Chapter 5

Key Technologies and the Revolution of Small, Smart, and Cheap in the Future of Warfare

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The convergence of fourth industrial revolution technologies is making possible smaller, smarter, and cheaper weapons systems that will challenge the few and exquisite systems of today's militaries. Based on land, sea, and air, these small, smart, and cheap weapons will fundamentally change the character of war and may come to dominate Great Power conflicts.

The U.S. Civil War demonstrated the impact of the Industrial Revolution on warfare. The advent of mass production, railroads, telegraphs, and steam warships meant mass became a dominant, if not *the* dominant, element on the battlefield. World War I reinforced this fact. Even with the advent of maneuver warfare, World War II remained largely a competition of mass. In the 1980s, American leaders turned to precision weapons to defeat the Warsaw Pact's mass.[1] Thankfully, we never found out if precision weapons could defeat the Warsaw Pact, but the technologies developed to do so proved devastating in the 1991 Gulf War and Operation *Iraqi Freedom*. Unfortunately, these weapons and the platforms to deliver them have become progressively more expensive. The result is the United States entered the 21st century building fewer but ever-more-capable weapons systems.

Twenty years into the new century, the United States, China, and Russia continue to pursue high-end systems such as fifth-generation fighters, heavy bombers, and aircraft carriers. Yet by reducing the price of precision and advanced manufacturing, the fourth industrial revolution is creating a new generation of smaller, smarter, and cheaper weapons that challenges these weapons systems. In short, we are moving to an era of mass *precision*. A key question in the unfolding era of Great Power competition is which nation can most rapidly and effectively adapt to this revolution.

Technological Convergence

Like all previous industrial revolutions, this one is not based on a single technology but the convergence of an array of technologies that are rapidly maturing. This chapter studies only those most directly affecting military capabilities in the next 5 years (2020–2025).

Nanotechnology has made long-range precision systems affordable. Hypersonic weapons, although expensive, are creating yet another challenge. Furthermore, since each of these technologies is new, improvements in capability are happening fast while, with the exception of hypersonic weapons, costing a fraction of what it costs to improve current weapons systems technology.

Nanotechnology

Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. To put this scale into perspective, a sheet of newsprint is about 100,000 nanos thick.[2] Nanotechnology is applicable to chemistry, biology, physics, and materials science to dramatically increase a range of properties such as strength, combustibility, and conductivity.

The most immediate military application of nanotechnology is nano-explosives. Open-source reporting indicates nano-explosives have demonstrated an explosive power 10 times that of conventional explosives.[3] Nano-research continues, which means much greater conventional explosive power is available to states and, inevitably, nonstate actors as well. Increased explosive capacity can give new, smaller weapons the same effectiveness of much larger older ones.

The second area of interest is nanomaterials. Carbon nanotubes (created from graphene) are over 400 times stronger than steel and are exceptional conductors.[4] They are being used to reduce the weight needed for structural strength in many products—electronics, vehicles, medical devices, and even water purification. When techniques under development eventually make graphene available cheaply in large quantities, they will free designers to improve performance across the spectrum, from bicycles to high-end military applications.

Nanomaterials also dramatically increase battery storage capacity, and graphene-based supercapacitors can recharge almost instantly.[5] Nanomaterials are making smart, adaptive fabric that changes to match the background and nano-based paints, making the acquisition of electronically or visually coated objects challenging.[6] Potentially, some of the most valuable nanoproducts are radiation-hardened circuits to protect electronics from microwave weapons. In short, improvements in materials, circuitry, energy storage, and explosives based on nanotechnology will lead to major increases in range, payload, and stealth for various vehicles.

Drones

Exponential improvements in drone capabilities are being driven by commercial interests. Autonomous air, ground, and maritime drones are available to anyone who wishes to purchase them for surveillance/reconnaissance, communications, logistics, and even strike.

Surveillance/Reconnaissance Drones. Long-endurance (30+ hours), military, remotely piloted unmanned aerial vehicles such as the Global Hawk are expensive ($130 million) and require extensive support structures to maximize their effectiveness—up to 171 personnel for each orbit.[7] Today, commercial demand for long-endurance surveillance systems is resulting in solutions that are much less expensive and require only a few personnel. Defiant Labs' DX-3 autonomous vertical takeoff and landing (VTOL) drone has a mission range of 900 miles and carries light detection and ranging technology or integrated optical and thermal cameras with high-resolution zoom.[8] Aerovel's autonomous VTOL Flexrotor provides long-term (32 hours) and long-range (1,800 miles) observation. It carries visual and infrared video and still cameras as well as synthetic aperture radar.[9] Each costs about $200,000.

Clearly, the rapid advances in commercial, autonomous surveillance drones and machine interpretation is lowering the cost of operating long-range, multispectral, and radar surveillance missions.

Communications Relay Drones. Long-endurance or tethered drones can provide temporary nodes either to extend the range of existing systems or to provide rapid replacement for a node that has sustained damage.

Strike Drones. Predator-type remotely piloted military strike drones have received extensive coverage over the past two decades. Like a traditional airplane, it is a runway takeoff and runway landing platform. But the important advances are taking place in autonomous, VTOL drones. At the high end, for $2 million or 1/45th the cost of an F-35, the Kratos XQ-222 drone features a 3,000-mile range (over two times the F-35) with a 600-pound payload.[10] The cost advantage actually increases with time. With its vertical takeoff and recovery system, the XQ-222 has minimal monthly training costs, needs no airfield, and requires no training pipeline for pilots and maintainers, no pilot bonuses, no retirement costs, no health care, and so forth. The U.S. Air Force is testing a version it has designated the XQ-58A. Unfortunately, the XQ-222's presence at the Paris Air Show in 2017 indicates America will not be the only nation with this capability.

Strike drone technology is not limited to million-dollar systems, however. The United States has shipped over 4,000 of its $15,000 Switchblade drones to Afghanistan since 2011. Measuring 2 feet long and 3 inches wide, and weighing only 6 pounds, it can fly for approximately 6.2 miles and provide live video to the operator. Because it is armed, operators can use it to "suicide" into any targets they find.[11] Moreover, major states do not have a monopoly on strike missions. Iran demonstrated its capabilities in the strike on the Saudi Arabian Abqaiq oil facility in September 2019. Tehran also provided weapons for Yemeni cruise missile attacks on U.S. warships. Even before Iran's activities, the so-called Islamic State conducted over 80 drone attacks between October 2016 and January 2017 that resulted in about a dozen dead and 50 injured enemy soldiers.[12]

Commercial firms are testing autonomous VTOL drones that are GPS-independent, hardened against electronic interference, range hundreds of miles, deliver with an accuracy of 1 meter, and are inexpensive enough to be disposable.[13]

Maritime Drones. The commercial shipping industry is working on an array of unmanned surface vessels (USVs), from North Sea ferries to electric coastal cargo vessels to full-size container ships and tankers. By 2018, the U.S. Navy was developing its own USVs to detect and strike enemy combatants, clear a mined strait within hours using a swarm of vessels, trail an adversary's submarines, and guard a critical infrastructure.[14]

Imaginatively employed, unmanned underwater vehicles (UUVs) could be a relatively inexpensive substitute/augmentation for a submarine force. Both the U.S. and Chinese navies are pursuing numerous autonomous maritime platforms.

Ground Drones. In Iraq, Shia militia employed four armed robots to fight the Islamic State.[15] Russia deployed its Uran-9 remotely operated minitank to Syria with mixed results.[16] This is not surprising. All revolutionary systems encounter major problems during initial deployments. Despite early setbacks, many nations continue to develop unmanned ground vehicles.

In short, both military and commercial drone usage—on the ground, at sea, in the air—is exploding. The global smart commercial drone market is projected to reach $179 billion by 2025,[17] and there appear to be few limits to the planned uses.

Counter-Drone Efforts. Since 2002, Defense Advanced Research Projects Agency (DARPA) has sponsored the annual Black Dart live-fire exercise to explore ideas for defeating drones. Since then, anti-drone technology has taken many different paths: kinetic kill, directed energy (lasers and electromagnetic pulse), software attacks, and electronic and GPS jamming.

Lasers, software attacks, and electromagnetic pulse initially appeared to have the most potential impact on swarms. Unfortunately, each approach has significant limitations. Certain atmospheric conditions (dust, haze, water vapor) as well as reflective paints and ablative coatings can significantly reduce the effectiveness of lasers. Software attacks require the enemy to cooperate by leaving a path into his system to insert the software. Electromagnetic weapons can be defeated by hardening a drone's electronics. During the Cold War, mission-critical electronics were protected from the potential electromagnetic pulse of a nuclear detonation by enclosing the electronics within Faraday cages.[18] Today, radiation-hardened electronics can be placed into a system during its manufacture.[19]

In a new approach, DARPA is exploring the use of drone swarms to *defeat* drone swarms. It sponsored a 2017 competition among teams from the U.S. Service academies to see which could develop the most effective software and tactics for one swarm to defeat another. The teams then flew mixed swarms of 25 drones against each other with remarkable success.[20] This concept has not been tested against larger swarms, and no attempt has been made to operationalize the concept. The fact remains, however, that current civil and military systems cannot defeat swarms of autonomous drones.

Artificial Intelligence

Artificial intelligence (AI) is a wide-ranging, dynamic field. Chapter 6 of this volume addresses a number of AI implications for wider defense and security. In this chapter, we address two AI areas of particular importance in the rapid evolution of small, smart, and cheap weapons: GPS-independent navigation and target identification. At the cheap end, a University of Pennsylvania quadcopter "uses a smartphone for autonomous flight, employing only onboard hardware and vision algorithms—no GPS is involved."[21] At the expensive end, DARPA is developing precise navigation using variations in Earth's magnetic field.[22] Both systems are immune to GPS jamming or spoofing—a growing challenge from Russia and inevitably China.[23] These systems can get a drone to the target area but they cannot ensure it can hit a specific target.

Thus, the second key element for truly autonomous drone strike operations is accurate target identification. Many researchers are working on limited AI that will provide accurate identification from onboard sensors.[24] At the low end, an early 2019 online journal rated seven commercial drones that can identify and follow a person.[25] These drones can certainly identify an aircraft on a parking apron. At the high end, the Air Force Research Lab is using a neuromorphic chip to identify military and civilian vehicles in radar-generated aerial imagery.[26]

Swarms

Truly autonomous drones will require no human intervention to execute missions, thus they will be able to operate in large numbers. This requires they be inexpensive. In 2014, a University of Virginia team 3D printed a drone in a single day, then added a small electric motor, 2 batteries, and an Android phone for guidance to produce an $800 autonomous drone with a range of approximately 30 miles.[27] Today, a factory with 1,000 Carbon3D printers could print 100,000 such drone bodies daily. The limitation is now the assembly and shipment of the finished products. Both processes can be automated with robots.

Launching thousands of drones will be challenging, but by using standard shipping containers set up like multiple-launch rocket systems, numerous drones can be moved and employed quickly. Sheer numbers will overwhelm any current antiair system.

Small states and insurgents are not only operating but also manufacturing military drones. Azerbaijan builds a licensed version of Israel's Orbiter 1K.[28] In 2016, the Polish army contracted to buy 1,000 Polish-manufactured combat drones annually at a price of about $7,000 each.[29] They have high-explosive, high-explosive anti-tank, and fuel-air explosive (also known as thermobaric) warheads.

Small Warheads Technology

As of 2020, design is clearly mastering the first two challenges to drone swarms: autonomous navigation and target identification. The last challenge—the payload limitation of small drones—can be overcome by three separate approaches. The first and least technically challenging approach is "bringing the detonator." The second approach, the use of explosively formed penetrators (EFPs) as warheads, requires more technical expertise. The third approach uses swarms and counts on the cumulative damage of dozens of small warheads to accomplish the mission.

"Bringing the detonator" uses the drone to deliver a small initiating charge to the much larger supply of explosive material provided by thin-skinned targets such as ammunition dumps, parked aircraft, fuel trucks, or rocket launchers. A few ounces of explosives delivered to the right point on these targets will initiate secondary explosions that completely destroy them. Russian separatists have repeatedly used small drones to drop simple thermite grenades on Ukrainian ammunition dumps. The resulting secondary explosions have destroyed hundreds of thousands of *tons* of ammunition.[30]

To penetrate nonexplosive targets such as supply trucks or light armored vehicles, one can use the second approach, EFPs. A properly built thumb-sized EFP weighing only 3 ounces can penetrate up to one-half inch of steel. Increasing the size of the EFP to only a few pounds allows it to destroy even well-armored vehicles.

The combination of drones, AI, and advanced manufacturing means there could be thousands of mobile, smart, active hunters spread widely over tomorrow's battlespaces.

Space

Even as governments and large firms squeeze more capability out of expensive satellites, cube satellites—or CubeSats—measuring about 4 inches on a side are creating cheaper alternatives.[31] Costing under $125,000, CubeSats are key to a new industry that sells space as a service. Using a network of CubeSats, Planet, a commercial venture, has achieved the elusive goal of taking a medium-resolution photo of every place on Earth every day.[32] Viasat is building a network that will allow customers to view images and video from the ever-increasing network of observation satellites in near real time.[33]

Major powers have lost their monopoly on the use of space. "Cheap space" means that in an era of disruptive technologies and Great Power competition, all military planners must assume almost any enemy can see their forces whenever they are moving.

Hypersonic Weapons

Hypersonic weapons, also known as hypervelocity weapons, travel between 5 and 25 times the speed of sound.[34] There are three distinct approaches to achieving hypersonic weapons—boost-glide rockets, cruise missiles, and artillery projectiles. Each approach is rapidly maturing and will dramatically change the character of conflict. Most are not projected to be operational in large numbers within the next 5 years.

Boost-glide rocket systems require a ballistic missile to attain speed and altitude before they maneuver in the manner that gives them their name. When operational, they will provide maneuverable, long-range precision with devastating destructive power.[35] Both Russia and China seem to be developing boost-glide as strategic weapons with a focus on carrying nuclear warheads. The United States hopes to have a boost-glide system operational by 2028.[36]

In contrast, hypersonic cruise missiles have the potential to be much cheaper and launched by a variety of ground, sea, and air platforms but are much smaller and have limited range. China's DF-17 hypersonic glide vehicle will have a range of about 1,200 miles and is nearing operational readiness.[37] Russia's Tsirkon hypersonic cruise missile, with a range of 250 to 600 miles against land and sea targets, will be operational by 2023. It can be fired by surface ships and submarines.[38] The U.S. Air Force is working on the AGM-183 air-launched rapid-response weapon, and the U.S. Army is developing a long-range hypersonic weapon that it plans to transition to a program of record in 2024.[39] Both provide specific threats to fixed facilities such as airfields and seaports.

The final technology, hypersonic artillery shells, is cheaper but with much less range—currently only about 50 miles.[40] The U.S. Army has set a goal of an artillery piece with a 1,000-mile range but has no projected date for fielding such a system.[41]

In sum, these advances in nanotechnology—drones, AI, swarms, space, and hypersonics—will revolutionize combat in all domains of warfare in the emerging era of Great Power competition and change the tactical and operational context of future conflicts.

Tactical Impact

The ascent of small, smart, cheap technologies will have major tactical impacts on each individual domain of combat: ground, sea, air, space, cyber, and electromagnetic—and more importantly on cross-domain operations.

Ground

When we combine simple drones, additive manufacturing, autonomous navigation, and target identification, ground forces may face thousands or even tens of thousands of autonomous aerial drones. Furthermore, if packaged in standard commercial containers or trucks for movement within the battlespace, they will be difficult to identify or preempt.

Combined with mines, GRAMM (guided rockets, artillery, mortars, and missiles) fires, and other precision weapons, the emerging family of drones can create a deep zone denied to movement by either side.

Today, ground forces are in the first stage of the historically demonstrated process where a new technology starts out assisting the old. Then, as the technology improves, it becomes a partner until it finally replaces the old system (assistant-to-partner-to-replacement process). Ground forces are working out how to employ weapons to assist their current forces in combat. However, with the rapid improvements in cruise missiles and drones, division commanders may soon control weapons with a 1,000-mile range and be full partners with manned aircraft. Moreover, joint doctrine will have to adjust if ground forces must soon control weapons that exceed the range of fighter bombers.

The final step—replacement—will require careful consideration of which combat functions can be allocated to autonomous drones. The AI limitations of such autonomous systems indicate they will be better at conventional conflict than unconventional, where determining human intention is much more challenging. This area requires extensive wargaming, computer simulation, field experiments, and air-ground coordination.

Sea

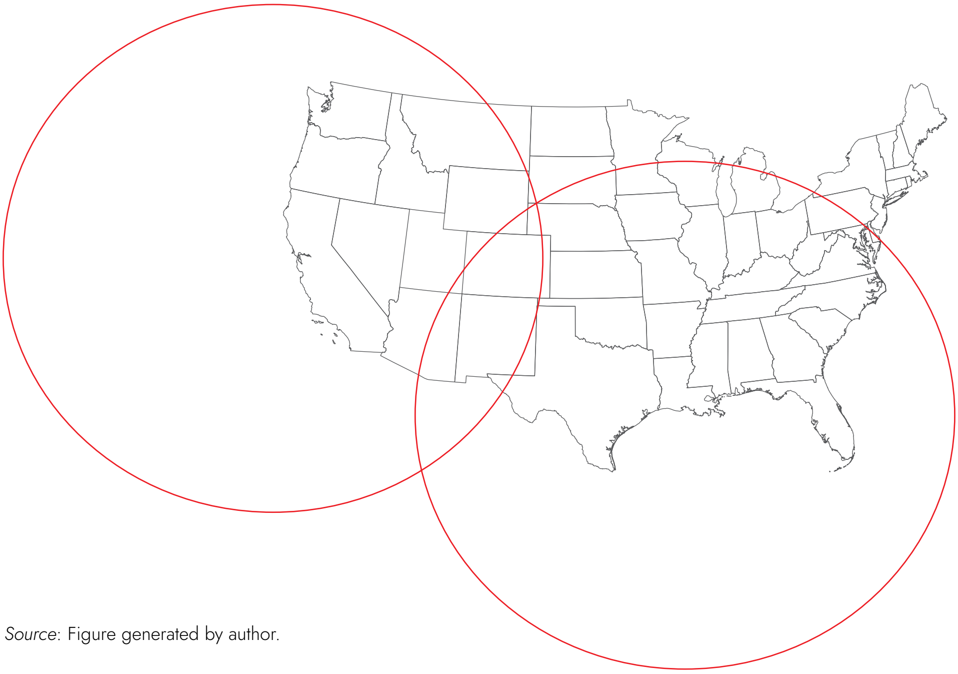
At sea, it will soon be possible to pit numerous relatively cheap drones as well as cruise and ballistic missiles against the few but exquisite platforms of the U.S. Navy. Studies by the Navy's assessment division indicate that in naval combat the first salvo wins.[42] Although winning the first salvo wins the battle against another conventional fleet, it is less applicable for a fleet fighting a land-based force. The ground force can hide, creating no signature until it fires. In contrast, ships and aircraft create signatures merely by moving.

Russia, China, and Israel have already produced containerized cruise missiles, which can provide various platforms with ship-killing weapons. Container ships could be converted to warships by the addition of 40 to 50 containerized weapons and a simple command and control system for about $125 million, or a fraction of the purchase price of a Navy littoral combat ship (LCS). Unlike the LCS, container ships are well built due to the requirement to resist hogging and sagging of their long hulls in heavy seas. In short, they could be a survivable and cheaper class of ship and could add numerous missiles to a fleet.

In addition to increasingly capable cruise missiles, VTOL drones such as the XQ-58A described earlier in this chapter mean almost any seagoing vessel can be a small aircraft carrier. Drones do not have to carry weapons large enough to sink a ship to achieve a mission kill. A drone detonating against an aircraft on the deck of a carrier or firing a fragmentation charge against a phased array radar will significantly degrade that platform's capabilities. In addition, many warships carry weapons in box launchers topside. These provide easily identifiable target points and great potential for secondary explosions. Aircraft carriers may well be the most vulnerable. The USS *Oriskany*, USS *Forrestal*, and USS *Enterprise* fires all demonstrate that a small explosion on a deck full of armed, fueled aircraft can result in a carrier being put out of action for weeks to months.[43]

Undersea weapons pose an even greater challenge to navies. The wide array of commercial unmanned underwater vehicles may provide even small nations with a submarine force. If developed as weapons systems, commercial UUVs could dramatically change naval

Figure 5.1. Kalibr Cruise Missile Ranges if Launched from West or Gulf Coasts



Source: Figure generated by author.

combat; the skills and organization needed to build and employ a short-range UUV force are orders of magnitude less than those needed for a submarine force.

While currently unable to intercept ships under way, UUVs can serve as self-deploying smart mines. With the right fuze, they could wait for a specific class of ship—commercial or military—before attacking. Although these systems cannot stop trade, damaging a few ships will cause major increases in maritime insurance rates. To date, no nation is capable of rapidly clearing smart mines with a high degree of confidence. Clearly, mines provide another major advantage to the defense.

The arrival of numerous relatively cheap, autonomous drones and cruise missiles will drastically change war at sea in the emerging era of Great Power competition. To adapt, navies must conduct rigorous and ruthless wargames to examine how a near-peer competitor will use many small, smart, and cheap weapons as well as a limited number of hypersonic missiles to destroy the few and exquisite platforms most navies currently deploy.

Air

Small, smart, cheap new technologies present two enormous challenges to aviators: how to protect critical high-demand, low-density assets and how to protect aircraft at their bed-down sites.

Clearly, China sees U.S. enablers—Airborne Warning and Control Systems aircraft and aerial tankers—as a critical vulnerability and have dedicated major resources to crippling American airpower by defeating enablers with long-range, air-to-air missiles. Beijing is working hard to extend its cruise and ballistic missile ranges to force the United States to base its enablers and fighters so far from China's shore that they are no longer a threat. In 2018, China announced the activation of a brigade of 22 DF-26 missile launchers that can range U.S. bases on Guam.[44] Prudent planners must also assume China will experiment with antiaircraft missiles in shipping containers. Mounted on various commercial ships, these could ambush tankers en route to the fight. Another way China seeks to reduce the effectiveness of and perhaps even defeat America's advanced aircraft like the B-21 is to destroy them on the ground. Or, as figure 5.1 shows, Chinese ship-based *Kalibr*-class cruise missiles can range almost all U.S. tanker and bomber bases from launch positions off the coasts of the United States. Without tanker support, manned aircraft are rendered impotent in the Pacific.

Fortunately, destroying air bases will not affect mobile, vertical launch drones, which can hide easily in urban or most rural terrain. These drones can also almost turn any oceangoing vessel into an aircraft carrier—particularly if they are employed as suicide drones and the ship does not have to be around for recovery. Small ships will carry only a few containers, but it is important to remember that 18 Harpy drones fit in a single 20-foot container. Each Harpy can carry a 55-pound payload to a range of 600 miles—and hunt autonomously in visual, infrared, and electromagnetic spectrums. From mainland China, these drones can reach Kadena Air Force Base in Okinawa, Japan. A Chinese battery could launch 54 Harpies while a battalion could launch 162. Thus, the sheer number of drones could overwhelm defensive systems.

The combination of cheap drones and much more capable cruise missiles offers opportunities to overcome legacy, manned airpower's key vulnerabilities. But it also may offer even small- and medium-sized states antiaccess/area-denial and precision, long-range strike capabilities. Airpower is facing enormous change. Relatively cheap, autonomous drones and somewhat more expensive but more capable cruise and ballistic missiles and potentially hypersonic missiles are rendering manned aircraft obsolete. The United States does not currently have a way to defend airbases against this new generation of weapons. Aircraft carriers, although tougher targets, are also under increasing threat. Nor can current or envisioned systems find and attack these mobile systems to preempt them. Airmen must embrace drones and work rapidly to transition them from their current status as partners for manned aircraft to that of replacements.

Space

In space, the advent of micro- and cube satellites, paired with commercial launch platforms, will provide space surveillance and even make attack from space a possibility. In April 2020, the Northrup Grumman Mission Extension Vehicle successfully docked with Intelsat 901 and serviced it in orbit.[45] The system could be used to destroy as well as repair. Whether space assets will be used to attack targets on Earth remains an open question.

Because China has demonstrated the ability to use both kinetic and soft kill on satellites, we should assume the United States is developing similar capabilities.[46] This evinces a clear understanding that any major conflict will involve fighting in space to defend one's own assets. Resilience is also required. A combination of small satellites, long-endurance solar-powered drones, and perhaps even balloons can mitigate the loss of current space assets and is being actively explored by the United States. It is good news that the U.S. Air Force is shifting the emphasis of U.S. Space Command from that of a service provider to that of a warfighting command.[47]

Cyber

Cyber operators have enjoyed enormous success in stealing data and money but much more varied results in attempts at physical damage. China has been at the forefront of cyber espionage and focused its teams "on the satellite, aerospace, and communications sectors."[48] The Snowden files confirmed that China had penetrated Lockheed Martin's top-secret data on the F-35.[49] There is no question that many nations continue to pursue cyber espionage. Even the most advanced cyber actors that have attempted it (Russia, Israel, and the United States) have achieved relatively modest physical destruction outcomes despite often months or even years of intensive efforts.[50] Perhaps the only reassuring aspect of the increasing state-sponsored cyber activity is that it may be reducing the chance of a major surprise. Historically, devastating surprise attacks have usually taken place after a long period of peace when new operational concepts clash for the first time.

In contrast, cyber warfare is constant, global, ongoing, and evolving. The many sides in these cyber contests are constantly sharpening both offensive and defensive skills and testing them against each other. In addition, cyber attacks focused on societies are, by definition, attacking complex adaptive systems. These systems show remarkable resilience and power of recovery. The ongoing conflict in cyber space will accelerate as the fourth industrial revolution continues. However, it is virtually impossible to predict if a specific attack will succeed or how long it will remain effective.

One aspect not normally discussed is the potential for physical attacks on an enemy's cyber capability. All networks have nodes in the real world. For instance, satellite downlinks, servers, and fiber-optic networks are vulnerable. Furthermore, unlike cyber attacks that have great uncertainty, physical attacks on known locations can cause more predictable major damage to an opponent's cyber networks. It is also easier to coordinate real-world attacks than to mix cyber and real-world attacks. This is an area ripe for cross-domain exploitation.

Electromagnetic

Use of the electromagnetic (EM) spectrum is essential to conduct warfare in every other domain. If a force can dominate the spectrum, it can severely limit or even defeat an enemy's efforts in land, sea, air, space, and cyber. With proper and constant training, naval and air forces can operate in emission-controlled environments, but such a posture severely degrades their capabilities. Land forces can fight without communications, but unless well trained and practiced in maneuver warfare, the result is a series of disconnected local engagements. If an enemy truly dominates the EM spectrum, it can make it difficult for an adversary to communicate with space assets. Also, cyber systems often rely on EM communications links that could be subject to jamming, degradation, or deception.

Although the United States has not yet officially recognized the EM spectrum as a domain of war, China has made it a key element of its newly organized Strategic Support Force (SSF). The SSF not only integrates space, cyber, information, and electronic warfare

(EW) in support of Chinese operations, but also directs advanced research in EW.[51] For its part, Russia has dedicated millions of dollars to upgrading its EW capabilities. As a result, Moscow has been able to use EW to damage or destroy Ukrainian command networks; jam radios, radars, and GPS signals; and control fires.[52] Clearly both China and Russia have assigned high priority to operating in this environment.

Miniaturization of electronics, massive increases in computer power, creation of electromagnetic pulse systems, and improved sensors are driving the EM spectrum to be a key area of high-tech competition—one that may well determine the outcome of future engagements. The vulnerability of current communications systems provides great impetus to develop truly autonomous, sealed weapons systems.

Operational Implications

Technological convergence is driving the "democratization" of military power by providing small states—and even groups—capabilities that used to be the preserve of major powers. Five factors will have a direct impact on the operational level of war: range obsolescence, the loss of immunity to attack, the tactical dominance of defense, the return of mass, and the requirement to mobilize.

Range Obsolescence

As discussed, missiles and drones have three major advantages over manned aircraft—range, basing flexibility, and cost. An increasing number of drones and ballistic and cruise missiles outrange all fighter bombers. Because many are truck mobile, they are extremely difficult to suppress, much less destroy. Moreover, they are forcing U.S. warfighters to be based so far from the frontlines that the fighters are effectively neutralized. Finally, they are relatively cheap (see figure 5.2).

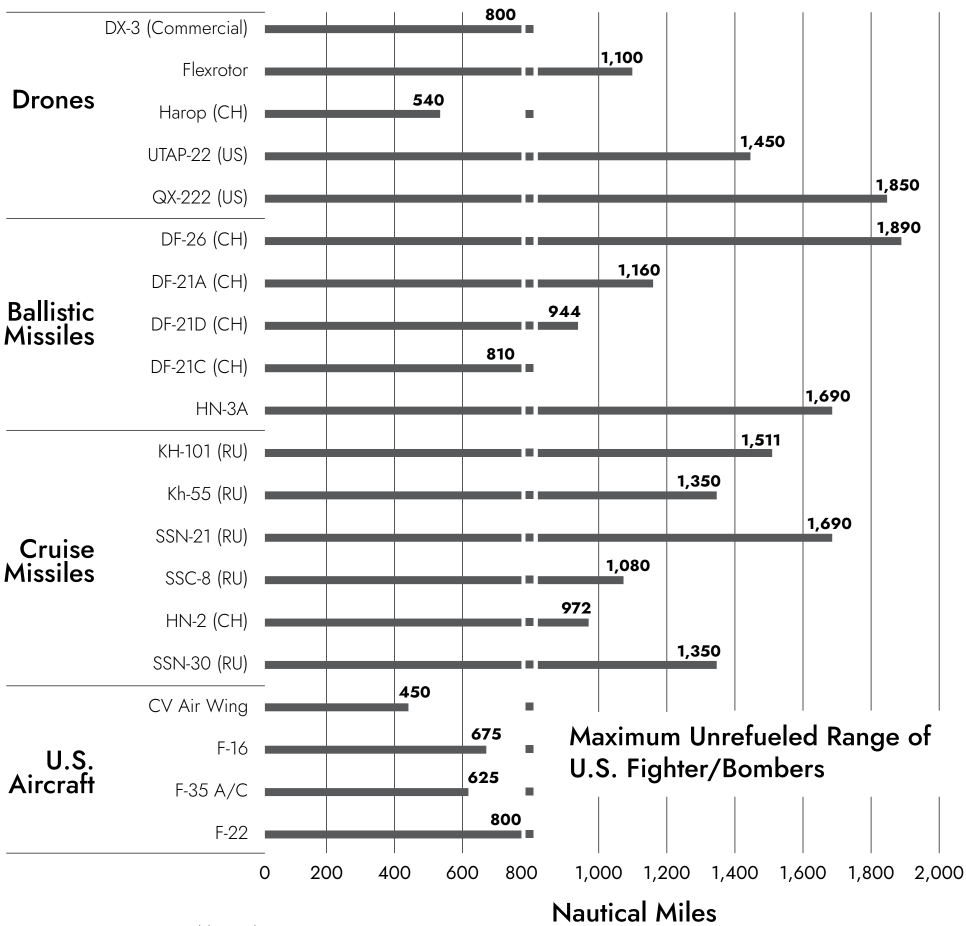
Loss of Immunity to Attack

Long-range drones, containerized weapons on commercial ships, sea mines, and submersible drones will provide small states and even nonstate actors the capability to strike air and sea ports globally. The United States will no longer project power anywhere in the world with impunity. Future enemies will be able to impose real costs that directly affect U.S. citizens, and they may not be shy about employing these weapons. Small states and nonstate actors have shown cyber capabilities that have distinctly reduced U.S. immunity to counterattack when America gets involved in a conflict overseas.

Internationally, attacks on Saudi oil facilities and U.S. facilities on Iraqi bases have demonstrated major increases in opponents' abilities to threaten intermediate bases. If threatened, would friendly nations allow U.S. forces to use their transit facilities? Can the United States protect commercial airfields, key government facilities, and key economic assets in host countries to ensure continued access?

Small precision weapons also provide opportunities for state sponsors to vastly improve the capabilities of proxies, as demonstrated by the Yeminis firing cruise missiles at U.S. warships.[53] Of more immediate concern will be the far larger number of weapons that can hit critical operational support bases such as Bagram, Afghanistan. Even if the United States can protect major fixed bases, can it defend all patrol bases, gatherings of local leaders, and

Figure 5.2. Range of Missiles, Drones, and Aircraft in Nautical Miles



Source: Figure generated by author.

host-nation facilities essential to current U.S. operations? Even more challenging than protecting fixed facilities will be defending the convoys that move personnel, equipment, and supplies within the theater.

Tactical Dominance of Defense

Emerging autonomous systems will provide an inherent advantage to defenders because they do not have to generate any active signature until they choose to fire. Finding a defender's system hidden in urban clutter, underground facilities, or even the complex littoral environment is much harder than finding the aggressor's system as it moves to attack—particularly if it moves in the air or on the sea.

This is a major advantage of the United States and its allies because we are on the operational defensive in both Asia and Europe. If the United States chooses to create a new generation of inexpensive, smart weapons, it can share them with its allies. Japan, South Korea, Australia, and Europe all have defense industries that could produce these weapons to provide their nations with affordable, effective defensive capabilities against either China or Russia. In addition, the United States could provide these systems to smaller allies like those on the First Island Chain and the Nordic and Baltic countries. With allies adopting these systems, U.S. forces could integrate more effectively into the defense of these nations. This ability could significantly improve the capabilities of U.S. contact and blunt layers (as described in the National Defense Strategy) while making it easier for the surge forces to enter the theater.[54]

The proliferation of precision weapons may create a situation similar to World War I, where any person in range above the ground could be cheaply killed. The result was static, trench warfare. Able to reach out 1,000 miles in the surface, subsurface, and air domains, these drones and cruise and ballistic missiles may again make defense the tactically dominant form of warfare. Power projection may be limited to strike operations using a family of drones and cruise and hypervelocity missiles.

Proponents of directed energy weapons (DEW)—lasers and microwave systems—suggest their systems will defeat such drone and missile swarms and thus return offense to the tactical battlefield. Unfortunately, these systems are still expensive and power hungry, ineffective under some environmental conditions, and may be subject to defeat by relatively inexpensive countermeasures. At the same time, DEW will favor defenders who have the huge advantage of fixed-power facilities and the ability to blend into complex terrain.

If DEW systems ever become capable of defeating thousands of drones, they may also be able to defeat the much fewer conventional aircraft, guided bombs, and missiles the United States can deploy. This ability would reinforce the dominance of the defense. A key question that must be explored is whether land power—by taking advantage of complex terrain, unlimited magazines, massive power networks, and the ever-increasing range and speed of land-based weapons—will come to dominate the sea, air, and space domains.

Return of Mass

As noted at the beginning of this chapter, technological convergence means that mass with precision has arrived. Additive manufacturing will make numerous cheap drones and advanced GRAMM systems available. Sheer numbers of cheap, mass-produced, unmanned precision weapons may simply overwhelm the exceptionally capable but manned U.S. legacy weapons systems. Large numbers of relatively inexpensive precision weapons will defeat the current U.S. inventory of exquisite but few systems. In response, the Pentagon must figure out how to produce precision weapons in mass.

Requirement to Mobilize

Mobilization in World War II was possible because civilian industry could rapidly convert to military production. By 1990, the complexity of modern military weapons systems made rapid mobilization difficult if not impossible.[55] Advanced manufacturing—particularly 3D printing and robotics guided by task-specific AI—may radically change this situation. 3D printing is inherently flexible because the product produced depends only on the materials the printer can use, the design of the printer, and the software that is loaded. With a change of software, 3D printers can go from producing commercial products to producing weapons. Thus, as 3D printing assumes a greater role in industry, the possibility of industrial mobilization will reemerge. However, successful mobilization cannot be accomplished quickly without a significant planning effort. The Pentagon must be prepared to provide the computer files for the 3D printers as well as produce the required government-furnished equipment. The Pentagon must also be prepared to enlist and train new personnel, build them into coherent units, and then move those units and the weapons to an overseas battlefield. Unfortunately, the Pentagon has only recently begun to think about these issues.[56]

Cumulative Impact on Military Operations

The convergence of technology over the next 10 to 20 years means everyone—even nonstate actors—will have precision strike capabilities. Nations with access to as few as 100 3D printers could have access to thousands of precision drones. By pairing these drones with passive sensors, defenders will not have to emit any signal until they choose to fire. In contrast, attackers must create a signal when moving to the target area. Thus, defenders will choose when to initiate the fight and will be able to do so with a massive barrage of precision weapons. In short, a prepared defense will be able to create tactical dominance.

Unfortunately, because of the huge physical and electronic signature of major military bases, they will prove the exception to the dominance of the defense. Rapidly improving inexpensive drones can reach 500 miles today. Relatively inexpensive cruise missiles reach 1,000 miles or more. Both can be deployed on platforms that will offer new opportunities for surprise mass attacks on U.S. bases at home and overseas.

The combination of these factors means that states and nonstates will be able to impose significant casualties and even economic damage to opponents who try to land ground forces in their home territories. In human and financial terms, intervention will be much more costly in the future than it is today.

Impact on Great Power Competition and Conflict

The technologies of the fourth industrial revolution will not change the fundamental nature of war. It will still be driven by Carl von Clausewitz's primary trinity of passion, chance, and reason. It will remain the domain of fog, friction, and uncertainty. Technology will not bring clarity or brevity. For millennia, political and military leaders have embarked on wars where they thought they understood the situation and could win a short and decisive war—and subsequently paid the price for ignoring the true nature of war.[57]

In the conventional arena, the revolution of small, smart, and cheap favors the United States over China or Russia. Operationally and tactically, the United States is on the defensive in both Eastern Europe and Asia.

China is obviously the most serious military challenge. Its rapid buildup of conventional forces, fundamental reorganization to improve jointness, and intensive development of "system attack and destruction warfare" directly challenges U.S. doctrine for force projection.[58] In response, the Department of Defense is working on a joint warfighting concept to meet these new challenges. While still a work in progress, the emergence of small, smart, and cheap technologies can do much to neutralize China's ongoing investments in system attack.

By adopting mobile missile systems, VTOL drones, missile merchants, and smart mines, U.S. forces could move from dependence on large, fixed, easily targeted bases and platforms to systems that can disperse and hide throughout the First Island Chain as part of both the contact and blunt layers noted in the National Defense Strategy.[59] This would greatly strengthen the American strategy that is based on defending the First Island Chain, denying China use of the seas inside the First Island Chain, and dominating the seas outside that chain.

As noted, the relatively low cost and simplicity of these systems mean the United States can share production of these weapons with Australia, Japan, Singapore, and South Korea. The United States can also share them with the Philippines and Indonesia to provide these nations with weapons that can challenge Chinese forces. Forward basing or rotating similarly equipped U.S. forces to train with these allies will reinforce political aspects of the alliances even as it strengthens their military power.

In Europe, the fundamental challenge for the North Atlantic Treaty Organization (NATO) is to prevent Russia from seizing territory before the Alliance can mobilize and respond. The concern is that once Russia seizes territory, it will "escalate to deescalate" by threatening to use tactical nuclear weapons against any forces moving to eject Russian forces. Given the reluctance of the population of NATO member states to engage in conflict with Russia, it is uncertain if many states will fight even if not threatened by nuclear weapons.[60] If Russia threatens the use of nuclear weapons, the probability of NATO action will decrease significantly. Given the long mobilization and deployment times of Alliance forces, the only way to prevent this outcome is to prevent Russia from seizing the territory in the first place.

By equipping front-line states with a mix of inexpensive drones and improvised explosive devices, NATO could create a tough, quickly mobilized, and deep defense on its borders. If NATO states invest heavily in autonomous drones and cruise missiles, they could provide supporting fires in a matter of hours rather than the weeks or months currently envisioned.[61]

The Changing Character of War

In contrast to the unchanging nature of war, the character of war—how it is fought—has changed continually. Despite America's love of technology, how people fight wars will remain based more on the political, economic, and social aspects of their societies than the technology involved. Historically, each society's employment of new technology has been heavily shaped by these same aspects. For over 200 years, Swiss pikemen dominated the battlefields of Europe. There was no technological mystery to making or even using pikes, but only the Swiss had the necessary social cohesiveness and trust to fight in tight formations under elected leaders. The hierarchical political entities of Europe could not.

Each society will use the emerging technologies in ways best suited to its unique needs. Furthermore, conflict will not be based solely on those aspects of one society but the interactions of all the societies in the conflict. In the dawning era of Great Power competition, wars are likely to be bloodier, longer, and more financially ruinous. Fortunately, the emergence and convergence of fourth industrial revolution technologies provide real advantages for the United States—if it can seize them.

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