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Technologies Converge and Power Diffuses

The Evolution of Small, Smart, and Cheap Weapons

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EXECUTIVE SUMMARY

Dramatic improvements in robotics, artificial intelligence, additive manufacturing (also known as 3D printing), and nanoenergetics are dramatically changing the character of conflict in all domains. The convergence of these new and improving technologies is creating a massive increase in capabilities available to smaller and smaller political entities—extending even to the individual. This increase provides smaller powers with capabilities that used to be the preserve of major powers. Moreover, these small, smart, and cheap weapons based on land, sea, or air may be able to dominate combat.

This new diffusion of power has major implications for the conduct of warfare and national strategy. Because even massive investment in mature technology leads to only incremental improvement in capabilities, the proliferation of many small and smart weapons may simply overwhelm a few exceptionally capable and complex systems. The advances may force the United States to rethink its procurement plans, force structure, and force posture. The diffusion of power will also greatly complicate U.S. responses to various crises, reduce its ability to influence events with military force, and should require policymakers and military planners to thoughtfully consider future policies and strategy.

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INTRODUCTION

Dramatic improvements in robotics, artificial intelligence, materials, additive manufacturing (also known as 3D printing), and nanoenergetics are dramatically changing the character of conflict in all domains. The convergence of these ever-improving technologies is creating a massive increase in capabilities available to smaller and smaller political entities—extending even to the individual. This paper discusses how the new diffusion of power has major implications for the conduct of warfare and national strategy as well as force structure and procurement. It cannot begin to explore the explosion of all the new technologies that are daily changing our lives, but it will take a look at a few that will have short-term impacts on how wars are fought.

Fortunately, the current level of technological change and its application to defense strategy is not unprecedented. History reveals both opportunities seized and resources wasted. From 1914 to 1939, there were technological breakthroughs in metallurgy, explosives, steam turbines, internal combustion engines, radio, radar, and weapons. At the beginning of World War I, battleships were considered the decisive weapon for fleet engagements and a reasonable measure of a navy's strength. The war's single major fleet action, the Battle of Jutland, seemed to prove these ideas correct. Accordingly, during the interwar period, battleships received the lion's share of naval investments. Navies took advantage of rapid technological gains to dramatically improve their capabilities. The displacement (i.e., weight) of a battleship almost tripled, from the 27,000 tons of the pre–World War I U.S. *New York* class to the 71,660 tons of Japan's *Yamato* class. The largest main batteries grew from 14-inch to 18-inch guns with double the range. Secondary batteries were improved, radar was installed, speed was increased by 50 percent, cruising range was more than doubled, and armor was thickened.[1] Yet none of these advances changed the fundamental capabilities of the battleship—they simply provided incremental improvement on existing strengths. This is typical of mature technology—even massive investment leads to only incremental improvement.

In contrast, aviation was in its infancy in 1914. Aircraft were slow, had limited range, were lightly armed, and were used primarily for reconnaissance. Air combat was primitive—one early attempt to fight in mid-air involved a grappling hook! Military aviation made great strides in tactics, technology, and operational concepts during World War I. Yet, after the war, aviation—particularly naval aviation—remained an auxiliary force. Aircraft supplemented, and were subsidiary to, ships at sea and armies on land, and were funded accordingly. The U.S. and British governments focused most of even this limited investment on heavy bombers. Despite this neglect, by 1941 carrier aviation in the form of fighters, dive bombers, and torpedo bombers dominated Pacific naval warfare. Most of the advances in aircraft design and production that eventually applied to naval aviation were initially developed for civilian uses. Aircraft production, a highly competitive business, led the rapid technological advances. Relatively modest investment in these new technologies resulted in massive increases in aircraft capability. As a result, aircraft—the small, smart, and many weapons of World War II's naval forces—were able to swarm and destroy the few and exquisite battleships. By mid-1942, the battleships were reduced to near irrelevance, serving only as expensive anti-aircraft and naval gunfire platforms.[2]

However, the transition from battleships to carrier aviation took almost 20 years. Thus, the early investment in battleships was correct. Modern militaries' failure to adapt more swiftly lay in not understanding when the character of naval warfare changed and naval aviation capabilities exceeded those of the battle line. Interestingly, the industrial democracies invested relatively little in submarines, the other powerful newcomer to the naval battle. Submarines progressed from deadly but fragile in World War I to a weapon system that almost defeated Britain and did destroy Japanese industry in World War II. Institutional biases can keep investment focused on the dominant technology even as multiple emergent technologies clearly challenge it.

EVOLVING TECHNOLOGIES

As noted in the introduction, we are currently in an area of rapidly evolving technologies that, when combined, may radically alter the way we fight. This section considers how a few of the new technologies that are already changing our lives will also impact how wars are fought: additive manufacturing, nanomaterials and energetics, near-space systems that provide space-like capabilities, artificial intelligence, and drones.

Additive Manufacturing

In the last few years, additive manufacturing, also known as 3D printing, has gone from an interesting hobby to an industry producing a wide range of products from an ever-growing list of materials. The global explosion of additive manufacturing means it is virtually impossible to provide an up-to-date list of materials that can be printed, but a recent top-10 list includes metals, such as stainless steel, bronze, gold, nickel steel, aluminum, and titanium; carbon fiber and nanotubes; stem cells; ceramics; and food.[3] In addition to a wide range of materials, additive manufacturing has gone from being able to make only a few prototypes to being able to produce products in large quantities. For example, United Parcel Service (UPS) has established a factory with a hundred 3D printers. It accepts orders, prices them, prints them, and ships them the same day from the adjacent UPS shipping facility. And UPS plans to increase the plant to 1,000 printers to support major production runs.[4]

At the same time, additive manufacturing is dramatically increasing the complexity of objects it can produce while simultaneously improving speed and precision. Recent technological developments suggest that industry will be able to increase 3D printing speeds by a factor of a hundred, with a goal of a thousand-fold increase.[5] How long that increase will take is uncertain, but Joseph DiSimone, who has achieved the hundred-fold increase, only founded his firm Carbon 3D in 2013.

In addition to increasing production speed, new techniques are providing higher quality products than current methods. In January 2015, the 3D electronic printing company Voxel8 revealed a new printer ($8,999) that printed a complete operational drone with electronics and engine included.[6] In February 2015, Australian researchers printed a jet engine.[7] Further, with additive manufacturing material wastage is near zero—thus it may be cheaper to make a part from titanium using this technology than it would be to make it from steel using traditional machining. Only two decades old, additive manufacturing is starting to encroach on a wide range of traditional manufacturing.

Nanotechnology

Nanotechnology is another field that is advancing rapidly in many areas. Two are of particular interest with respect to national security. The first is nanoenergetics, or explosives. As early as 2002, nanoexplosives generated twice the power of conventional explosives.[8] Since research in this field is tightly guarded, it is difficult to say what, if any, progress has been made since that point. But even if two times is as good as it gets, a 100 percent increase in destructive power for the same size weapon is massive. Much smaller platforms will carry greater destructive power.

The second area of interest is that of nanomaterials. This field has not advanced as far as nanoenergetics, but the potential for carbon nanotubes to dramatically reduce the weight needed for structural strength, for example, will have significant implications for increasing the range of all electrically powered vehicles. In a related field, numerous firms are applying nanomaterials to batteries and increasing their storage capacity.[9] In fact, a recent accidental discovery may triple battery power storage and increase battery life by a factor of four.[10] At the University of California–San Diego, researchers have found a cheap way to coat products with a super-thin, nonmetallic material that manipulates radar waves.[11] These improvements in energy storage, materials, and explosives will lead to increases in range, payload, and stealth for a wide variety of vehicles, including cheap drones.

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Space and Space-Like Capabilities

The wide availability of cheap, persistent surveillance operating both in space and at very high altitudes will provide the information necessary to employ these new technologies. In space, several companies are deploying cube satellites.[12] Google's Skybox Imaging aims to market a service that provides imagery with one-meter resolution, along with interpretation of the photos. The site under surveillance can be revisited several times a day.[13] A buyer could track port, airfield, road, and rail system activity in near real time. Initially Skybox and other cube-sat companies achieved low-cost launches by serving as ballast on larger rockets. Today, New Zealand's Rocket Lab is proposing to conduct weekly launches specifically for cube satellites to allow for frequent, inexpensive launches. Although Rocket Lab has not yet opened its space port, numerous firms have signed up for its launch services.[14]

Other firms are working on systems that can duplicate the communications and surveillance functions provided by satellites using systems that operate in the earth's atmosphere. Google's Project Loon is attempting to provide reliable, cost-effective Internet services for much of the Southern Hemisphere by deploying a constellation of balloons that will drift in the stratosphere and beam signals down to earth, providing coverage where cell towers don't reach.[15] High Altitude Long-Endurance drones are another avenue to satellite-like capabilities without the satellite. The U.S. Air Force has successfully tested Global Observer, a high endurance unmanned aerial vehicle (UAV), to conduct surveillance and intelligence operations.[16] For very long endurance, several organizations are pursuing solar-powered drones.[17] The British Ministry of Defense is studying the Zephyr 8, a solar-powered drone that can fly at altitudes up to 70,000 feet, to provide surveillance and communications at a fraction of the cost of current satellites.[18]

Artificial Intelligence

Two areas of artificial intelligence are of particular importance in the evolution of small, smart, and cheap weapons—navigation and target identification. The Global Positioning System (GPS) has proven satisfactory for basic autonomous drone applications such as the Marine Corps' K-MAX cargo-hauling drone in Afghanistan.[19] However, GPS will continue to be insufficient for operations in narrow outdoor or indoor environments, dense urban areas, and areas where GPS is jammed. Academic[20] and commercial[21] institutions are working to overcome the limitations of GPS to provide truly autonomous navigation for drones. Inertial and visual navigation are advancing rapidly and are already affordable enough to use in small agricultural drones.[22] Clearly commercial applications for navigating in agricultural areas and inspecting buildings in urban areas can be adapted for military uses. Such systems would serve to get a drone to the target area, but would not ensure it could hit a specific target. Today, artificial intelligence (AI) can in fact identify a distinct object—such as an aircraft or fuel truck—using on-board multi-spectral imaging.[23] In short, the artificial intelligence necessary for many types of autonomous drone operations currently exists—and is operating aboard small commercial drones. Hobby-drone manufacturer Parrot is now selling software for $20 that makes its Bebop drone autonomous.[24] The University of Pennsylvania has developed a quadcopter that "uses a smartphone for autonomous flight, employing only on-board hardware and vision algorithms—no GPS involved."[25]

Artificial intelligence is the development that makes the convergence of material, energetics, drones, and additive manufacturing such a dangerous threat. It is advancing at such a rapid rate that over 1,000 distinguished researchers signed an open letter seeking to ban autonomous weapons. They stated "the deployment of such systems is—practically if not legally—feasible within years, not decades."[26] It is the autonomy that makes the technological convergence a threat today. Because such drones will require no external input other than the signatures of the designated target, they will not be vulnerable to jamming. Because they will not require human intervention, autonomous platforms will be able to operate in very large numbers. They can be programmed to wait patiently prior to launch or even proceed to the area of the target but hide until a specified time or a specified target is identified.

Drones

Commercial drone capabilities have increased dramatically in the last five years and their usage has spread widely. Still, small drones can only carry a limited payload. This limitation can be overcome with two separate approaches. First is the use of explosively formed penetrators (EFPs).[27] The second, and less technically challenging approach, is to think in terms of "bringing the detonator."

Weighing as little as a few pounds, EFPs can destroy even well-armored vehicles. In Iraq, for example, coalition forces found EFPs in a wide variety of sizes—some powerful enough to destroy an Abrams tank. Others were small enough to fit in the hand—or on a small drone.[28] And nanoexplosives at least double the destructive power of the weapons. The natural marriage of improvised explosive devices (IEDs) to inexpensive, autonomous drones is inevitable.

The primary limitation on production of EFPs in Iraq was the need for high-quality shaped copper plates that form the projectile when the charge is detonated. Until recently, this was a significant challenge that required a skilled machinist with high-quality machine tools. However in the last few years, additive manufacturing has advanced to the point where it can be used to print a wide variety of materials, including copper.[29] NASA has printed a copper combustion chamber liner for a rocket motor.[30] Thus, we can expect small and medium sized drones to pack a significant punch against protected targets.

The second approach, which might be called "bringing the detonator," applies to aircraft, vehicles, fuel, chemical facilities, and ammo-dump targets. In each case, the objective is to simply detonate the large supply of explosive material provided by the target. Even a few ounces of explosives delivered directly can initiate the secondary explosion that will destroy the target.

The convergence of new technologies discussed above may allow these small, smart, and cheap weapons based on land, sea, or air to dominate combat. Anyone with a television or access to YouTube during the last decade has become very familiar with the United States' use of drones to both hunt enemies and protect U.S. and allied forces. Although numbering in the tens of thousands worldwide, these drones represent only the first wave. Like many technologies, early versions were expensive and difficult to operate, thus only the wealthy employed them. But, over time, the technology becomes cheaper, more reliable, and more widely employed. We are seeing this with the explosive growth in commercial drones. Additive manufacturing will soon make them cheap enough for small companies or even individuals to own a large swarm of simple, autonomous drones.

In fact, the U.S. Air Force is actively exploring the use of swarms—but focusing on smart swarms that communicate and interact with each other and other platforms.[31] The U.S. Navy is also pursuing swarming technology with the Low-Cost Unmanned Aerial Vehicle Swarming Technology (LOCUST)[32] as well as small craft.[33] While these programs are vague about how many drones they envision being able to employ, recent dramatic cost reductions in each of the needed technologies will increase the number by an order of magnitude. Researchers in England have prototyped a simple drone body that costs roughly $9 a copy.[34] Researchers at the University of Virginia are 3D printing much more complex drones in a single day, then adding an Android phone for guidance to produce a $2,500 autonomous drone.[35] Thus, a small factory with only a hundred 3D printers using the new printing technology noted above, and capable of producing 100 units each, could make 10,000 drones a day. The limitation is no longer the printing but the assembly and shipment of products. Both processes can be automated with industrial robots.

Nor will cheap drones be limited to the air. In 2010, Rutgers University launched an underwater "glider" drone that crossed the Atlantic Ocean unrefueled.[36] Ashore, mobile land mines

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and autonomous anti-vehicle weapons are also under development.[37] However, developing truly autonomous land drones—those that actually move on the ground—will remain the most difficult challenge simply because land is the most complex combat environment. Land drones require both much more advanced mechanical systems and artificial intelligence to operate. Thus, we can assume it will take significantly longer to field these systems.

It is one thing to have access to thousands of drones, it is quite another to have the logistics and manpower available to effectively employ them. One method that demonstrates it can be done is the Chinese system that mounts 18 Israeli-made Harpy Unmanned Combat Air Vehicles (UCAV) on a single five-ton truck.[38] With a two-person crew, the Chinese can transport, erect, and fire these fairly large drones (they have a nine-foot wingspan). Originally designed to attack radar systems, the advanced version can now loiter and autonomously hunt a variety of targets. A similar-sized truck could be configured to carry, for example, hundreds of the U.S. Switchblade[39] or Israeli Hero[40] drones.

IMPLICATIONS FOR THE MODERN BATTLEFIELD: LAND, SEA, AIR, SPACE, AND CYBER

Allied combined arms teams ensured that offense dominated the battlefields of Desert Storm and Operation Iraqi Freedom. However, the 2006 Israeli-Hezbollah Summer War showed that, under the right conditions, well-trained, determined irregulars armed with advanced anti-tank weapons could make the defense dominant. Since then, conventional ground warfare has become both deadlier and cheaper. Direct-fire gunnery systems have improved. Wire-guided and fire-and-forget missile systems are proliferating, but both are very expensive. In contrast, artillery can now provide much cheaper precision fire. The U.S. Army issued a contract in 2015 for a new fuze that makes any 155mm artillery round a precision weapon. Each fuze costs only about $10,000.[41] The Defense Advanced Research Project Agency (DARPA) is pushing the cost much lower via a smart missile with a two-thousand-meter range that can be fired from a M203 grenade launcher. Since the missile weighs only two pounds, DARPA is modifying it to fire from a drone.[42]

The next great leap may well be inexpensive drones. For much less than the price of a precision fuze, commercially available autonomous drones will provide greater range than artillery without artillery's large logistics and training tail. These drones, deployed in large numbers, will provide a particularly nasty challenge for ground forces.

Today, even relatively light forces are dependent on vehicles and helicopters for support. For over a decade, Western forces have struggled with hunting IEDs to ensure the ability to move about the battlespace. A simple explosively formed projective device mounted on a commercial drone would give an insurgent the ability to hunt targets such as vehicles, helicopters, airfields, fuel farms, and ammo dumps. Today, hobbyists can track and close with moving vehicles under conditions similar to those needed to engage a military convoy.[43] Optical recognition software would allow such a weapon to autonomously identify and engage many of those targets. When one combines simple drones with additive manufacturing, ground forces face the real possibility of confronting thousands of smart drones in wave attacks.

Sea Domain

Obviously, swarms of autonomous drones can also threaten any naval force trying to project power ashore. The drones will not need to sink a ship to achieve a mission kill. For instance, a drone detonating against an aircraft on the deck of a carrier or firing a fragmentation charge against an Aegis's phased array radar will significantly degrade that platform's capabilities. Surface combatants' self-defense systems and speed will make them difficult targets. But amphibious or cargo ships have to slow or stop to operate and thus will be much more vulnerable. And with drones achieving trans-Atlantic range already—for example, the Rutgers University experiment cited above—home ports, as well as intermediate staging areas, must now also be defended.

Undersea weapons will pose an even greater challenge to navies. In Asia, Vietnam, Japan, South Korea, and Indonesia are all upgrading their submarine forces. However, a submarine force is expensive, complex, and difficult to operate. Unmanned underwater vehicles may provide a much cheaper deterrent. This year, the U.S. Navy launched an autonomous underwater glider and plans for it to operate for five years without refueling.[44] It can patrol for weeks following initial instructions, then surface periodically to report and receive new instructions. Similar drones can be purchased around the world for about $100,000 each[45] but commercial firms are striving to reduce the cost by 90 percent.[46] If developed as weapons systems, they could dramatically change naval combat. Offensively, they could become self-deploying torpedoes or mines with trans-oceanic range. Defensively, they could be used to establish smart minefields in maritime chokepoints. They can be launched from a variety of surface and subsurface platforms or remain ashore in friendly territory until needed, and then launch from a port or even the beach. Imaginatively employed, they could be a relatively inexpensive substitute for a submarine force. For the cost of one *Virginia*-class submarine, a nation could purchase 17,500 such drones at current prices.[47] If additive manufacturing can reduce the cost of these systems by roughly the same 40 percent predicted for satellites, one could buy nearly 30,000 such drones.[48] Of more importance, the skills and organization needed to build and employ a glider are far less demanding than those needed for a nuclear submarine.

Sea mines should be a particular concern to trading nations. Mines have the distinction of being the only weapon that has denied the U.S. Navy freedom of the seas since World War II. First, mines defeated a U.S. amphibious assault—the U.S. landing at Wonson in Korea in October 1950. While U.S. forces were eventually able to clear lanes through the primitive minefields, other Allied forces attacking up the east coast of Korea had already seized the amphibious objectives before the first amphibious forces got ashore. After Wonson, Rear Admiral Doyle, Commander Amphibious Group 1, lamented that the most powerful navy in the world was stopped by weapons designed a hundred years ago delivered by ships designed two thousand years ago. Not much has changed. "In February 1991," notes Scott C. Truver in the *Naval War College Review*, "the U.S. Navy lost command of the northern Arabian Gulf to more than 1,300 mines that had been sown by Iraqi forces."[49] These were simple moored sea mines.

Mines have become progressively smarter, more discriminating, and more difficult to find. They have sensors which can use acoustic, magnetic, and other signals to attack a specific kind of ship.[50] As early as 1979, the United States fielded CAPTOR mines—encapsulated torpedoes that are anchored to the ocean floor. When they detect the designated target, they launch the torpedo, which is effective out to a range of 4.9 miles (8 km).[51] Today, China possesses self-navigating mines and even rocket-propelled mines.[52] We are now seeing early efforts to use unmanned underwater vehicles to deliver mines. Since commercially available drones are already crossing the ocean autonomously, pairing drones with mines will almost certainly make it possible to mine sea ports of debarkation and perhaps even sea ports of embarkation as well as sea lines of communication.

These drones can also be used against commerce. Launched from shore bases, these systems will allow any nation bordering, for example, the South China Sea and its critical straits to interdict trade. While the systems cannot stop trade, damaging a few ships will cause dramatic increases in maritime insurance rates. To date, no nation has developed a mine hunting force capable of clearing smart, self-deploying mines with a high degree of confidence.

Air Warfare

For air power, the key problem will be protecting aircraft on the ground. An opponent

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does not have to fight modern fighters or bombers in the air. Instead he can send hundreds or even thousands of small drones after each aircraft at its home station. Support aircraft, such as tankers, airborne early warning and control aircraft (AWACs), and transports, are even more difficult to protect on the ground. Even aircraft protected by shelters, radars, fuel systems, and ammunition dumps will be highly vulnerable. Currently, range is a problem for printed drones. But an Aerovel commercial drone first crossed the Atlantic in 1998, and the company now sells an extremely long endurance (40 hours plus) drone[53] for about $200,000.[54]

While manned aircraft will become vulnerable due to basing issues, cruise missiles will become both more capable and cheaper. As noted earlier in this paper, Lockheed expects to be able to cut the cost of two new satellites by 40 percent using additive manufacturing.[55] If we can obtain similar cost savings, Tomahawk Land Attack Missiles will cost about $606,000 each. These missiles carry a 1,000-pound warhead for a distance of up to 1,500 miles (Block II).[56] While somewhat expensive, missiles such as these can provide long-range heavy strike capabilities—particularly if the warhead uses nanoexplosives. Since they can be fired from a variety of land and sea launchers, they can be either dispersed or hidden in underground facilities (to include commercial parking garages and commercial ships) until minutes before launching. They will thus be immune to most pre-emptive strikes and much less expensive than ballistic missiles. The combination of cheap drones and much more capable cruise missiles may offer small- and medium-sized states anti-access/area-denial (A2/AD) and precision, long-range strike capabilities.

Space Warfare

In space, the advent of micro- and cube satellites, paired with commercial launch platforms, will allow a middle power to develop an effective space program for surveillance, communications, navigation, and even attack of other space assets. Surveillance and navigation satellites are already within reach of most small or medium powers—and they could buy the services from a commercial company if they were unable or unwilling to develop them on their own.

As noted earlier, high-altitude, long-endurance drones, and even balloons, are being tested by a number of commercial firms as alternatives for providing Internet connectivity and surveillance. They will provide medium powers space-like capabilities for much less money than it cost the space pioneers, including the United States, Russia, and China.

Cyber Warfare

While one would not normally think of drones as part of conflict in cyberspace, it is important to remember that all networks have nodes in the real world. Some are quite exposed. For instance, satellite downlinks and points where fiber optic networks come ashore are vulnerable. Smart drones provide a way to attack these nodes from a distance.

Offering more potential for precision effects, Boeing successfully tested its Counter-electronics High-Powered Advanced Missile Project (CHAMP) in 2012. CHAMP is a drone-mounted electromagnetic pulse (EMP) system that successfully knocked out all electronic targets during its test.[57] Such a system can target specific nodes of an enemy's network while not damaging friendly nodes.

STRATEGIC IMPLICATIONS

Technological convergence will provide much smaller powers—and even small groups—with capabilities that used to be the preserve of major powers. The proliferation of these capabilities will greatly complicate U.S. responses to various crises and will reduce our ability to influence events with military force. Four factors will have direct strategic impact on the United States: the loss of immunity to attack, the tactical dominance of defense, the return of mass, and a requirement to mobilize.

Loss of Immunity to Attack

The United States will cease to have a monopoly on long-range, precision strike capabilities. Many states, and even insurgent or terrorist groups, will be able to project force at intercontinental range. Very long-range drone aircraft and submersibles provide the capability to strike air and sea ports of debarkation—and perhaps even embarkation. The United States will no longer project power anywhere in the world with impunity. This will create major political problems in sustaining a U.S. military campaign both domestically and internationally. Domestically, will the U.S. public support distant actions if they result in a significant threat to the nation or even an increase in the cost of imports? Even a few self-deploying mines in U.S. ports will drive up maritime insurance—and hence the cost of imported goods.

Internationally, opponents will have an increased ability to threaten intermediate bases. For instance, a great deal of our support for Iraq flows through Kuwait. Suppose the Islamic State of Iraq and Syria (ISIS) demonstrates to Kuwait that it can hit an airliner sitting at Kuwait International Airport? ISIS states it will not do so as long as Kuwait withdraws landing rights for those nations supporting the Iraqi government. Is the West prepared to provide the level of defense required to protect key targets across those nations providing interim bases and facilities in the Middle East and Europe?

Of more immediate concern will be the far larger number of weapons that can hit in-theater bases, particularly large logistics facilities such as Bagram, Afghanistan, or Taji, Iraq. Advances in additive manufacturing, artificial intelligence, and composite materials; improved energy densities in gel fuels; new energy-reflecting coatings; and nanoexplosives mean there are powerful, autonomous, stealthy drones in our immediate future. Defending against this threat is possible but expensive—particularly when the cost of defending against these weapons is compared to the cost of employing them. Could we keep Bagram open against a threat like this? And would the benefits of doing so outweigh the costs?

Tactically Dominant Defense

While these systems create a genuine threat to all nation states, they and their descendants will provide a significant boost to anyone's defense. This shift to defense dominance may create a situation similar to what existed between 1863 and 1917, where any person who was in range and moving above the surface of the ground could be cheaply targeted and killed. The result was static trench warfare. Drone swarms may make defense the dominant form of warfare in ground, air, sea, and space domains. Drone swarms may also be able to attack the physical elements that support the cyber domain. The Department of Defense needs to run rigorous experiments to understand the character of such a conflict. If the experiments show defense to be tactically dominant, DoD will have to work out how U.S. forces can still achieve their inherently offensive operational and strategic missions.

The Return of Mass to the Battlefield

Since the 1980s, U.S. forces have bet on precision to defeat mass.[58] This approach helped numerically smaller Allied forces to defeat Iraq's much larger army (twice), as well as remove the Taliban from power, while significantly degrading al Qaeda in Afghanistan using a very small ground force. However, technological convergence is pointing to the revival of mass (in terms of numbers) as a key combat multiplier. Additive manufacturing may make large numbers of cheap drones available to all states and many non-state actors. How will our forces, which are dependent on a few, exquisite platforms—particularly air and sea—deal with the small, smart, and many? Currently, DoD is testing various directed-energy weapons and jamming to deal with the exponential increase in potential targets. It is imperative that these systems be tested against a thinking, reacting opposition that employs countermeasures such as autonomy to defeat jamming or smoke that can defeat visual, radar, and infrared targeting, or shielding that can protect a drone from directed electromagnetic energy.

The Return of Mobilization

After the fall of the Soviet Union, the United States abandoned the concept of mobiliza-

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tion. A primary driver was the fact that the U.S. defense industry simply lacked the surge capability to rapidly equip a mobilized population. Mobilization in World War II was possible because industry could rapidly convert from civilian to military production. By 1990, the complexity of modern military weapons systems, and the manufacturing plants and skills needed to produce them, made such a rapid conversion difficult, if not impossible. Additive manufacturing is inherently flexible, since the product produced depends only on the materials the machine can use and the software that is loaded. Thus, as additive manufacturing assumes a greater role in industry, the possibility of industrial mobilization will reemerge. Can the Pentagon manage such a mobilization? To succeed, it will require significant peacetime planning.[59]

POLICY IMPLICATIONS

The diffusion of power has implications for U.S. strategy, force posture, force structure, and investment. The United States has a range of grand strategic options, from restraint to aggressive interventionism.[60] Obviously, the strategy selected will drive much of our force posture. However, the diffusion of power will drive that strategy. The viability of projecting power from the United States becomes questionable when almost any enemy can strike selectively from in theater to the United States.

This raises the troubling issue of moving forces from home bases to the combat zone. Will other nations provide flight transit or port rights if it means their homeland is subject to significant attacks? How much additional combat power will we have to dedicate to protecting both our lines of communications and allied infrastructure and population? Americans will find our options limited and will be required to rethink how we project power. Our enemies and allies will know this. Thus we have to think through the implications of forward basing in theater versus basing in the United States and deploying only for a crisis.

This is particularly critical in Asia. What steps can we take to assure allies that, in fact, we can honor our treaty obligations? Do we need to deploy more forces forward into the Pacific to ensure they are there for the fight? Or just pre-position the equipment and supplies beforehand? How dispersed will forward forces have to be to survive? How much would we have to invest in hardening forward bases versus investing in protecting stateside bases and building the lift necessary to deploy? Are we willing to employ long-range strike weapons from the United States if we know the enemy can reply in kind?

Whether forward-stationed or deployed in a crisis, once U.S. forces arrive in theater their increased vulnerability to stand-off attack and resultant requirement for hardening and dispersion will dramatically impact our force structure. Hardening, which includes digging in whenever troops are not moving, will require increased engineering assets, while dispersion will require increased logistic, force protection, and command-and-control assets.

As the United States develops its strategy and subsequent force posture, it will also have to rethink its procurement focus. Is the current plan of purchasing a few extremely capable platforms viable in a world where cheap, smart weapons in large numbers will hunt those exquisite platforms? Or should the Pentagon move to a concept of large numbers of much cheaper but individually less capable platforms? And of course this evaluation of options will have to be done in a period of decreasing budgets and increasing per unit procurement costs.

The convergence of technology and resultant diffusion of power should force thoughtful consideration of both policy and strategy. Perhaps the fundamental policy question will be a reconsideration of the ability of the United States to use military force to influence international events. Increasingly, we will have to ask the question "Is the strategic benefit of an intervention worth the cost when the enemy can strike back in and out of theater?"

NOTES

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