense of drones expresses full confidence in the Constitution's ability to protect individuals' privacy. Albeit speaking from the perspective of having a dog in the fight, American Unmanned Vehicle Systems International, the drone industry group, has expressed agreement with this position, suggesting that existing constitutional provisions protect privacy: "[o]ver the last 225 years, the court system has done a pretty good job of protecting our Fourth Amendment rights, and that is something we absolutely support."[83] Indeed, many types of drones would fall outside the "naked-eye" provision and be unconstitutional, and several cases point to important privacy protections under the Fourth Amendment. In one case, *Kyollo v. United States*, the Supreme Court decided the constitutionality of a government thermal imager to identify illegal marijuana growing and raised concerns about whether permitting the government to collect information through "advancing technology" was reasonable. The technology went beyond the "human eye" in using an imaging system that was found, in turn, to reach beyond the limits of constitutionality. As John Villasenor from UCLA Law School concludes, "under a balanced reading of *Kyollo*, the government use of a UAV to reveal 'details of the home that would previously have been unknowable without physical intrusion' would be unconstitutional today."[84]

More contemporary cases involve the legality of GPS tracking devices that the government affixed to a vehicle without obtaining warrants. These cases were both considered of questionable constitutionality, with Supreme Court justices across the ideological spectrum expressing the view that new technologies such as GPS monitoring went beyond “reasonable societal expectation of privacy,” as Justice Sotomayor put it, a view shared by Justices Scalia and Alito. These cases point to the prospect not of drones running rampant in the infringement of privacy but of reaching some constitutional bounds in the form of the Fourth Amendment.[85]

The rapidly changing technology, the increasing use of drones by law enforcement and private citizens, the ambiguity surrounding the parameters of an individual’s right against “unreasonable searches and seizures,” and the definition of what constitutes a “search” all point toward the likelihood that drone-specific legal cases will continue fill courts around the country. Andrew Couts observes that these questions are “slippery” under the best circumstances: “throw drones in the mix and … the fine line across which surveillance by the state becomes ‘search’ gets downright knotty.”[86]

The privacy issues surrounding everyday consumer drones, however, raise a somewhat different set of considerations to these government issues. Those involving the United States government use of drones more directly hinge on questions of constitutionality, primarily through the Fourth Amendment protections, and generally raise more serious opposition, in part because government drones are generally larger and hi-tech, and individuals may fear some inappropriate government use of the information obtained through a drone. For privately owned consumer drones, the concern is more simply about preserving privacy. Individuals worry, for example, about whether previously intimate activities such as sunbathing at a nude beach would become matters of public consumption. As a Brookings Institution report on privacy concludes, “there is no firm consensus about how best to safeguard privacy rights from nongovernmental drone surveillance.”[87] These privacy matters reside at the state level, which has given rise to considerable interstate variation depending on philosophies about the balance between the individual’s right to engage in drone hobbyist activity and an individual’s right to privacy. Whereas some states have passed “peeping Tom” laws in the context of drones, others are yet to address such concerns.

But what about safeguarding privacy from foreign governments? In the United States, drones manufactured by Chinese companies, such as DJI, raise concerns about state espionage. These companies are believed to have ties with the Chinese government, highlighting the potential for these drones to collect sensitive information and pose national security risks. In response to these concerns, the Countering CCP Drones Act aims to limit the use of Chinese-manufactured drones within the federal government, specifically targeting drones purchased using Federal Communications Commission funding. If enacted, US government agencies, including law enforcement and other federal departments, would be prohibited from using drones from these manufacturers for official purposes, protecting critical infrastructure and sensitive information from potential foreign surveillance.[88] The FBI also released a Cybersecurity Guidance report with recommendations for Unmanned Aircraft Systems (UAS) to mitigate cybersecurity risks. The guidance included encryption, software updates, risk assessments, regular cybersecurity risk assessments, supply chain verifications, regulatory frameworks, and training.[89] For private citizens, the FBI urged vigilance and caution with drone technology emphasizing awareness of the potential cybersecurity risks and the need to take measures to protect their data and privacy. In a more positive light for US industry, the act and FBI recommendations encourage the use and development of drones from domestic manufacturers, such as Skydio, whose designs align with the FBI and CISA (Cybersecurity and Infrastructure Security Agency) drone cybersecurity recommendations.[90]

Does the public support the use of domestic drones?

In terms of the American public, which has generated the most extensive opinion data, Americans are generally supportive of using armed drones for counterterrorism abroad, but are more ambivalent when it comes to the use of drones for law enforcement and domestic surveillance. Take Chula Vista, for instance. A manager at a high-end golf course in the suburban part of town might be way more open to drone surveillance than the residents of the densely populated, lower-income areas of the west side who are kept up at night due to the sound of the rotors.[91] The CEO of the National Constitution Center, David Eisner, indicated that he “had assumed that the idea that American police would be using the same technology that our military is using in Afghanistan would garner an almost hysterical response.” He attributed this attitude to the populace’s sense of insecurity and willingness to trade off civil liberties in exchange for more security.[92]

A more detailed set of polls helped unpack the aspects of drones by law enforcement that individuals find objectionable. Table 6.1 summarizes poll responses for a range of activities involving the use of drones. As the table suggests, Americans have tended to support drones for security and humanitarian purposes but not for police activities that might have adverse impacts on them, such as issuing speeding tickets. They are also more leery of armed drones than the unarmed drones. For instance, support for armed drones in the service of border control generated far less support than when the drones in question were not specified as armed or unarmed—implying that they were unarmed.

Table 6.1 Public Support for Drones for the Purposes of Law Enforcement, by Activity

Question: “Use of Drones to …”	Support	Oppose	Don’t Know
Issue speeding tickets	21%	72%	6%
Control illegal immigration	62%	30%	8%
Help with search and rescue missions	83%	11%	6%
Armed drones to help hostage situations	52%	38%	9%
Armed drones to patrol border	44%	49%	8%

Source: Monmouth University Polling Institute; field dates: July 25–30, 2013.

These polls lend some credence to the public’s view that domestic drones should be used to bolster security at home while remaining non-intrusive on a day-to-day basis. A separate poll by Duke University and the Institute for Homeland Security Solutions corroborated this intuition. In their poll, 67 percent of the public supported drones for homeland security, 63 percent for fighting crime, and as high as 88 percent for search and rescue. Sixty-seven percent of individuals, however, expressed considerable concern about monitoring in public spaces, and 65 percent were concerned with the potential safety issues of frequent domestic drone use by law enforcement. Support was considerably lower at 26 percent for the use in traffic violations.[93] The concerns intimated in these studies track fairly closely with the concerns raised by civil liberties groups. Many think that drones raise potential privacy issues. This constituency points to the Fourth Amendment tenet that people have the right "to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures." Indeed, with this in mind and given the wider context of concerns about race and policing, some have expressed concerns about drones being disproportionately deployed in particular geographical areas, or to target particular communities. This is especially pertinent in light of police drones tracking Black Lives Matter (BLM) protests in 2020. According to *The New York Times*, the Air National Guard and Department of Homeland Security utilized government aircraft, including Predator drones, to monitor 15 cities during the protests filming demonstrators in New York, Philadelphia, and Dayton, Ohio [and] Minneapolis.[94] In addition, according to documents obtained by *The Intercept* via the Freedom of Information Act, the US Marshals Service flew unmanned drones over Washington, DC, in response the BLM protests.[95]

Overall, therefore, it is important to keep in mind what the Congressional Research Service has cautioned as "far-reaching issues concerning the extent of government surveillance authority, the value of privacy in the digital age, and the role of Congress in reconciling these issues".[96]

How are federal agencies regulating nonmilitary drones?

Before 2015, recreational and commercial drones were largely unregulated and unrestricted in the United States. Since then, the FAA has aimed to balance what seems like the inexorable push of drone technology, which favors more rapid integration, with the competing pressures of safety, which could push in a more restrictive direction.

The primary concern of regulations is the avoidance of midair collisions. As of 2024, the FAA received over 100 incident reports per month in which drones have flown too close to manned aircraft or airports.[97] There have been a number of well-publicized incidents involving hobbyist drones meddling with wildfire prevention efforts, flying around major sporting events, bringing airports to a standstill, or acting complicit in the attempted assassination of heads of state. Federal regulations already seek to limit such activities in part by requiring that individuals register their drones (and themselves) through drones pilot licenses. Manufacturers themselves also try to limit where individuals can fly drones through "geofencing" software and "no-go zones," but enforcement continues to be a challenge. This is especially true with users who get creative by circumventing these kinds of techniques/approaches, such as through the refusal of updates.

But the FAA has had an important role to play in managing air traffic that increasingly includes drones. As former-FAA Director Huerta put it, the "see-and-avoid" principle is a "bedrock principle of aviation … the pilots take action to avoid one another."[98] With over 70,000 flights per day in the United States and commercial and recreational flights operating at various altitudes, "the risk of collision between these users and unmanned aircraft must be adequately mitigated before unmanned aircraft can routinely utilize the national airspace system."[99] A government report at that time concluded that unmanned aircraft did not have those capabilities. For that reason, strict limits on where drones fly had been imposed, in particular the line-of-sight provision, which helped the drone operator avoid air traffic.[100] Today's

FAA regulations allow drones to be flown in the National Airspace System (NAS).

To fly legally in the NAS under FAA regulations, an individual must be registered as either a Recreational Flyer or a Certified Remote Pilot for commercial, government, or other non-recreational purposes. Recreational Flyers must adhere to specific rules, including flying only for personal enjoyment, following the safety guidelines of an FAA-recognized Community-Based Organization (CBO), and maintaining a visual line of sight with the drone. If a co-observer is assisting, they must stand next to you and be in direct communication with you. Additionally, Recreational Flyers must give way to and avoid interfering with manned aircraft, fly at or below authorized altitudes in controlled airspace using air traffic management systems, complete The Recreational UAS Safety Test (TRUST) and carry proof of completion, have a current FAA registration, and ensure their drone is equipped with a Remote ID.

Certified Remote Pilots, who operate drones for commercial, government, or other non-recreational purposes, must adhere to specific FAA regulations to fly legally in the NAS. To become certified, these pilots must obtain a Remote Pilot Certificate by passing the FAA Part 107 Aeronautical Knowledge Test. They are responsible for conducting pre-flight inspections to ensure the drone is in safe operating condition, maintaining the drone within visual line of sight (VLOS), or using a visual observer. However, they can apply for waivers to conduct BVLOS operations when necessary, which “allow drone pilots to deviate from certain rules under part 107 by demonstrating they can still fly safely using alternative methods.”[101] This includes, but is not limited to, approval for flying drones “from a moving aircraft or a vehicle in populated areas,” to fly “beyond your ability to clearly determine the position, altitude, and movement” and to fly “[o]ver 100 miles per hour groundspeed.”[102]

Certified Remote Pilots must comply with all airspace restrictions, yield the right-of-way to all manned aircraft, and avoid flying directly over people or moving vehicles without a waiver. Certified Remote Pilots are responsible for staying informed about any Temporary Flight Restrictions

(TFRs) and maintaining their FAA registration, which includes displaying a Remote ID on their drone. With frequent updates to FAA regulations, Certified Remote Pilots must stay current with any changes in rules and operational requirements to ensure safe and compliant drone operations.[103] With companies increasingly using drones for delivery programs and other tasks, the demand for trained drone pilots is on the rise. Updating drone laws and enhancing pilot training and certification processes will be essential to ensure safe and efficient operations. These updates will be crucial in supporting innovation and integrating drones into everyday business operations.

As drones became more prevalent in a domestic setting, the FAA originally set up six (later boosted to seven) test locations across the United States—in Virginia, North Dakota, Alaska, Nevada, Texas, New York, and New Mexico[104]—that can help test the interaction between drones and manned aircraft. As Michael Huerta (who was then FAA administrator) asserted, "Having all six national test sites up and running will give us more and better data to help expand the safe use of unmanned aircraft into our airspace."[105] In other words, these test sites provided controlled spaces for understanding the implementation of wild fire spotting or disaster relief, for example, and better integrating drones into federal and local policies.

How are subnational entities regulating the use of drones?

Back in 2013, the American Civil Liberties Union concluded in its analysis of state-level regulations on drones that "the legislative and public debate over drones is just getting started."[106] In this they were correct. Since 2013, at least 44 states have drafted legislation against drones.[107] As one state senator in Virginia argued, "I think it's important to get ahead on issues like these before they get out of control … we can imagine the problems that drones will bring in the future."[108] He proposed a bill that would put a moratorium on drones because of potential violations of the Fourth

Amendment of the Constitution, the right against “unlawful search and seizure.” It was the first anti-drone legislation passed in the country.[109]

Since this time, what has emerged is a tapestry of heterogeneous policies that reflect state-level views about the appropriate use of drones. Although the FAA regulates what is referred to as the NAS, a number of states stepped up to address what they see as lacunae in the federal regulations. Much as the federal regulations on drones continue to evolve in response to the emerging technology, so too are states trying to adapt to that changing technological landscape. In particular, the use of drones for law enforcement is a matter left up to the states, and some states are deciding that the federal laws on safety and privacy do not go far enough and that they want to augment the national-level regulations.

By 2024, all states, excluding Alabama, had passed legislation regarding the use of drones.[110] Much like cell-phone-while-driving rules, many drone rules are state-specific, some are more restrictive than the federal regulations, and almost all likely to change over time. Generally, the categories of state regulations for the use of drones are as follows: (1) no additional prohibitions beyond the federal (FAA) prohibitions; (2) state laws that ban drones by private citizens; (3) state laws that ban the use of drones by law enforcement; (4) state laws that ban the use of drones by both private citizens and law enforcement.

In brief, California passed laws prohibiting the use of drones for capturing video or sound recordings without consent, classifying it as an invasion of privacy. Tennessee prohibited capturing images at events with more than 100 people and restricted flights over prison grounds. Mississippi prohibited the use of drones to spy on others for lewd purposes. Nevada defined drones as “aircraft” and regulated their operators. This state also prohibited weapon use on drones and restricted drone operations near airports and critical facilities. North Carolina meanwhile granted the Chief Information Officer the authority to approve drone operations by state agencies and required testing for commercial drone operations, aligning with federal guidelines. Oregon prohibited the use of drones for hunting, fishing, or trapping, including locating game or interfering with lawful hunting activities. These state-by-state restrictions suggest that the federal guidelines were overly (or perhaps helpfully) broad and that different locales viewed the specific challenges as warranting a more tailored approach to regulation.[111]

Many of the states' regulations reflect cultural and political peculiarities. For example, Texas' law "is designed to protect oil pipelines from being photographed by environmentalists while allowing law enforcement agencies to do surveillance of citizens based on a legal standard that's only one step from a hunch."[112] It also allows real estate brokers to use drones for marketing, specifically authorizes the collection of images for scholarly research, and allows surveillance on property within 25 miles of the United States border "with the consent of the individual who owns or lawfully occupies the real property captured."[113] Arkansas prohibits the use of drones for voyeurism, and Mississippi designates the use of drones for "peeping Tom" activities as a felony. Arizona's legislation offers protection just for US citizens (as opposed to immigrants) against surveillance. Georgia, which has promoted the aerospace and in particular the drone industry in its state, and hosted the International Conference on Unmanned Aircraft Systems in 2013, has sought to make the state drone-friendly. As a top-five aerospace employer in 2012 eyeing the potential $10 billion drone industry with the burgeoning commercial sector, Georgia has worked to sidestep regulations that might be seen as anything but friendly to drones.[114] It passed a resolution in 2015 that established a House committee study on the safe use of drones.

A number of states also prohibit drones by law enforcement agencies. Virginia was the first state to pass a moratorium on law enforcement drones in 2013, although by 2015 the two-year moratorium had expired and a law replaced the moratorium, allowing drones for law enforcement but only after police have acquired a warrant. Lawmakers in Idaho, Florida, Illinois, Montana, Oregon, and Tennessee had followed Virginia's initial anti-law enforcement drone move, with Florida passing a "Freedom from Unwarranted Surveillance Act" to directly signal their opposition to the use of drones for surveillance.[115] The legislation mirrors the United States

House of Representatives bill titled *Preserving Freedom from Unwarranted Surveillance Act of 2013*, which would protect individuals against "unwarranted governmental intrusion through the use of unmanned aerial vehicles commonly called drones."[116] The only exceptions are for those with permits, although exceptions can also occur if the Department of Homeland Security claims the presence of a terrorist threat or if there are circumstances in which "swift action" must be taken to save a life.

7
THE FUTURE OF DRONES

Is life imitating art or art imitating life when it comes to drones?

Science fiction has long been a creative playground providing inspiration for technical innovation. Not only this, but the genre has helped us glimpse into the future, offering predictions (and warnings) about how advanced technologies will shape our world. *The Terminator* (1984) is one of the most well-known movie depictions of "killer robots" and the dark side of super Artificial Intelligence (AI). The plot is that at some point prior to 2029 the US government integrated its defense capabilities with Skynet, "an AI system created for the U.S. military designed to control the nation's nuclear arsenal and defense network."[1] Despite hopes of more effective and faster responses to eliminate threats, the system becomes self-aware and, when humans try to deactivate it, launches "Judgment Day"—a nuclear salvo to eliminate the threat of humans. Enter Arnold Schwarzenegger as the humanoid T800 "hunter-killer" robot. Sent back in time to 1984, his task is to find and kill John Conner, a young boy who will grow up to disable Skynet.

To some people, *The Terminator* is a glimpse into our coming dystopia. For others, the movie indulges in hyperbole and distorts the realities of AI and robotics. There can be little doubt that countries are competing for AI advantage, with China looking to be a global leader by 2030 and Russia's President Putin announcing that "[w]hoever becomes the leader in this sphere will become ruler of the world."[2] The United States, not one to shy away from competition, has also committed to $500 million in private and government spending to build "the physical and virtual infrastructure to power the next generation of AI."[3] In addition, the United States is investing billions more in its Semiconductors (the building blocks of AI) and the creation of thousands of autonomous drones (through the Replicator initiative explored later in *What are the trends in autonomous drones?*). However, in order for us to accurately explore just how realistic *The Terminator* and other artistic interpretations are, and what future all of this investment is building, we first need to outline some useful definitions, starting with AI.

What is AI? As AI expert Toby Walsh argues, "there are many differing definitions of AI [but] [b]roadly speaking, AI researchers are attempting to develop software to perform tasks that humans require intelligence to complete."[4] With this in mind, AI can be broadly defined as the ability of machines to perform tasks that usually require human intelligence—things like recognizing faces, making decisions, solving problems, and even learning from experience. Unlike traditional computer programs that follow strict, pre-set rules, AI systems can improve over time using techniques like machine learning and neural networks. Yet there is not one type of AI in development; it exists (or is theorized) at different levels:

- Narrow AI is the type of AI we use today—designed for specific tasks like recognizing faces, recommending movies, or assisting with voice commands (think Siri and Alexa).[5] It is powerful but limited to what it was programmed to do and cannot think beyond its assigned function. It is this Narrow AI that helps doctors detect diseases by analyzing medical scans, powers self-driving car systems, and personalizes online shopping and entertainment recommendations. Outside civilian life, this level of AI powers a drones' ability to scan enemy positions, identify targets, and provide intelligence to commanders. As we will see, since at least 2017 AI has been used to analyze the drone's footage or broader data sets to identify potential threats, reducing the workload on human analysts, and hastening the process (see Project Maven).[6]

- Artificial General Intelligence (AGI) is the next step—an AI that could think, reason, and solve problems across different areas, much like a human.[7] While AGI remains theoretical, experts debate whether it could be developed in the coming decades. If achieved, AGI would have the ability to understand and learn any intellectual task a human can, making it vastly more capable than today's AI. In everyday life, AGI could revolutionize the workforce by automating complex jobs that currently require human intelligence.[8] It could serve as a personal tutor for students, diagnose and treat medical conditions with expert-level precision, and even handle advanced scientific research, potentially leading to breakthroughs in fields like climate change or space exploration. On the more warlike side, AGI could make battlefield decisions in real time, coordinating troops, predicting enemy movements, and even strategizing without human intervention (although due to the friction and complexity of war this is up for debate).[9] More pragmatically, however, military planners might use AGI to run realistic war simulations with millions of data points, optimize logistics, and develop new defense technologies.
- Super AI (or artificial super intelligence, ASI) is the most powerful of the three; it is a theoretical concept in which AI surpasses human intelligence entirely.[10] It would be capable of reasoning, innovating, and making decisions at a level beyond our comprehension. If developed, Super AI could either be humanity's greatest invention—or its greatest threat (like the fictional Skynet). In civilian life, a true Super AI could solve problems that have eluded human minds for centuries, such as ending poverty, generating endless clean energy, or perfecting political institutions. It could govern cities with unhuman efficiency, ensuring optimal resource allocation, eliminating waste, and preventing crime before it happens. However, such power also raises questions—would humans remain in control, or would Super AI decide it knows what's best for us?[11] In war, if Super AI had not

> already solved war (or ended humanity to stop war), it may lead a military armed with unstoppable autonomous drones across air, land, and sea, optimizing warfare beyond human capabilities, and executing strategies with ruthless efficiency. But, of course, it also may not. Due it being a theoretical concept, if it is achieved, we still have many years to define its role in the world.

As such, while Narrow AI is already shaping our world, AGI and Super AI remain theoretical—but possibly not forever. What unites all three, however, is how each level of AI is impacting the development of drones. With this additional definitional context in mind, we can now explore the question whether life is imitating art or art is imitating life when it comes to science fiction and broader cultural representations of future drones.

According to The Movie Database (TMDB), as of 2025, there have been at least 83 movies that have featured drones in a prominent way.[12] These range from *Angel Has Fallen* (2019), which depicts an attack by lethal autonomous swarming drones on the president of the United States (Morgan Freeman), through to *Outside the Wire* (2020) where a drone pilot (Damson Idris) finds himself paired with a top-secret android officer on a mission to stop a nuclear attack. Out of all 83 of these films, few are truly science fiction, choosing instead to examine contemporary trends in the contemporary context or near future. One exception is *Skyline* (2010), which portrays aliens invading Earth, the US Air Force using drones to attack a spaceship hovering over Los Angeles, and one of the drones firing a nuclear weapon at the ship. Most of the films, however, have historically imitated some aspect of the American use of drones in the years after 9/11. These 'counter terror drone movies' arose quickly during this period. Keeping in mind that the United States was quietly using drones in Afghanistan beginning in October 2001, and that its first strike outside a "hot" battlefield was in 2002, with no additional strikes until Pakistan in 2004, the introduction of drones into film in 2005 reflects Hollywood's attentiveness to what were then subtle changes on the battlefield.

The first film to portray drones did so with a multirole carrier-based Navy drone. The movie was *Stealth* (2005), in which the Navy creates a combat drone controlled by AI. The project goes awry when lightning strikes the drone, which causes it to go rogue. In the end, human pilots on the aircraft carrier must destroy the drone before it engages in more rogue attacks that would incite a world war. Film critic Roger Ebert declared that the plot defied logic, only in part because the drone-related aspects of the film were outlandish, but mostly because of other implausible aspects of the film, such as that one of Navy officers crosses the Korean Demilitarized Zone and that the "North Koreans have neglected to plant land mines in the part of the DMZ that Wade must cross."[13]

More plausible and indeed successful was *Mission Impossible 3* (2006, in which drones play a somewhat minor role when foreign mercenaries use a drone to attack Ethan Hunt (Tom Cruise) and his team, allowing the mercenaries to extract Davian (Philip Seymour Hoffman), who had captured Ethan. Drones were also portrayed in combat missions in several other movies, including most prominently in *Syriana* (2005), where the CIA used a Predator to assassinate the foreign minister of a recalcitrant emirate; the *Bourne Legacy* (2012), in which a CIA drone attacks the protagonist; *Eagle Eye* (2008), in which a Reaper is hijacked by a supercomputer attempting to eliminate the executive branch and the drone fires multiple missiles at the protagonist during a chase in downtown Washington before its subsequent destruction; *Hummingbird* (2013), in which the protagonist, an antihero and former soldier, is spotted and possibly killed by a British drone; *Furious 7* (2015), in which a drone is deployed over Los Angeles by the movie's antagonist to pursue and destroy the protagonists' vehicles; *Spider Man: Far from Home* (2019), where Spider Man (Tom Holland) must first confront and overcome a swarm of autonomous drones before he can tackle Mysterio (Jake Gyllenhaal); and *Land of Bad* (2024), starring Russell Crowe as an Air Force drone operator nicknamed "Reaper" who is charged with the protection and rescue of an Air Force Sergeant "Kinney." Reflecting apprehension toward drones, Kinney is initially doubtful of the ability of drones to save soldiers but by the end is saved through Reaper's drone operation. What is interesting is that all of these films involve a similar conventional plotline, in which drones are commanded or commandeered to strike targets either to assassinate key people or to save the day. However, other movies do explore more complex themes.

The *Top Gun* (1986) sequel, *Maverick* (2022), originally involved Tom Cruise (as Maverick) working with drone operators that had replaced Navy pilots and adjusting to the new cultural reality of "real-life Navy test pilots thanks to advances in drone warfare" [14]. Although the version that made it onto the screen dropped the drone theme, it did so at the expense of reality according to critics, who considered the all-manned aircraft plot "technically outdated" because the "mission could have arguably been better executed by today's drones, without risk of human life."[15] Yet, although the technology may be here, perhaps the producers questioned whether non-specialist viewer audiences were not ready for this new technological era of robot warfare, perhaps preferring traditional dogfights (a topic to which we will return in *What is the future of drone technology?*).

A handful of films have also involved the ethical and psychological aspects of drones. *From the Sky* (2014) is a short film about an Arab father and son who travel through an area frequently targeted by US drones. The father suffers from post-traumatic stress disorder (PTSD) due to the drone strikes. In *The Other Side* (2014), a Pakistani boy observes American drone strikes in his neighborhood and subsequently joins a terrorist group. Picking up this theme of how strikes in places such as Pakistan have had ripple effects, *Four Lions* (2010) portrays four incompetent British jihadists traveling to a training camp in Pakistan, where they unsuccessfully attempt to shoot down an American drone. *Good Kill* (2014) takes the perspective of drone operators themselves, as it focuses on a US Air Force pilot who questions the morality of his job in the face of the vast degree of collateral damage caused by his missions. *Eye in the Sky* (2015) is perhaps one of the better representations of such drone issues and did an impeccable job of highlighting the challenging ethical questions around drone strikes. The movie initially shows an individual strapping on a suicide vest inside a compound showing the certainty of his weapon and intention. It then tracks the surveillance imagery of the individual, watching and waiting for him to make his move. But at the last minute, a young girl selling bread enters the scene and the team of British and American analysts must decide whether to proceed with the strike, knowing that this young girl will also be killed. These ethical questions are subjective and difficult. International law is not determinate on the question whether collateral damage would be permissible, since the strike could be considered legal if it meant saving dozens of people who might perish in a suicide bomb detonating in a crowded market. As such, the movie examines the difficulty of these questions through the internal disagreement within the team about whether to proceed with the strike. One interesting futuristic aspect to the moviewas the use of a micro- or nanodrone in the shape of a beetle to fly inside the compound to obtain the high-definition visual confirmation of the target and the target's intent. As this chapter will show, while this technology may not have existed in a deployable form in 2015, *Eye in the Sky* may have predicted an important trend for the future.

Drone (2017) also dealt with the ethics of drone strikes, with a CIA drone operator dealing with the burden of keeping his work a secret. Notably, the film was accused of being exploitative and xenophobic due to its portrayal of a vengeful Pakistani man seeking retribution against the protagonist for killing his family, raising questions about public opinion and US drones strikes.[16] In addition, two films address the domestic legality of drone policy. While *The Giver* (2014) shows how drones are used by the government to monitor citizens and report acts of wrongdoing, *Robocop* (2014; it was a remake of the original 1987 film, which raises questions about robotics, autonomy, and ethics) acknowledges the legality of combat drones abroad but cites the fictional Dreyfus Act, which prevents domestic use of combat drones.

Overall, therefore, while film has been the most prolific media to involve drones, its portrayals have either focused on military strikes, the ethics and broader impact of the US drone program, or, on occasion, the more futuristic depictions of nanodrones or drone swarms against high-value targets. To be fair, this is not an unrealistic representation of how drones have been used, and will likely continue to be used in the near future. We need only think of concerns about drone proliferation, assassinations, and saturation strikes raised in Chapter 3. In addition, true autonomous drone swarms, as we will see later in the chapter (see *What are the trends in autonomous drones?*), do appear to be on the metaphorical horizon, as do nanodrones. Nevertheless, there is certainly more to the future of drones, aspects which are picked up in other forms of media.

Let us look at television and video games as key examples. The 2014 season of the hit show *24: Live Another Day* centered on American drones, including one hijacked by a terrorist and used to attack London. In addition, popular suspense-filled thriller *Homeland* focused on an accidental CIA drone strike on a wedding party in Pakistan, quite closely mirroring an actual strike that occurred in Yemen. *Black Mirror*, a TV series that explores "techno-paranoia," aired an episode (2017) in which autonomous "dog" drones are depicted as lethal machines hunting humans in a post-apocalyptic world, presenting frightening examples of AI gone rogue. Between 2011 and 2016, the TV show *Person of Interest* used drones as part of a broader exploration of surveillance, AI, and security. The series revolves around an AI called "The Machine," which analyzes vast amounts of data from various sources, including surveillance cameras, phones, and online activity, to predict threats to national security (such as terrorist attacks). While the show does not focus solely on drones, they appear in various episodes as tools for gathering intelligence, tracking individuals, and executing tactical operations.

As for video games, most of the *Call of Duty* franchise involves some aspect of drones. *Call of Duty: Black Ops 2* (2012) includes American drones hijacked by a terrorist organization and used to attack China, a plot that bears resemblance to the TV show *24*. *Call of Duty: Modern Warfare* (2019) and *Warzone* (2020) use drones for reconnaissance, with the "Recon Drone" kill streak allowing players to mark enemies. In *Call of Duty: Modern Warfare 3* (2023), however, lethal drones are offered as a reward for kill streaks. The "Breacher Drone," is a lethal One Way Attack drone that explodes on impact and can be used against other players or equipment.

VALORANT, a tactical shooter game created by Riot Games in 2020, prominently features a Russian character, "Sova," (owl in Russian) who uses a handheld reconnaissance drone to mark enemy positions. In the game, the drone is strategically important as it allows Sova to confirm that contested areas are safe without risking his own life. In Tom Clancy's *Ghost Recon Breakpoint* (2019), swarming drones are featured as a significant enemy threat. The game introduces advanced autonomous drones that serve as aggressive enemy units. Such games are not just played for fun, however; the Ukrainian *Death From Above* (2024) and *Drone Flight Simulator* (2025) are both set during the Russian invasion, with the latter billed as an "ultra-realistic combat simulator for future military personnel and FPV enthusiasts."[17] In fact, it is safe to say the list is seemingly endless, or at least well beyond the remit of this volume. From *Watch Dogs* and *Hellgate London*, to *Mass Effect* and *Drone Swarm*, drones have become a core part of the mechanics of combat video games. Alongside those used in TV, they reflect current trends in real-life drone deployments, with some insightful near-future predictions around autonomy and swarms. Yet this is not unique to video games.

Books, poetry, and visual art have also increasingly drawn on drone imagery, a reflection of their place and impact on contemporary culture. Of course, there have been many academic nonfiction books written on the topic, but when it comes to popular fiction, we get more freedom to explore possible and impossible future worlds. For example, in Tom Clancy's *Threat Vector* (2012), China hacks into American military networks and disables the country's drone arsenal, raising issues about drones and cyberattacks. In *Ghost Fleet* (2015), Peter W. Singer and August Cole bring together military scenarios in the form of drones, AI-driven warships, and robotic soldiers, but also fiction in the form of space pirates (a group of American privateers who operate in space to disrupt enemy satellite networks). Former counterterrorism czar Richard Clarke also infused his foreign policy expertise in a book called *Sting of the Drone* (2014). The plot is built around a Pakistan-based terrorist group who hacks into Predator drones at Creech Air Force Base in Nevada, US, and uses them against the

US government. In terms of poetry, there have been numerous collections written on the topic of drones, mainly in reference to the Global War on Terror. These range from Landay poems by members of the Pashtun population in Afghanistan that detail the local impact of targeted killings and signature strikes, through to the collection "DRONE" by Kim Garcia, which won the 2015 Blackwaters Prize for its portrayal of "the divisive effects drone warfare has on humanity."[18] Similar themes have been picked up in popular music and the visual arts.

The album *Drones* by the rock band Muse (2015) offers a commentary on the Obama drone program, while the off-Broadway play *Grounded* (a one-person drama) gets into the minds of a conflicted drone operator. It is situated during a 12-hour shift in an Air Force trailer, where the pilot wrestles with the intimacy of seeing targets nearly side-by-side with her own family, capturing many of the 2010s debates about the stress and emotional pressures placed on drone pilots and sensor operators. This successful play was set to be adapted to the silver screen with Anne Hathaway reprising her off-Broadway role as the US Air Force pilot; however, the project has since stalled.[19] An opera adaptation of *Grounded* debuted at the Kennedy Center in 2023, but drew criticism because it was sponsored by defense contractor, General Dynamics, and rewrote sections of the original play to exclude references to the "horror of war," despite director Timothy O'Leary's insistence that General Dynamics had no input on the show.[20]

Overall, from this sample of cultural output, it appears that most artistic representations of drones are imitations of life, reflecting the moral, ethical, or legal dilemmas of the day and the current technologies in use. Here they largely neglect how drones are used in other domains (such and land and sea) and how technology much evolve in unforeseen ways. Yet, in some cases—usually in science fiction, fantasy, and future-focused storylines—we see a probing of terrorist attacks with drones, the use of nanodrones, autonomous drones, uncontrollable swarms, and out-of-control AI. With this in mind, let us looks at the plausible future.

What is the future of drone technology?

As this book has documented, militaries are increasingly relying on drones, as are state governments, nonstate actors, hobbyists, relief organizations, and industry. Strong and apparently enduring interest in drones is likely to push big technological advancements. But in which direction? Certainly, there are the more incremental innovations such as selfie-taking drones or drones that can fly further and faster; but when it comes to the military, the more significant moves are heading in two directions. On the one hand, you have smaller, lighter, and more autonomous drones that can be deployed individually or en masse. On the other, you have larger military drones that are either stealthy and equipped with larger payloads or longer-range drones that act as "wingmen" alongside manned aircraft and/or as autonomous OWA loitering munitions.

With this in mind, let's start by looking at the smaller drone systems, with one important innovation being toward miniaturization. This has been enabled by advancements in smaller and more powerful computation and sensor technologies, alongside lighter and stronger composite materials, which have developed since the turn of the century. When these elements are combined into smaller drone technologies, they allow the deployment of tactical mass on the battlefield or more effective surveillance and reconnaissance without detection. As *Vice* put it over a decade ago, "in keeping with its vision for a 'smaller and leaner' military that's agile, flexible, fast, and cutting-edge, the DoD [US Department of Defense] will work on 'miniaturizing' drones and drone weapons to make them smaller, lighter and less energy-consuming." That comment draws on the DoD's 25-year Unmanned Roadmap from 2013, which observed that by going in the direction of miniaturization, the DoD would also make the systems more affordable.[21] Such investment is now paying dividends, buoyed by commercial innovation, with more advancements to come in the future.

In fact, over the last 10 years, smaller drones have had a considerable, growing, and important battlefield utility. This is either for soldiers who seek to identify threats over a hill or in a compound without themselves being in the line of fire (usually in a context where the other side does not have drones) or for lethal deployment at a tactical level to strike personnel, vehicles, air defense systems, or other drones and drone pilots. The size advantage also makes smaller drones difficult to regulate or defend against, as the technology is difficult to pick up on traditional air defense systems and constantly innovating due to said military and commercial innovation.

As addressed early in the book (Chapter 2), most of the smaller drones deployed today fit broadly under the broad headings of Class 1 small and mini drones. These are characterized by the Pentagon as under 20 pounds, although many are much lighter than that. One of the earlier and enduring variants of these smaller systems was the Raven, a small hand-launched fixed-wing drone made by AeroVironment. Compared to today's drone tech, it is neither particularly small nor light, with a 4.6-foot wingspan and a 4.2-pound weight. Nevertheless, the Raven was able to relaypictures from 15,000 feet, which led to their popularity and a production run of about 19,000.[22] Today, this category of systems is better reflected through the quadcopter drones deployed by Islamic State and the First-Person View (FPV) drones used by both sides in Ukraine, (which are discussed in depth early in the book, see Chapter 2).

At the lowest end of this scale, however, sit nanodrones, much smaller than a quadcopter and designed for fundamentally different tasks. While they no longer capture the popular imagination as in the 2010s (see *Eye in the Sky*, which we mentioned in the section "Is life imitating art or art imitating life when it comes to drones?"), these much smaller drones mimic birds, flies, and insects, and will likely come back into vogue as the technology matures.[23] As the Air Force Research Lab (AFRL) suggested, the objective is to mimic nature in order to hide in plain sight[24] The implication here is that these nanodrones might look like insects, but would actually be conducting surveillance, collecting images, or potentially conducting lethal strikes. These aircraft tend to have a shorter battery life and range, but have the advantage of entering locations that would be inaccessible to other forms of aerial surveillance.

A key example is AeroVironment's Hummingbird drone. Funded by the Defense Advanced Research Projects Agency (DARPA), the drone was developed to look like and maneuver much like a hummingbird. It has a 6.5-inch wingspan and weighs 19g, making it only slightly larger than the average hummingbird. The drone is also able to perch on objects, such as a window ledge, and gather intelligence about its target via its built-in audio and video recorders. Hummingbird drones could also be used to locate survivors in rubble and investigate locations where there are potentially hazardous chemicals.[25]

Another example is the T-Hawk, named for the tarantula hawk—a type of wasp. Although not quite "insect-looking," the T-Hawk has a vertical takeoff and landing ability and the ability to hover and stare, allowing it to identify and monitor Improvised Explosive Devices (IEDs), do battle damage assessment, and carry out homeland security operations, all while fitting in a backpack. It was used to conduct surveillance after the Fukushima nuclear disaster in Japan in 2011, highlighting the utility of this drone to carry out operations that are too dangerous for humans.[26] The RoboBee is another fascinating example. Designed in the Harvard University Robotics Laboratory and smaller than a penny, it has wings that gyrate similar to those of an insect.[27] The RoboBee can ascend into the air, hover, and carry out controlled flight maneuvers. In his review of small drone technologies, Adam Piore writes that "until recently, inventors lacked the aerodynamics expertise to turn diagrams into mechanical versions of something as quotidian as a fly or a bee."[28] In 2019, however, the RoboBee broke new ground, becoming the lightest vehicle to fly without a power cord at only 0.25 grams.[29] Since then, this is something we have begun to see play out globally with incredible innovation through the 2020s.

In March 2024, Chinese state media reported that researchers in Xi'an, the capital of Shaanxi Province, had flown a birdlike ornithopter. The drone, "Little Falcon," generates lift by flapping its wings and shifting directions by folding them. The same lab had also flown another birdlike drone the year prior and sustained flight for over three hours, a revolution for drones of this size.[30] Given their clear utility, these small nano-mimic-drones will only increase in prevalence internationally over the coming decades, both in terms of civil and military use. Yet this progress is not without its critics, especially when it comes to commercial rollout.

Commercial drones naturally raise privacy concern, but these concerns are heightened further when the drone resembles an insect and can hide in plain sight. What could seem like a fly might actually have sensors and small cameras. Eric Schmidt, Google's former CEO, expressed concern about the privacy issues of small drones that fly into a neighbor's backyard, but also (much like in the movies) those that could be used as terrorist weapons or for espionage and surveillance.[31] His recommended solutions included an international treaty that would regulate inexpensive nanodrones. "It's got to be regulated" Schmidt stated, "[y]ou just can't imagine that British people would allow this sort of thing, and I can't imagine American people would allow this sort of thing. It's one thing for governments, who have some legitimacy in what they're doing, but have other people doing it … It's not going to happen."[32] Similar concerns have been raised about nanodrones that do not look like insects.

The Zano, a personal nanodrone, was but one example. This drone was designed as "the personal paparazzi nano drone," a worrying prospect given the history of media/press privacy violations.[33] Unfortunately for Zano's backers the project failed within a year, and investigations later determined that Zano's promotional videos were faked.[34] Yet, such drones do exist and are purchased in their thousands. With a weight of 249 grams and a price tag under $600, the DJI Mini 3 Pro poses a similar privacy issue. To add to the concern, this drone can fly for 47 minutes and sports a 48-megapixel camera capable of filming in 4K HDR at 60 frames per second. These drones have proven incredibly popular, with the latest version, the DJI Mini 4 Pro, rated the best overall drone of 2025 by PC Magazine.[35]

It is here we return to the military trends in the deployment of such system. This is because given DJI's record of combat use, it will come as no surprise that the DJI Mini family of drones have been deployed in Ukraine. As drone expert David Hambling has argued, "small quadcopters rule the battlefield in Ukraine … now every squad leader can have a folding Mavic

Mini 2 small enough to fit into a cargo pocket but able to send back HD video from three miles away for half an hour."[36] Still, it is not the only nanodrone deployed to the conflict. Another, much more advanced, example is the Teledyne FLIR's Black Hornet Nano. Resembling a miniature helicopter, the Black Hornet flies using a larger main rotor and a smaller tail rotor for directional control. The Black Hornet 3—the latest iteration—has had a global spotlight thrust upon it due to its use in Ukraine from 2022. At least 1,300 of these drones have been supplied to Ukraine to assist ground units. Measuring just 6.65 inches long with a weight of 33 grams, this latest Black Hornet is capable of transmitting video and still images at a range of up to two kilometers. Despite its small size and weight, it is still able to fly for up to 25 minutes. It is well suited to reconnaissance, as it flies nearly silently and has a host of features such as thermal imaging, automatic return when the signal is lost, and auto-hover.[37] The Black Hornet is able to be directly controlled by a pilot or to fly to target autonomously using a global positioning system (GPS).[38] As such, it is clear to see how the miniaturization of drone technology in both the commercial and military sectors is quickly maturing, marking a trend of development and interest that will almost certainly increase in the years to come. However, it is not just the small drones that will dominate the future of war.

Accompanying mini and nanodrones will be much large drone systems, incomparable in terms of size and function. One current trend in larger drones is toward faster, stealthier, systems. The most sophisticated armed drone has been the Reaper, which remains quite vulnerable even to a rudimentary set of air defense systems. Recent additions to the Reaper seek to upgrade its stealth capabilities such as the addition of the Reaper Defense Electronic Support System/Scalable Open Architecture Reconnaissance (RDESS/SOAR). This pod, which can be attached to MQ-9 Reapers (operated by the US Marine Corps among others), reportedly makes the Reaper mostly undetectable.[39] China, the United Kingdom, and America are also developing stealth drones that are designed for aerodynamics and low observation. A new development is the use of plasma active flow control (AFC). AFC is the use of high-pressure air to maneuver instead of moving control surfaces such as rudders. The use of AFC within the drone could allow drones to be built with better shapes to reduce radar reflection and decrease drag.[40]

In some of its most ambitious plans, the Pentagon envisioned a long-range strike bomber that can flip a switch and transform from a manned aircraft to one that is unmanned and flown remotely or fully autonomously. An optimistic interpretation is that this vision would be "the best of both worlds," bringing the deployable advantages of unmanned and manned aircraft to hand when needed. For instance, General Cartwright, former vice chairman of the Joint Chiefs of Staff, argued that while there are psychological hang-ups about using unmanned bombers to deliver nuclear weapons, intercontinental ballistic missiles are also unmanned, setting a precedent for use as force multipliers.[41] Nevertheless, a less sanguine interpretation would point to previous military efforts to produce such multirole platforms, including the F-35, and the tendency for enormous cost overruns in the effort to be all things to all people (or services). It is perhaps with these costs in mind that the Pentagon has now shifted its focus, investing more in the idea of "loyal wingmen" that would fly separate, but alongside the crewed system.

These drones, also known as Collaborative Combat Aircraft (CCAs), are semi-autonomous or fully autonomous drones that would assist the primary bomber or be sent on separate unmanned missions. Programs like the Boeing MQ-28 "Ghost Bat" in Australia, the US Air Force's XQ-58 Valkyrie, and China's Feihong FH-97A are pioneering this technology. Indeed, with such international buy-in, the CCAs are expected to transform air combat. By increasing firepower as a force multiplier, extending sensor range, and assuming high-risk roles, loyal wingman drones are intended to enhance operational effectiveness and reduce the risk to the piloted bomber. As the Royal Australian Air Force stated in relation to their Ghost Bat, the "uncrewed aircraft is a pathfinder for the integration of autonomous systems and artificial intelligence to create smart human-machine teams."[42] Such systems have been in development for decades; the drones tested by

Joe Kennedy Jr. and his crew during World War II and the Lightening Bug drones in Vietnam, mentioned previously in the book (Chapter 2), are early examples of this manned-unmanned partnership. However, with Australia's over $1 billion investment in the drones and China's plans to use the FH-97A to lead "swarms of smaller drones" or act "as a companion wingman for Beijing's stealth fighters, such as the J-20," it is likely the loyal wingman approach to drone warfare will only increase in prevalence in the near to medium term.[43]

Even further on the horizon is the idea of a combat drone that can engage in dogfights. These were the type of air-to-air combat missions that were common in World War II or were later popularized by the *Top Gun* movies. While this type of combat is becoming less and less frequent, with stand-off weapons reducing the need for these maneuvers, the experimental X-47B unmanned combat air vehicle program had toyed with the idea of a future dogfight capability. This project was eventually modified to non-lethal use to create the Carrier-Based Aerial–Refueling System (CBARS) program. With successful tests carried out, the CBARS will be the first drone used to refuel mid-air, although it has yet to be deployed.[44] Until now, however, a dogfight capability has been elusive. On December 23, 2002, during the American effort to depose Saddam Hussein, a USAF MQ-1 Predator drone fired a Stinger missile at an Iraqi MiG-25.[45] These air-to-air missiles had been attached to the drone's airframe in what can only be called a haphazard effort to defend the aircraft against aerial threats. Indeed, the Stinger missile did not hit the Iraqi aircraft, which subsequently shot the drone out of the sky. While this lopsided engagement could hardly be called a success story of unmanned flight, it was nonetheless significant in that it was the first time a drone had done battle with a manned counterpart.

The possibility of unmanned dogfighters presents numerous advantages. The most obvious advantage is that aircraft loss would not result in the loss of the human pilot. Furthermore, a drone is not hindered by the limitations posed by having a human on board: not only would such an aircraft not require support systems such as an oxygen supply and a cockpit, but it would also be unhindered by the G-force limitations of the human body.

Such a drone would thus be able to execute high-G maneuvers, a crucial component of dogfights, without knocking out or killing its pilot. Nevertheless, the capacity remains elusive. One possibility is the conversion of a pre-existing manned aircraft into a drone, so-called necro-aeronautics.[46] The US Air Force has already converted the Korean War-era F-86 Sabre and the Vietnam-era F-4 into target drones for training purposes. More interestingly, a fourth-generation F-16 Falcon was converted into an unmanned platform. During testing, the drone, dubbed the QF-16, successfully completed 9-G maneuvers typical of those required during dogfights. Closer yet, the X-62A VISTA, a modified F-16, has been used for AI-controlled dogfighting. Although the results of the 21 dogfights it has tested are not public, the jets flew at up to 1,200 miles per hour and performed defensive and offensive maneuvers.[47] After a flight in just such an AI-controlled jet, Secretary of the Air Force Frank Kendall told reporters that he would trust the AI with the decision to launch weapons.[48] With this prospect in mind, it is here we turn to the latest trends in autonomous drones.

What are the trends in autonomous drones?

Have we now reached that point in history where the Terminators have moved from fiction to reality? Well, not quite, but AI decision-making and lethal autonomy are advancing quicker than ever. As pre-existing robotic technologies that have traditionally placed humans at arm's length, drones have become the test vehicles for many autonomous applications. From scientific research and commercial delivery, through to law enforcement and military application, this volume has shown how drones have been at the spearhead of autonomous trials. Yet, as we look to the future, how should we expect autonomous drones to change? As predicted in some of the fictional representations of drones, swarms are one key example of this burgeoning experimentation. It is through their analysis we can cast light on some of the broader technical trends and limitations in autonomous drones for both civil and military use.

In an interview in 2022, futurist Peter W. Singer explained how "[a]nyone who argues swarms of drones won't appear on a future battlefield is one day going to sound like the people who once argued that the submarine or tank or airplane were mere science fiction."[49] Put simply, they are no longer fictional hype, instead in the 2020s swarms are accepted as a maturing technology soon to be a mainstay of military force. But what actually is a drone swarm? The term is often misused to describe a general grouping of *individual* drones used en masse with a centralized point of control or some semi-autonomous elements. For example, we can explore these more basic rudimentary swarms through the agricultural sector to give us a sense of these more basic swarms in civil application.

Hylio, a drone company focused on crop spraying, received approval in 2024 from the Federal Aviation Administration (FAA) to have farmers operate their 165-pound drone in rudimentary swarms. Each one of their flagship Hylio AG-230 drones can carry eight gallons and spray 50 acres per hour.[50] Previously, large drones such as Hylio's required both a pilot and a line-of-sight spotter, and the new ruling opens up more commercial use as long as the drones are operated between 10 feet and 30 feet from the ground, stay within visual line-of-sight, and stay within a geo-fenced boundary.[51] As the US Office of Government Accountability has made clear, as the technology improves it could be used to "fight wildfires, detect crop disease, and more. Yet, these civil advancements are not 'true swarms'.

To be a "true swarm" the decentralized and autonomous *interconnectedness* of the drones is paramount. As drone experts Zachary Kallenborn and Philipp Bleek have argued, swarms "are fundamentally information-dependent," they are "multiple unmanned systems capable of coordinating their actions to accomplish shared objectives."[52] As such, drone swarms are groups of interconnected and coordinated drones that must work together autonomously to achieve a common goal. For example, the thousands of drones used in light shows by Intel (US) and Damoda (China) are not (for now at least) 'true swarms' as they are pre-programmed and/or centrally controlled. This is why there have been infamous cases of such “swarms,” hundreds strong, falling from the sky when the central connection is lost.[53] A benefit, and worrying feature, of a true swarm is that autonomous decentralized systems would continue to operate if external control or oversight is cut (making defense against nefarious swarms a worrying prospect).[54]

In military terms, the primary advantage of a true drone swarm is that they can evade and overwhelm enemy defenses so that if even a small percentage make it through, they can still achieve considerable damage. Swarms have the added advantage of being equipped with sensors, cameras, and other intelligence-gathering technologies in ways that allow them to cover large areas or collect vast amounts of data simultaneously. Indeed, today defending against rudimentary drone swarms is difficult enough. Yet with true swarms, we will see smart drones, deployed in their thousands that are not only difficult to intercept with Electronic Warfare (EW) or kinetic measures, but can actively evade projectiles fired to intercept them. As a means to indicate how this technology is advancing, let us go through some of the latest developments in military swarming and the limited examples of reported ‘true swarms’.

In May 2021, during Operation Guardian of the Walls, the Israel Defense Forces deployed AI-guided drone swarms in combat against Hamas militants in Gaza. This was one of the first documented uses of autonomous ‘true drone swarms’ operating as coordinated units in an active conflict. The drones employed artificial intelligence to navigate, maintain formation, and identify targets in real time, supporting missile and mortar strikes. The system enabled the drones to communicate and share data, reportedly allowing for more precise targeting and situational awareness with reduced direct human control. Yet such claims have also been challenged, with the deployment also raising concerns about the use of AI in targeting decisions, particularly regarding civilian casualties and the potential for errors in complex environments.[55]

In another case in July of 2024, Boeing completed its second phase of live flight trials for its autonomous drone swarms. These trials were conducted at the Snowdonia Aerospace Centre in the UK and involved four fixed-wing Albatross UAVs working collaboratively to detect and jam a simulated enemy radio frequency. Each UAV was equipped with advanced mission systems utilizing multispectral machine vision and novel search algorithms to autonomously respond to environmental changes and coordinate with other UAVs in the team.[56]

Next, the US DoD's Replicator initiative follows this swarming vision of the future. The first stage of Replicator aims to produce AI-enabled drones on a large scale. As the US DoD's Defense Innovation Unit (DIU) has stated, the initiative "will deliver all-domain attritable autonomous systems (ADA2) to warfighters at a scale of multiple thousands, across multiple warfighting domains, within 18–24 months, or by August 2025."[57] The second stage of Replicator will, according to the statement made by Secretary of Defense Lloyd Austin during the Biden administration, focus on the threat to installations and "force concentrations."[58] In essence, it is designed to counter the kind of drones discussed previously that have threatened the United States and allied forces in the Middle East and Europe. In practical terms, this heightened autonomous drone production capability would be critical to the future defense of nations like Taiwan, who are, in turn, critical to keeping the United States advantaged in high-tech systems due to their semiconductor industry. As the US Navy Admiral Samuel Paparo (the Indo-Pacific Command Chief) described, an initial stalling of a Chinese invasion would involve turning the Taiwan Strait "into an unmanned hellscape … so that I can make their lives utterly miserable for a month, which buys me the time for the rest of everything."[59] Indeed, the United States is increasingly looking to the necessity of loitering munitions, large drone swarms, and effective electronic warfare in a potential future defense of Taiwan.[60] Yet this has not always been the case. In fact, it is only recently that we have seen an official embrace of the fully autonomous future.

Many countries (including the United States) have historically been hesitant to move to fully lethal autonomous weapons. Indeed, some drone experts, such as Kallenborn, take this concern one step further by arguing that "[a]rmed, fully-autonomous drone swarms are future weapons of mass destruction."[61] As Kallenborn explains, "drone swarms combine two properties unique to traditional weapons of mass destruction: mass harm and a lack of control to ensure the weapons do not harm civilians."[62] As the earlier section (Chapter 4) on international law suggested, decisions about combatants versus civilians are inherently fraught, especially in environments where civilians routinely traverse into combatant status and back and where the definition of "direct participation in hostilities" can be quite ambiguous. Autonomous systems may be able to provide more capacity and speed for data analysis, but they are not able to ask subjective and inherently philosophical questions of where indirect participation ends and direct participation begins. It is this concern that underpins one of the central questions are the heart of the lethal autonomous weapons debate: Should a machine be able to make the decision about whether or not a human lives or dies? This question is not as straightforward as it seems, especially as the definition of what constitutes a lethal autonomous weapon system (LAWS) is also open for debate.

The key point of disagreement rests on how much independence a weapon should have before it is considered fully autonomous. Some define LAWS as weapons that can identify and attack targets on their own, without human input, while others believe systems where humans approve targets selected by AI should also be included. A key concern is how much human control should remain and where should it remain—should a person always be directly involved in and monitoring life-and-death decisions, or is it enough that humans program the system in advance?[63] critics worry that fully autonomous weapons lack human judgment and accountability, potentially violating international humanitarian law. In essence, they argue there must be appropriate human control in line with international law and that international law may need to be amended to keep up with the technology.[64] Supporters argue that these systems could be the "moral choice" reducing mistakes and civilian casualties by making more precise targeting decisions without human error.[65] In the middle, is the school of thought that rejects the idea of a human being in the loop control, but concedes there should always be human accountability – a place where the buck stops when things go wrong.[66]

Over the last decade roboticists have tried to tackle this problem by equipping machines with a moral compass, an "ethical adapter," that can generate a sense of compassion when faced with the prospect of lethal force. The ethical adapter also tries to inculcate an "after-action reflection," which means the robot can then try to modify its future behavior based on what it learned from the previous event (including error). Another emotion that roboticists are trying to generate is one of guilt, wherein if "specific affective threshold values are exceeded, the system will cease being able to deploy lethality partially or in totality."[67] Robert Arkin, who studies AI, asserts that ultimately the ethical adapter on an autonomous system can ultimately reduce civilian casualties compared to their human counterparts.[68] Yet, such conclusions are open to debate, with Philip Alston, former UN Special Rapporteur on extrajudicial, summary, or arbitrary executions, arguing that "the notion that the laws of war can be reduced to programmable formulae and the idea that the human conscience can be mechanically replicated are both far more problematic than Arkin's work would suggest."[69]

In response to these developments and concerns, a transnational movement has mobilized to prevent the use of systems that engage targets and acquire situational awareness in the absence of human intervention. One movement, named the Campaign to Stop Killer Robots, questions the basic premise that fully autonomous systems can function ethically and of their own accord. The group was launched in April 2013 by Jody Williams, who was also responsible for the movement that culminated in the Ottawa and Oslo Treaties that banned landmines and cluster munitions, and has proposed a ban on fully autonomous weapons. It works through the mobilization of nation-states, which have worked within the Convention on Certain Conventional Weapons (CCW), to create a treaty that would preemptively ban additional development and use of these systems.[70]

In November 2014, countries involved in the CCW agreed to a second round of discussion about lethal autonomous weapons systems. Mary

Wareham (Human Rights Watch Arms Advocacy director and Campaign to Stop Killer Robots coordinator) cited this move as an acknowledgment of the importance of the topic; she also, however, cautioned that "the technology is moving faster than the international response."[71] Nevertheless, the movement has progressed over the last decade, with 30 countries calling for a ban on the use of LAWS by 2023.[72] The CCW has not, however, created a commonly agreed-upon definition of what constitutes a LAWS, but the position of the UN as of 2023 is that they are both "politically unacceptable and morally repugnant."[73]

The private sector has also expressed hesitation regarding fully autonomous systems, taking a view that has traditionally sought to keep such weapons inside Pandora's Box. In 2015, Elon Musk—the boss of Tesla, who later became head of X and SpaceX, and played a significant role in the second Trump administration—joined forces with scientist Stephen Hawking and Apple co-founder Steve Wozniak to write an open letter about the potential consequences of autonomous weapons. The letter built on Hawking's and Musk's previous cautions about AI, warning that there might be unintended consequences of greater automation since machines are not able to understand the positive and negative effects of their actions. The letter stated that "if any major military power pushes ahead with AI weapon development, a global arms race is virtually inevitable … autonomous weapons are ideal for tasks such as assassinations, destabilizing nations, subduing populations, and selectively killing a particular ethnic group," meaning that the proliferation of this technology would be a dangerous development.[74] In 2018, Musk and Demis Hassabis, the co-founder of Google DeepMind, joined over 2,400 signatories to a pledge against the construction of LAWS.

Yet as of 2025, this has begun to change, with a number of Silicon Valley tech companies reneging on their stance on the use and development of AI for military purposes. Specifically, in February 2025, Alphabet, the parent company of Google, went back on its pledge to not use AI to "cause overall harm" while other tech companies like OpenAI and Amazon have openly worked with the defense industry. In response, the Campaign to Stop Killer

Robots has argued that this drawing back on the "pledge to not use Artificial Intelligence (AI) for weapons should push political leaders to establish international legal frameworks to regulate AI in weapons."[75] As such, with a growing appetite for autonomous drones, whether for military effectiveness or debatable moral ends, it is now clear that the United States and its leading tech companies will continue to test and pioneer the technology.

Yet, as this volume has shown, with the spread of remote-control drones, all weapons proliferate, meaning these hi-tech systems will likely pose a threat back to the United States and its allies in the future, deployed in novel and often disturbing ways by their adversaries. Some worry about the spread of the technologies to violent nonstate actors, noting a growing "accessibility and appeal to … terrorist, hacking, and drug trafficking groups."[76] For others, it is state actors that remain the primary concern. The downing of Russian Lancet-3 loitering munitions in Ukraine, for instance, revealed their reliance on American chipmaker NVIDIA's AI modules, the Jetson TX2.[77] Despite sanctions on providing these modules to Russia, the chips are moved to distributors who then sell them to other end users who then transfer them to Russia.[78] Put simply, Russia's most advanced short-range OWA drone "runs on American AI."[79] This is, however, just one way in which autonomous drones are spreading.

One of the world's leading drone manufacturing nations, Turkey, is also pioneering its own technologies. Turkey is currently producing "military-grade autonomous drones [that] can fly themselves to a specific location, pick their own targets and kill without the assistance of a remote human operator."[80] Not only are they producing these systems, but according to a UN report on Turkish actions during the Second Libyan Civil War, they have also deployed them in combat. While the exact details are still contested, a UN report revealed that "[l]ogistics convoys and retreating [Haftar-affiliated forces] were subsequently hunted down and remotely engaged by the unmanned combat aerial vehicles or the lethal autonomous weapons systems such as the STM Kargu-2 … and other loitering munitions."[81] It has not been confirmed if anyone died in the attack, but the lethal use of such systems is only a matter of time as their use around the world grows.

In Ukraine, for instance, the deficit in manpower has created a demand for automation and autonomy. Some manufacturers such as Saker have constructed small computers that can be attached to existing FPV drones, allowing them to lock onto targets using simple computer vision algorithms. Saker has additionally used its targeting software on a reconnaissance drone which then dispatches loitering munitions striking a target as far as 25 miles away.[82]

The prevalence of jamming and electronic warfare also accelerated the embrace of autonomy in Ukraine. The reason is that once in autonomous flight, jamming no longer has the same impact with no crucial communication link between the drone pilot and the drone left to sever.[83] In this situation, the software on board can both know the flight path and recognize the terrain as a means to lead the device to the target. Once at its intended location, it can use AI and its algorithmic machine vision to recognize the target and release the weapon without pilot intervention. Such developments have been driven by Russia's invasion of Ukraine and Ukraine's push for state survival in a time of supreme emergency.[84] It is likely that as other countries face similar threats in the future, or as great power tensions grow, it will be similar scenarios that will drive the global innovation, adoption, and deployment of lethal autonomous drones.

Finally, in addition to being an innovator and industry leader in the design, manufacture, and sale of remotely piloted military drones, Israel has also pioneered autonomous weapons systems. For example, the Smart Shooter turret uses AI to track targets and fire "tear gas, stun grenades and sponge-tipped bullets," while the SkyStrike drone, is described as a "fully autonomous loitering munition that can locate, acquire and engage operator designated targets with a flexible warhead of up to 10 kg (22 pounds), enabling high-precision performance."[85] However, it is through the development of autonomous data processing systems to aid in military decision-making and the generation of targets for weapons like drones, that Israel has really led the way.

Due to the backroom role these systems play, they often receive less attention than the development and deployment of armed offensive weapons systems. Nevertheless, if a target list is generated through AI and a human makes the decision to kill based on that AI-processed data, then it raises questions about the extent of appropriate and meaningful human control in the kill chain. Put simply, Israel's deployment of such systems is directly linked to our understanding of future drone use and it has not been without controversy. As *The Economist* asked in April 2024, "do the humans in Israel's army have sufficient control over its technology?"[86]

Perhaps the most prominent example of the deployment of these systems was during the "world's first AI war," in 2021, the same conflict where we saw true swarms used by Israel against Hamas.[87] The operation lasted 11 days and saw numerous AI systems aid in early warning, the processing of targeting data, and the mapping of the urban and underground environment. Here a number of new systems—called Alchemist, Gospel, and Depth of Wisdom—were developed for use during the fighting. Alchemist "analyzed incoming data and alerted troops in the field to possible attacks,"[88] while Gospel, according to high-ranking Israeli Defense Force (IDF) officials, is "a machine that produces vast amounts of data more effectively than any human, and translates it into targets for attack."[89] As Aviv Kochavi, a former head of the IDF, explained, "once this machine was activated" it produced "100 targets a single day, with 50% of them being attacked."[90] To put this into perspective, Kochavi explained that "in the past we would produce 50 targets in Gaza per year."[91] Depth of Wisdom was also used to map out the "network of tunnels, including the depth of each tunnel," a monumental task given the Hamas-controlled tunnels are said to be a 300-mile network "almost half the length of the New York City subway system."[92] Drones were then deployed in these tunnels to track combatants.[93]

Overall, 261 Palestinians were killed in the conflict, with 2,200 injured.[94] With this experience of modern warfare in mind, AI expert Branka Marijan raised important questions about the future of the technology asking: "[i]f military AI systems are so advanced and precise" then "why have so many civilians been killed and maimed in Gaza? And why so much destruction of civilian infrastructure?". For Marijan, the answer is increasingly obvious: much like the controversies around the US drone program and 'surgical precision strike', the precision of "AI-aided technology does not live up to the hype."[95]

Are drones here to stay?

The simple answer is yes, although the extent and form are still open for debate. Ten years ago, in the first edition of this book, there was more hesitancy as the technology, investment, and legal approval appeared to slow in the commercial sector and the military use remained in the hands of the United States and key allies. Today, however, the world is becoming awash with drones. The majority of militaries now have drones in their arsenal, and there have been no recent conflicts in which drones were not used. They have become a mainstay of modern warfare, not just because they spare the pilot but because they have become increasingly advanced, affordable, and available as a force multiplier. On the nonmilitary side, drones have 'taken-off' so quickly and in such number they have caused mass hysteria in New Jersey, New York, and Connecticut, with people surprised at their prevalence in the skies above them. Indeed, investment in the technology (both remote-controlled and autonomous) is growing.

In 2024, investment into drone startups remained impressive with an average of $27.2 million per funding round and over 3,000 companies receiving investments.[96] This investment has also been buoyed by the use of drones in Ukraine and military applications of the commercial tech. While in 2018, employees at Google revolted against the CEO when they learned of the company's involvement in a Pentagon contract, today's open and public turn to defense-related projects, including drones, marks a clear shift toward the profitability of the drone market (no matter the employee protestations). In fact, there has been more than $2 billion invested in startups in the drone, aerospace, and satellite sectors.[97] With this in mind, let us explore some of these drone companies and their plans for the future.

Skydio, which began as a startup focused on consumer drones, aims "to build true computer vision into drones, enabling them to navigate based not on GPS but on what they 'see.'"[98] The company is the brainchild of a group of individuals who met at the Massachusetts Institute of Technology (MIT) and were part of the founding team of Google X's Project Wing. The technology would help drones "sense and avoid collisions," one of the key impediments to broader integration of commercial drones into the national airspace given the potential for drones to collide with manned aircraft.[99] One of the cofounders explained that "the goal is to take something that normally costs $5,000 and sell it for $50." Lowering the cost of entry lowers the barriers for more individuals who are not willing to spend thousands of dollars on drone technology.[100] Despite this original goal, Skydio's release of the X2 autonomous drone in 2020 was its first venture away from the consumer market. With a $2.2 billion valuation from Series E funding in August of 2023, Skydio fully pivoted away from the consumer market to focus on military and government drones, continuing to use its AI-driven obstacle avoidance software but on an enterprise level.[101] Skydio's X2D Multiband demonstrates adaptation to battlegrounds like Ukraine with a focus on countering signal interference and GPS-denied navigation.[102]

Companies such as Anduril further reflect the defense applications and investment in the drone space (albeit in the context of counter-drone and software capabilities). Anduril's Lattice software (mentioned previously in Chapter 5) is a platform designed for defense and public safety applications, integrating data from various sensors and systems to provide real-time situational awareness. As the company states, Lattice "integrates with and fuses multiple sensors, data, and assets into a single AI-enabled software interface and automatically monitors land and maritime borders, alerting human operators to objects of interest on their desktop or mobile phones. Once alerted, operators can use Lattice to investigate further by tasking drone aircraft or sending coordinates to others for apprehension."[103]

Investment in defense startups has further developed with Y Combinator's backing of Ares Industries. This startup seeks to create smaller and cheaper cruise missiles by 2025 to counter smaller Chinese ships and unmanned surface vessels in a possible war in the Taiwan Strait. The introduction of Ares Industries into the legendary startup incubator marks the first time it has backed a weapons developer. Founders Devan Plantamura and Alex Tseng argue that the price of current cruise missiles in comparison to maritime drones and the lack of industrial capacity to construct them could lead to depletion within weeks.[104] While not directly having to do with the construction of armed drones, Ares demonstrates the demand for counter-drone systems and the growing willingness of Silicon Valley venture capitalists to involve themselves. Put simply, the introduction of drones presents both opportunities and concerns, which are driving the drone market from both sides.

Indeed, it is these worries and opportunities that help us sketch out the two possible future drone worlds. One future is a world in which individual concerns about safety, human control, and privacy become more powerful, prompting governments to impose strict regulations on commercial, individual, and military applications. This would be a world with fewer drones and a failed prognostication about the ubiquity of drones. Another future—far more likely—is a world where individuals, industry, governments, and militaries continue to embrace the technology—including technology with increased autonomy—across air, land, and sea. In this case, Amazon's Jeff Bezos will have been accurate in his 2015 prediction that drones would be "as common as seeing a mail truck."[105] Yet unfortunately for many in the world, this might more accurately be translated to "as common as seeing an AK47." One thing is for sure. Even if not ubiquitous, drones—in their many forms, and varied applications, some of which are still to be discovered—are most certainly here to stay. What remains for us all to decide is the extent to which they will impact our lives.

APPENDIX

Table A.1 Comprehensive List of State Actors That Possess Drones by Continent

	Country	Class I	Class II	Class III	Class III R&D or Acquisition	Source
1	Afghanistan					a (*)
2	Albania					b
3	Algeria					a
4	Angola					c
5	Argentina					a
6	Armenia					a
7	Australia					a
8	Austria					a
9	Azerbaijan					a
10	Bahamas					d (^)
11	Bangladesh					a
12	Barbados					e
13	Belarus					a
14	Belgium					a

15	Bolivia					*
16	Botswana					f (#)
17	Brazil					*
18	Bulgaria					*
19	Burkina Faso					g (!)
20	Burundi					*
21	Cameroon					*
22	Canada					*
23	Chad					(!)
24	Chile					*
25	China					*
26	Colombia					*
27	Cote D'Ivoire					h
28	Croatia					*
29	Cyprus					^
30	Czech Republic					*
31	DR of Congo					i
32	Denmark					*
33	Dominican Republic					*
34	Ecuador					*
35	Egypt					*
36	Estonia					*
37	Ethiopia					*
38	Finland					*
39	France					*

40	Georgia					•
41	Germany					•
42	Ghana					^
43	Greece					•
44	Guyana					^
45	Honduras					•
46	Hungary					•
47	India					•
48	Indonesia					•
49	Iran					•
50	Iraq					•
51	Ireland					•
52	Israel					•
53	Italy					•
54	Japan					•
55	Jordan					•
56	Kazakhstan					•
57	Kenya					•
58	Kyrgyzstan					j
59	Latvia					•
60	Lebanon					•
61	Libya					^
62	Lithuania					•
63	Luxembourg					•
64	Malaysia					•
65	Maldives					k

66	Mali					!
67	Mauritania					#
68	Mexico					•
69	Morocco					!
70	Myanmar					•
71	Netherlands					•
72	New Zealand					•
73	Niger					!
74	Nigeria					•
75	North Korea					•
76	North Macedo-nia					•
77	Norway					•
78	Oman					•
79	Pakistan					•
80	Paraguay					•
81	Peru					•
82	Philippines					•
83	Poland					•
84	Portugal					•
85	Qatar					•
86	Romania					•
87	Russia					•

88	Rwanda					m
89	Saudi Arabia					*
90	Senegal					n
91	Serbia					*
92	Singapore					*
93	Slovakia					*
94	Slovenia					*
95	South Africa					*
96	South Korea					*
97	Spain					*
98	Sri Lanka					*
99	Sudan					*
100	Sweden					*
101	Switzerland					*
102	Syria					*
103	Taiwan					*
104	Thailand					*
105	Turkey					*
106	Turkmenistan					*
107	Uganda					*
108	Ukraine					*
109	United Arab Emirates					*
110	United Kingdom					*
111	United States					*
112	Uruguay					*
113	Uzbekistan					*
114	Venezuela					*
115	Vietnam					*
116	Yemen					o
117	Zambia					*
118	Zimbabwe					p, q
	TOTAL	97	45	44	32	

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Chapter 1

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Chapter 4

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Chapter 6

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Chapter 7

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