SEPTEMBER 2013

DISRUPTIVE DEFENSE PAPERS

Game Changers

Disruptive Technology and U.S. Defense Strategy

By Shawn Brimley, Ben FitzGerald and Kelley Sayler

Foreword by Peter W. Singer

Center for a New American Security

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About the Authors

Shawn Brimley is the Vice President and Director of Studies at the Center for a New American Security.

Ben FitzGerald is a Senior Fellow and the Director of the Technology and National Security Program at the Center for a New American Security.

Kelley Sayler is a Research Associate at the Center for a New American Security.

Peter W. Singer is the Director of the Center for 21st Century Security and Intelligence and a Senior Fellow in the Foreign Policy program at the Brookings Institution.

FOREWORD

By Peter W. Singer

It has become in vogue for leaders to argue that one of the lessons of the past decade of war is that "technology doesn't matter in the human-centric wars we fight," as one four-star general put it to me. But that assumes a definition of "technology" as exotic and unworkable. To paraphrase the musician Brian Eno, technology is the name we give to things that we do not yet use every day. Once we use it every day, we do not call it technology anymore. Whether a stone or a drone, it simply becomes a tool we apply to a task.

More challenging than the tools themselves in a strategic context may be the pace of technological change. Many of us are familiar with Moore's Law, the notion first expressed by Gordon Moore, the cofounder of Intel, that the number of transistors on integrated circuits doubles approximately every two years. Moore's Law was originally intended to describe a phenomenon of computer hardware, but the broader exponential trend in which technology multiplies upon itself has been found to have broader historic patterns (also described as the Law of Accelerating Returns).[1]

In the military realm, we can see the power of this exponential growth in everything from raw firepower (for instance, from World War I to today, the range and effectiveness of cannon fire multiplied 20 times over, changing how and where we use it) to the tools that militaries have at their disposal to communicate and coordinate. Indeed, a single holiday greeting card that plays a little song today has more computing power than the entire U.S. Army had when my father served in it.

Chris Anderson, the founding editor of *Wired* magazine, explains that we have entered an era where we use technologies on a daily basis that "… were essentially 'unobtanium' 10 years ago. This is the stuff that used to be military industrial technology; you can buy it at RadioShack now. I've never seen technology move faster than it's moving right now, and that's because of the supercomputer in your pocket."[2]

But that technology of today is the past of the future battlefield. What happens next? And how can strategists, who too often fail to assume technological change, wrestle with it? If Moore's Law holds true the way it has for the past 40 years, it presents immense complexity. For instance, between the time the current team assembled to review U.S. defense strategy and when the Quadrennial Defense Report will be published, we will see a doubling of the technological power and complexity of our processing chips, computers and all that is powered by them.[3] And in the period the team is actually supposed to be planning for, the strategic horizon of the next 25 years, we will see technologies literally one billion times more powerful than today.

What this means is that we have a series of "game changers," as the following paper explores – up-and-coming technologies about which policymakers need to be mindful. It is important to distinguish this notion from the way that technologies are too often discussed in warfare. In contrast to what the acolytes of network-centric warfare proclaimed, technology is not a silver-bullet solution, nor does it "lift the fog of war."[4] What makes a technology "game changing," "revolutionary," "disruptive" or a "killer application" is that it both offers capabilities that were not available – and were in many ways unimaginable – a generation earlier and in so doing provokes deep questions whose answers are not readily available. These kinds of institutional, organizational and even individual soul-searching questions encompass not only what is possible, but also what is proper, in everything from doctrine and staffing to law and ethics. Such technologies – be they fire, the printing press, gunpowder, the steam engine or the computer – are rare but truly consequential.

In the past decade, the unmanned system has proven to be one of these killer applications (indeed, literally giving a double meaning to the term). The U.S. military went into Iraq with just a handful of unarmed robotic systems (also known as unmanned aerial systems, remotely piloted aircraft or drones) in the air and no unmanned systems on the ground. Today, there are over 8,000 drones in the U.S. inventory and roughly another 12,000 on the ground. And the technology has gone global, leaving the United States and 87 other countries wrestling with difficult questions: How do you staff units fighting remotely? What impact can and should they have on the choices of when and where to go to war? One example is the "drone wars" debate that has emerged after the United States used such systems not only in military operations in Afghanistan but also in a series of not-so-covert campaigns in places like Pakistan and Yemen.

Although the Predator drone still seems like science fiction to many in the public and the military, it is a technology that actually was first operational in the 1990s Balkan wars (but it was not until it was armed in the opening months of the Afghanistan operation following 9/11 that it truly became a game changer). The question for today's strategists is what comes next? That is, what are the technologies that today's naysayers derisively describe as "science experiments" that will actually be key to shaping the battlefield of tomorrow?

With the goal of exploring this question, the U.S. Department of Defense's Rapid Reaction Technology Office sponsored the NeXTech project series. The project began with a series of surveys and interviews of more than 60 top futurists, lab directors and scientists, as well as investors and venture capitalists (those who pay for the future to come true) to identify what game-changing technologies are out there. The goal that guided them was to identify what technology right now is akin to where the computer was in 1980 or the Predator was during the 2001 Quadrennial Defense Review – real but not yet noticed as transforming the world. The avenues of change in technology were overwhelming, as the following paper explains, extending from autonomous robotics to the "Internet of things."

The project then conducted a series of war games in partnership with organizations including the U.S. Army War College, U.S. Naval Postgraduate School and U.S. Naval Academy to explore first the relative barriers to entry of the technologies and then how they might, and might not, be used. The exercises looked at potential use by the United States and friendly forces in a range of scenarios from major combat to humanitarian disaster relief and, in turn, at potential use by unfriendly forces in scenarios that ranged from state militaries seeking to seize island chains to terrorist groups and drug cartels upgrading for the 21st century. For example, one scenario was inspired by the 2008 Mumbai terror attack but explored how a similar small raiding party of just a few men might operate if it had access to more contemporary technologies rather than just a mix of AK-47s and grenades (that still caused such chaos in Mumbai).

Unlike too many conventional exercises, the war games were also notable in bringing together a diverse mix of participants, including U.S. and allied military representatives from all services, ranks and generations (from admirals down to 19-year-old midshipmen). The Red Team was infused with a "nasty bastards" group that mixed everything from special operations forces from the United States, Europe, Asia and the Middle East to civilian subject experts from organizations that ranged from the Los Angeles County Sheriff's Department's expert on drug cartels to top thinkers from firms like Apple, Facebook and Google.

The project then conducted a unique "ethics war game." The team assembled a group of defense policy experts, military and civilian lawyers, representatives of human rights organizations, and various philosophers and ethicists to explore the legal, ethical and policy ramifications of these new emerging technologies and their uses.

As with all truly intellectually honest programs, there was no single conclusion or agreed upon takeaway answer. Rather, the first goal was to develop and then test a new, more rigorous, but less expensive, way of approaching the ripple effects that emerge from new technology. The second goal was to stimulate new thinking and new lessons on the range of potential futures that lie ahead.

In the following report, Ben FitzGerald, one of the NeXTech organizers, and Shawn Brimley, one of the participants, team up to explore what they found to be some of the key issues that policymakers should be paying attention to regarding disruptive technology and defense strategy today. It is an important contribution to the ongoing debate over the future of the U.S. military – a debate that deserves more attention from policymakers and planners alike. The technological edge that the U.S. military has enjoyed for the past few decades was a powerful inheritance, but it is yet to be determined whether it will be left to the next generation.

I. THE CHANGING GAME

By Shawn Brimley, Ben FitzGerald and Kelley Sayler

During the next decade, the rise of new powers and the accelerating diffusion of advanced technology throughout the international system will pose significant challenges to U.S. technological dominance in military affairs. Since the end of World War II, the United States has continually reaffirmed a strategic choice to leverage advanced technology – indeed to be *qualitatively dominant* – as a means of offsetting quantitative disadvantages. In recent years, however, the notion of such dominance has been more akin to a presumption than a reality. Such a presumption was never wise or sustainable, but in the current period, it threatens to undermine the foundation of U.S. defense strategy.

It might have been understandable to assume that U.S. technological dominance would continue after the Cold War and the 1991 Persian Gulf War, when the United States held a monopoly on precision-guided munitions and no near-peer rival was on the horizon. But the current strategic environment is complex and very different, featuring a rising power – China – that is executing a military modernization strategy explicitly aimed at countering the United States.[5] Moreover, continued globalization is making it easier for a wider range of both state and non-state actors to acquire existing military technology.[6]

Perhaps most significant, however, several developments are now poised to change the essential contours of the military technology game, including the exponential growth of unmanned and increasingly autonomous robotic systems, the power of data-mining technologies, the potential of additive manufacturing to usher in a new industrial revolution and the possibility that directed-energy weapons could dramatically alter the offense-defense balance in key military competitions. As a result, the next decade is likely to be the most disruptive since the early 1980s, when military planners in the Soviet Union began to worry openly about a "military-technical revolution" emerging in the United States.[7]

The rise of actors truly capable of challenging the United States, an increasingly globalized international system that accelerates the diffusion of technology and the emergence of several disruptive technologies that may quickly alter actual or perceived military power balances will occur as U.S. defense spending contracts significantly over the next five years or more.[8] With declining defense spending, there will be strong pressure to reduce investments in research and development, as well as in basic science and technology.

Given the confluence of these trends, the U.S. government needs to examine how emerging game-changing technologies may shape U.S. military strategy. This paper presents a framework for how U.S. policymakers should think about disruptive technology, identifies some key technologies with implications for the defense sector and recommends ways to help ensure that the United States retains its position of technological superiority during a particularly challenging period. We hope that this paper spurs additional work designed to better connect emerging technologies with U.S. policy and strategy development.

NeXTech: Exploring How Emerging Technologies Will Change the Battlespace

This report draws on the findings of the NeXTech project. Initiated at the direction of the Rapid Reaction Technology Office within the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, NeXTech assessed the implications of emerging technologies on future warfare. Led by Noetic Corporation, under the intellectual leadership of Peter W. Singer, NeXTech identified technology areas with the potential to affect the future strategic environment. This baseline knowledge was used to explore the social, economic and technical implications of new technology.

NeXTech developed and tested concepts through four war games, which considered definitions, blue force perspectives and red force perspectives, as well as the legal, ethical, moral and policy implications of game-changing technology. These war games brought together military professionals, policymakers, scientists, engineers, investors, ethicists and lawyers from a variety of backgrounds to identify and debate the issues that define game-changing technology.

II. TECHNOLOGICAL DOMINANCE IS A STRATEGIC CHOICE

Technological dominance has been integral to American military strategy since the end of World War II. Although the battle for technological dominance was a feature of that war, the ability of the United States to produce mass quantities of tanks, planes and ships was a core strength of the Allies. However, it was really the Cold War competition with the Soviet Union, whose conventional forces vastly outsized those of the United States, which elevated a qualitative technological edge to a position of primacy within U.S. military strategy and acquisition.[9] The choice to prioritize investments in fewer, better platforms eventually generated game-changing capabilities – such as long-range cruise missiles, stealth technologies and precision munitions – that contributed to U.S. technological dominance and helped to accelerate the Soviet Union's decline.

In part due to this legacy of dominance, generations of defense analysts and policymakers believed that the United States would always enjoy a technological edge over its adversaries. What was a matter of deliberate strategy during the Cold War became a matter of presumption in the 1990s.[10] America's presumed dominance was reinforced during the opening phases of the Afghanistan and Iraq wars, in which U.S. forces rapidly defeated conventional forces and dislodged governments before the long years of irregular warfare began.

Defense spending on research and development will probably continue to decline in the coming years for a host of reasons, such as the drawdown of the post-9/11 ground wars, the impact of the 2011 Budget Control Act, the resurgence of neo-isolationism among American political leaders and the unwillingness to address unsustainable cost growth in the Department of Defense (DOD).[11] Given the centrality of technological dominance in U.S. defense strategy, allowing this decline would be particularly unwise.

America's technological dominance is far more fragile than is commonly understood, for three important reasons. First, unlike the era immediately after the Cold War, today there is a real prospect of near-peer competitors, enabled by an international system that is making it easier to acquire the most sophisticated technology.[12] The most prominent example is China, whose ongoing military modernization campaign is designed to develop capabilities to limit U.S. freedom of action and hold U.S and allied assets in the Asia-Pacific region at risk. Moreover, rapid globalization and diffusion of technology has lowered the barriers for smaller states, and even non-state actors, to acquire and field advanced military capabilities or inexpensive but highly effective asymmetric capabilities.

The second, and potentially more consequential, trend is that the commercial sector now catalyzes far more technological innovation than the military industrial base. During the Cold War, much of America's technological prowess stemmed from military investments in missiles, satellites, precision munitions and stealth technology. In contrast, the current climate more closely resembles that of the late 19th century, when the commercial sector generated game-changing innovations like the telegraph and railroad. Likewise, the commercial sector will drive many of the innovations that will most define the next 20 years – additive manufacturing, robotics and unmanned systems, the "Internet of things" and energetics. This is actually a beneficial trend overall, as a robust commercial sector will generate innovative technologies that can be applied across the entire U.S. economy while also allowing DOD to benefit from private investments. But unless a consistent level of applied research and development spending in DOD is available to help translate key technologies from the commercial world and apply them to tomorrow's military challenges, the United States risks letting its technological advantages atrophy.

Retaining technological dominance is a strategic choice ... The nation must actively break down the bureaucratic antibodies that resist investment in innovation and redouble its focus on sustaining technological dominance.

Finally, sustaining investments in potentially game-changing military technologies is difficult enough during a time of plenty – it will be extremely difficult during the current period of austerity. History suggests that DOD – and in particular, the military services – will resist investment in technologies that call into question preferred legacy platforms, core competencies and concepts of operations.[13] Just as innovators during the interwar years of the 1920s and 1930s found it difficult to sustain investments in aircraft carriers and long-range bombers, today's innovators will need to compete against entrenched communities and interests that will fight tooth and nail to maintain favored programs during the downturn.[14] Strong civilian and military leadership on this issue will be vital in order to prevent serious harm.

Retaining technological dominance is a strategic choice. As the United States grapples with the challenges of shrinking budgets, rising powers and a globalizing world, it cannot assume that its current advantages will continue in the absence of sustained attention to both policy and investment choices. Instead, the nation must actively break down the bureaucratic antibodies that resist investment in innovation and redouble its focus on sustaining technological dominance.

III. BOUNDING THE FIELD: DEFINING "GAME CHANGING"

Almost any new technology can be described as potentially game changing. This is especially true in a competitive defense market with technologies, programs, approaches and priorities vying for finite financial and institutional support. Improved ground-combat vehicles, faster ships and more stealthy aircraft are sustaining innovations; they improve the performance of established military capabilities and enable more efficient prosecution of traditional operational concepts.[15] Vitally important as core elements of defense strategy and modernization efforts, such technologies do not disrupt traditional ways of executing military operations.

The recent NeXTech project loosely defined game-changing technology as "technology or [a] collection of technologies applied to a relevant problem in a manner that radically alters the symmetry of military power between competitors. The use of this technology immediately outdates the policies, doctrines and organizations of all actors."

This definition is notable for two main reasons. First, it reinforces the point that game-changing technology is disruptive, representing a discontinuous shift from the prevailing paradigm. Second, it stresses that technology itself is merely one, albeit vital, component of a game-changing technology. A scientific breakthrough or a new manufacturing method, power source, weapons system or platform provides potential; a variety of other factors determine that technology's game-changing value.

During the NeXTech project, these additional factors became so significant that the participants developed a framework to better understand them. This framework can help defense policymakers and industry leaders make better decisions about technology investment and translate that investment into better capabilities and concepts, and ultimately into improved strategic outcomes. The framework includes four primary areas that all must converge for a technology to be truly game changing: congruence, perspectives, societal values and organizational culture and time.

Congruence

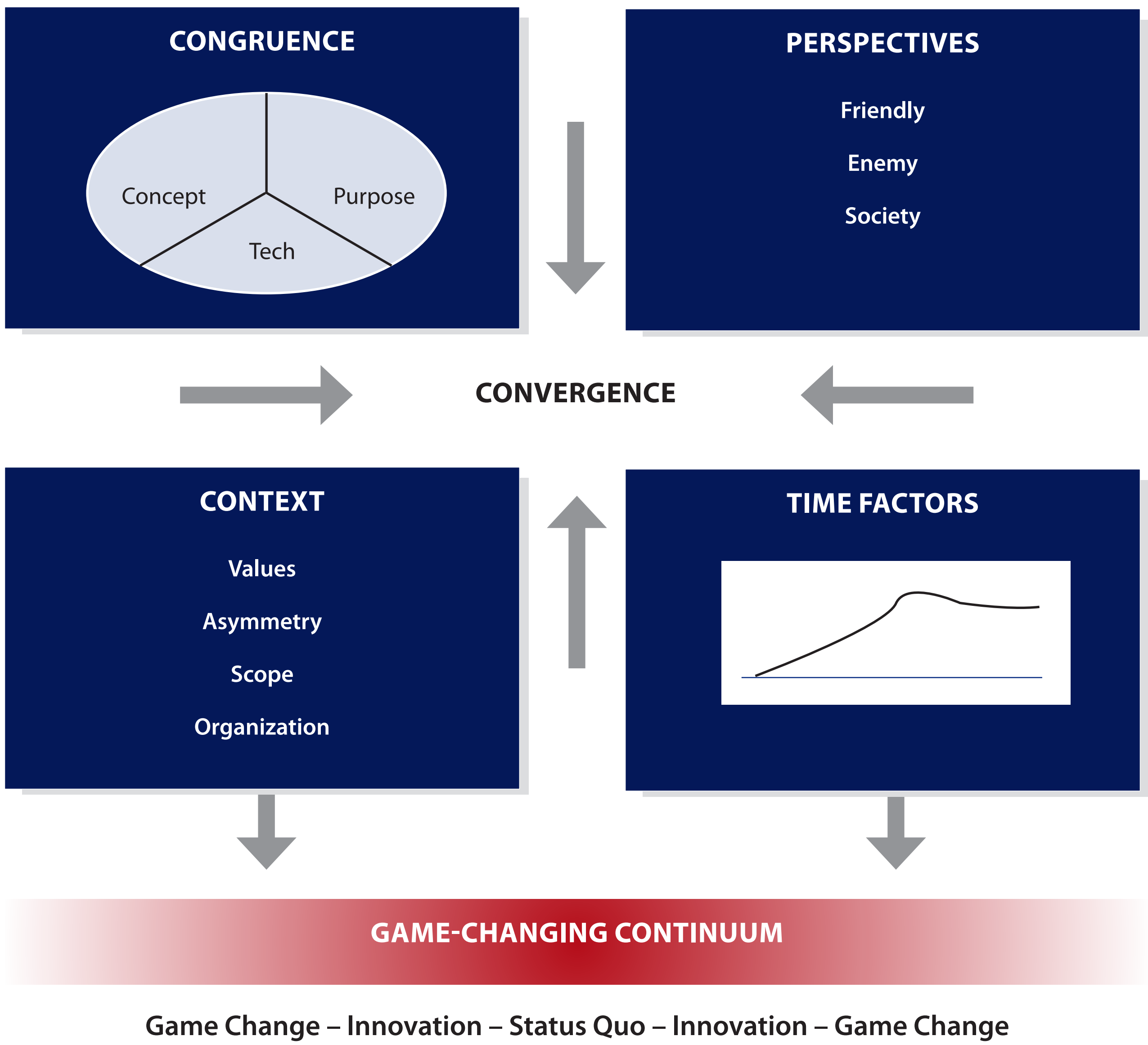
The core elements of a game-changing technology are the technology itself, a concept for its use and a relevant problem. The congruence of these factors provides the opportunity or potential for a new technology to have game-changing impact. Blitzkrieg is a clear example of how such congruence works: integrating fast tanks, aircraft and two-way radios into an operational concept of advanced maneuver warfare obviated the largely defensive technologies of Germany's opponents (most famously, France's Maginot Line). The synergies among these core elements produced a discontinuous shift in the balance of military power in Europe – a truly game-changing innovation.

Perspectives

Different actors derive different benefits from technology based on their strategic circumstance, operational environment and preferred concepts of operation. Dominant actors seek to maintain or improve on the status quo while weaker actors seek asymmetric opportunities to change their position. This means that, for these dominant actors, there is lower "marginal utility" for game-changing technology relative to weaker actors. That is, dominant actors derive less value in relative terms from new technologies given their dominance. Despite this, dominant actors must continue to innovate to, at a minimum, maintain their current status.

For example, sophisticated platforms like aircraft carriers, which were game changing in their time, are currently used by large nation states in the

FIGURE 1: NEXTECH FRAMEWORK



context of well-understood international norms and concepts. The adoption of these platforms by new actors may be disruptive, or may increase competition in terms of power projection, but is not fundamentally game changing. However, the emergence of capabilities that put at risk, or rapidly erode, the ability of aircraft carriers to be operationally useful would constitute a game-changing, or discontinuous, shift.[16]

Values and Organizational Culture

Societal values and organizational culture are important factors that enable or constrain the adoption of game-changing technology. Values – as expressed in law, policy, ethics and public perception – are profoundly influential in this regard. The active denial system (ADS), for example, has the technological ability to act as a nonlethal weapon, yet it is also seen as a "pain ray," which causes perception issues and concerns from human-rights lawyers about collateral damage.[17] Failure to factor these forces into capability planning risks wasted investment, as in the case of ADS, or significant public outcry and political fallout, reflected for instance in the ongoing debate over domestic surveillance in the United States.

Large organizations tend to resist technologies or innovations that may disrupt core ways of doing business. U.S. military history can provide any number of useful examples – from the Navy's resistance to submarines in early 20th century to the manned fighter-aircraft community's contentious relationship with unmanned systems today – showing how organizations can stymie the development of new technology, particularly during a period of fiscal constraint.[18]

Time

Time impacts the game-changing potential of technology in multiple ways. Technology takes time to mature but can then advance rapidly after it reaches a tipping point. The Predator system first flew in 1995, but did not became a game changer for U.S. counterterrorism efforts until it was enabled with GPS technology. Additive manufacturing (more commonly known as 3D printing), for example, existed for 30 years before it achieved the requisite speed and flexibility to revolutionize manufacturing. The technology, matched with an appropriate concept of operations, must also align in time with a relevant problem. The emergence of the precision strike regime during the 1991 Persian Gulf War and the other limited wars in the 1990s (such as Bosnia and Kosovo) is a good example of a series of pre-existing capabilities that became game changing when they aligned with a strategic and operational need to allow rapid, remote and effective destruction of an enemy's command and control mechanisms and forces, thereby creating a disruptive shift in military affairs.[19]

A technology's game-changing potential is finite, with only a short window of time for adoption before it is countered by other innovations or made irrelevant by a changing environment. The Future Combat System, Comanche, Crusader and Expeditionary Fighting Vehicle were all originally conceived prior to the fall of the Berlin Wall and were overtaken by a strategic, operational and fiscal environment that reduced their perceived relevance to current and future contingencies.

Convergence: Synergies Among the Factors

Successfully creating and implementing game-changing technology is therefore much more than an engineering or investment challenge – it requires all four factors to converge effectively. Creating the right catalysts for this type of convergence is difficult even under optimal conditions. Leaving these factors to chance dramatically reduces the possibility of technology achieving game-changing effect. Senior decision makers must consider how best to align the elements described above to leverage emerging technologies in support of national interests.

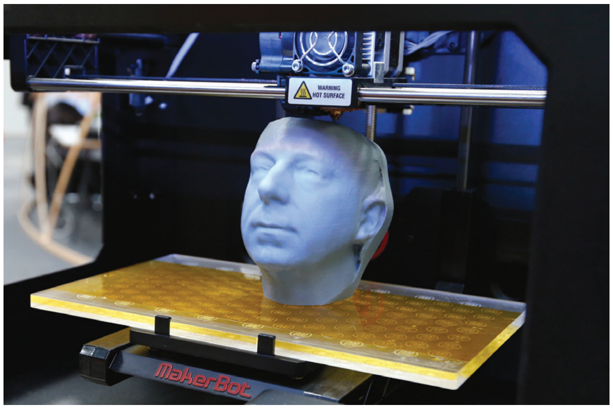
IV. ILLUSTRATIVE TECHNOLOGIES WITH GAME-CHANGING POTENTIAL

Given the number of variables required to align for a technology to become game changing, making bold predictions about game-changing technologies is an inherently risky and flawed proposition. During the series of NeXTech war games, participants explored five technology areas with the potential to cause a series of discontinuous shifts in military affairs: additive manufacturing, autonomous systems, directed energy, cyber capabilities and human performance modification. All of these technologies have great potential, but they may also have significant security and war fighting implications that are difficult to forecast and manage. Regardless of the future circumstances of these technologies, they justify further scrutiny to assess their viability and better understand how technology becomes game changing or not.

Additive Manufacturing

Additive manufacturing could fundamentally impact the defense industrial base – and the manufacturing process writ large – by dramatically increasing the pace of moving from prototype to production and by enhancing the flexibility and adaptability of production lines.[20] For the defense industrial base, this could enable small-batch development of major platforms, as well as mid-course design adjustments based on changes in the environment or unforeseen countermeasures.

Additive manufacturing will be readily available to the armed services. As the technology matures, methods for developing and adapting material solutions will improve and will likely result in cheaper, more tailored and more flexible manufacturing processes. In the context of military operations, additive manufacturing could significantly alter logistics by allowing deployed units to print specific parts in situ from available materials.[21] Similarly, it could affect the conduct of disaster relief and reconstruction missions by



A 3D printer MakerBot Replicator 2 produces a sculpture at the CeBit computer fair in Hanover, Germany in March 2013.

(FABRIZIO BENSCH/ Reuters)

enabling local communities to print customized parts and maintain their own equipment. It could also allow new approaches to tactical adaptation of equipment, as already seen in Afghanistan where the Rapid Equipping Force has deployed mobile labs to make improvements to everything from flashlights to power attachments for ground penetrating radar.[22] It is important to note, however, that potential U.S. adversaries may benefit from these technologies as well.

For non-state actors, basic 3D printers are commercially available and are increasingly capable of allowing small groups to build sophisticated items. Yet it may be challenging for them to gain access to advanced models capable of printing sophisticated systems.[23] If they are able to do so, however, they could gain the ability to manufacture material solutions that would otherwise be impossible to build or acquire. The marginal utility of this technology is therefore significantly higher for non-state actors, which, because they are not constrained by large bureaucracies, are well situated to incorporate the technology into their concepts of operation.

Despite this potential, the technology itself will need to mature in order to be truly game changing, particularly in terms of build volume capacity, improved finishes, the variety of printable materials and the ability to print disparate composite materials. If this maturation does occur, the technology will then need to be integrated into or replace existing manufacturing processes – which will in turn require circumventing entrenched bureaucratic, political, cultural and commercial interests – before its full potential can be realized in either civilian or military contexts.

In the years to come, the United States will not be the only beneficiary of this game-changing technology and may well be targeted by it.

Autonomous Systems

Autonomous and semi-autonomous systems have already revolutionized Intelligence, Surveillance and Reconnaissance (ISR) and counterterrorism. Unmanned aerial vehicles have allowed U.S. forces to act directly against threats in foreign countries with minimal footprint and risk to U.S. forces. The underlying technologies that support autonomous systems, including robotics, artificial intelligence, software and wireless networks all continue to develop rapidly. These advances offer additional opportunities to make a wider variety of autonomous systems that are smaller, cheaper and able to operate in swarms to overwhelm adversary defenses.[24]

In time, autonomous systems could be applied across a broader range of military operations and intelligence activities. Unmanned combat air vehicles are under continued development by both the U.S. and foreign militaries. To realize their full game-changing potential, militaries may need to use more contentious concepts of operation including fully autonomous ISR or even combat missions.[25] Unmanned combat ground vehicles or robots – perhaps using the concepts established for explosive-ordnance demolition robots in Iraq and Afghanistan – are likely to be increasingly used for basic tasks given rapidly rising personnel costs, the sophistication of adversaries' anti-access and area denial capabilities and the lethality of today's battle spaces.[26]

This shift to unmanned systems will likely be accelerated by the maturation of tag, track and locate capabilities, as well as other ISR developments.[27] The current limits on developing and employing autonomous systems stem from ongoing discussions on policy, ethics and organizational dynamics, not the technology itself. The United Nations and Human Rights Watch have both called for a ban on "killer robots," and U.S. drone strikes have proven highly controversial in Afghanistan and Pakistan.[28] At the same time, the U.S. military is reducing investments in unmanned aerial vehicles, showing that the future of drone technology remains uncertain.[29]

The United States lost its monopoly on drones years ago. Autonomous systems are now being developed by dozens of other state and non-state actors.[30] In the years to come, the United States will not be the only beneficiary of this game-changing technology and may well be targeted by it. Autonomous systems are therefore likely to be an area of intense competition in the near term, meaning that the speed of deployment will be crucial for gaining or maintaining the advantage. Furthermore, given current American dominance in manned and unmanned systems, U.S. adversaries stand to gain greater advantage from potentially disruptive developments.

Directed Energy

Directed-energy weapons generate effects through the use of millimeter waves, high-power

The Laser Weapon System temporarily installed aboard the guided-missile destroyer *USS Dewey* (DDG 105) in San Diego, is a technology demonstrator built by the Naval Sea Systems Command from commercial fiber solid state lasers, utilizing combination methods developed at the Naval Research Laboratory.

(JOHN F. WILLIAMS/U.S. Navy)

microwaves, lasers or electromagnetic pulses. These technologies have been under development since the 1960s and offer a variety of potentially game-changing applications that could be deployed within existing organizational constructs and concepts of operation.[31]

As currently conceived, these technologies would primarily replace or augment traditional munitions. For example, high-power microwaves and electromagnetic pulses would provide the ability to destroy electronic systems within a given area, whereas high-energy lasers would provide stealthy, highly accurate weapons that have no flight time, can engage more targets than traditional munitions and possess almost limitless magazines.[32] In addition, high-energy lasers would significantly enhance force and infrastructure protection, especially against adversaries with precision-guided munitions or large numbers of autonomous systems.[33] Although adversaries could potentially use electromagnetic pulses against the United States, the engineering complexity and power requirements of high-end directed-energy technologies mean that only developed nations will possess these capabilities for some time to come.

Directed-energy technology is also used in non-lethal weapons. Such weapons are intended primarily to provide escalation of force and crowd control functions, most commonly through the use of millimeter wave technology to generate heat rays and laser dazzlers to temporarily disorient or blind the target.[34] Although they are conceptually appealing and technologically feasible, these weapons have proven difficult to deploy given public concerns about human rights and military concerns that use of the technology would fuel enemy propaganda.[35]

In addition to these concerns, the technology's game-changing potential may be limited by other factors, including how well it can perform in challenging operational conditions (such as bad weather), the development of adequate energy sources and the availability of funding to move from research and development into production.[36] Nonetheless, directed-energy weapons provide an opportunity to both generate game-changing advantages and improve defenses against the game-changing technologies of adversaries.

Cyber Capabilities

With over 2.4 billion individuals online globally, cyber capability is already – and will continue to be – game changing, with rapid increases in Internet usage penetration, software innovation and the variety of applications and connected devices.[37] Beyond these current innovations, though, the Internet now serves as a platform to enable other game-changing technologies through open source development, crowd funding and the rapid transmission of technical data around the world.

As with most game-changing technologies, cyber technology has blurred previously well-understood boundaries, exposed vulnerabilities and created new threats and industries. The rapid pace of this change makes it even harder to establish shared norms and effective laws, policies, organizations and approaches for managing cyber security. Speaking after a bilateral meeting with Chinese President Xi Jinping, President Barack Obama noted these challenges:

> What both President Xi and I recognize is that because of these incredible advances in technology, that the issue of cyber security and the need for rules and common approaches to cyber security are going to be increasingly important as part of bilateral relationships and multilateral relationships. In some ways, these are uncharted waters and you don't have the kinds of protocols that have governed military issues, for example, and arms issues, where nations have a lot of experience in trying to negotiate what's acceptable and what's not.[38]

It is particularly concerning that these admissions of a lack of protocols are referring to the relatively mature domain of offense and defense in the current cyber realm, overlooking significant, emerging advances. Increasingly, cyber technologies can have real effects in the physical world. The well-reported Stuxnet attack against Iranian nuclear facilities provided an early example of this potential. The lack of overt response or retaliation to this attack also shows how major powers like the United States and China both benefit from the lack of rules and common approaches President Obama was referring to.[39]

The physical effects of cyber capabilities can be most clearly seen in the nascent "Internet of things," where connectivity between countless small electronic devices allows the creation of autonomous networks that share information on users' behalf.[40] The "Internet of things" could potentially optimize processes, resource consumption, and improve analytics through connected sensors across society. For warfighters, this could create game-changing alterations to current concepts of persistent ISR and enable large-scale management of autonomous systems.[41] However, this same connectivity also provides a means for sophisticated and lethal hacks and for hijacking of large systems, and it furthers a trend of putting technology previously unavailable to governments into the hands of individuals. Thus, the "Internet of things" provides significant opportunity to create asymmetric advantage for potential adversaries.

Human Performance Modification

In the DOD context, human performance refers to a person's physical, cognitive and socio-emotional functions. Human Performance Modification (HPM) refers to the use of drugs, techniques, machines or genes to enhance or degrade human performance.[42] This means that HPM has been, and continues to be, routinely undertaken in DOD through changes to training, provision of inoculations, research on post-traumatic stress disorder and a wide variety of well understood tasks. However, advances in biology and genetics are opening up a number of possibilities to increase the impact of HPM in ways that present significant opportunity but also pose deep philosophical and moral questions.

Culturally, DOD is comfortable undertaking HPM activity to return individuals to their baseline performance following injuries or the general degrading effects of conducting operations. DOD is less comfortable increasing individuals' performance beyond their baseline by, for example, improving IQ or night vision. Technologies to do so are increasingly available, and there are some indications that other nations are willing to run programs that the United States is not.

Other biological and genetic technologies provide the opportunity to undertake sophisticated ISR and offensive action on adversary forces: intelligence gathering based on genetic profiles; conducting tag, track and locate missions using bio-markers; or even assassinating high value targets through custom-designed viruses.[43] While these technologies may not yet be available, they are no longer in the realm of science fiction.

HPM shows the conceptual challenges associated with rapid increases in technological sophistication. Many aspects of HPM seem farfetched or are currently unpalatable, complicating discussions about the technology's development. DOD must, however, be prepared for a future in which adversaries take advantage of HPM, and it must decide how to either deter development and adoption of these capabilities or establish how they will be countered.

V. IMPLICATIONS OF GAME-CHANGING TECHNOLOGIES ON U.S. DEFENSE STRATEGY

The game-changing potential of these technologies is becoming increasingly apparent as defense analysts and policymakers continue to include them in war games, scenario planning and strategy development.[44] Individual technologies may lead to innumerable innovations at the tactical level (e.g., how dismounted infantry might employ swarms of unmanned autonomous vehicles, how land- and sea-based directed-energy missile defense systems could counter ballistic missiles, etc.). As the technologies develop, the majority of thinking by military planners will naturally occur at the operational and tactical level of warfare. However, the game-changing potential of these technologies requires an understanding of how they might fundamentally alter the strategic nature of military competition and even the conduct of war itself.

Offense Versus Defense

Game-changing technologies may alter the relationship between the offensive and defensive dimensions of conflict. In conventional warfare, the convergence of stealth technology, all-weather ISR platforms and precision-guided munitions allowed the United States to create and subsequently dominate an offense-dominant warfare regime – that is, these capabilities made it far more difficult for an adversary to succeed in a defensive posture. This convergence was a game changer and helped solidify U.S. military dominance for the past quarter century.

Several of the emerging technologies described above – particularly directed-energy weapons – could make it much easier to defend against today's precision-guided munitions by allowing defensive systems to accurately "fire" numerous times at an incoming target – helping to obviate any quantitative advantage an attacker might have. This could greatly alter the perceived balance of military

Game-changing technologies may alter the relationship between the offensive and defensive dimensions of conflict.

power in several competitive theaters including the Asia-Pacific region, where China's anti-access and area denial strategy is partly based on saturating U.S. missile defense systems on land and at sea with missile salvos.[45] Indeed, China's push toward parity in the precision strike regime by developing long-range missile technology is quite destabilizing, given the offensive nature of the regime.[46] The possibility of negating a missile saturation strategy by using directed-energy weapons would undermine an area of significant Chinese advantage, potentially altering the perceived local balance of power in ways that could be stabilizing for the region and advantageous to U.S. strategy in Asia.

Quantity Over Quality?

Several of these potential game-changing technologies hint at a future in which mass could reemerge as a prominent feature of high-end conventional conflict. Since the emergence of the precision strike regime, the quantity of platforms and payloads has become less important than their qualitative characteristics such as range, precision and stealth. Overwhelming the enemy with large salvos becomes unnecessary and cost inefficient when a combatant can be very confident that what is targeted will be struck, especially for air and naval combat strike capabilities. The shooter only has to fire enough to ensure that one gets through. This dynamic has profoundly shaped U.S. defense strategy – from acquisition practices and procurement levels to war planning and the posture of U.S. military forces overseas. U.S. qualitative technological dominance means that much of U.S. military strategy focuses on short engagements in which

U.S. forces can close with and destroy an enemy quickly and precisely, even if outnumbered.

This dynamic may change, however, as long-range precision systems proliferate in certain theaters. If the United States faces an adversary that has roughly similar types of long-range, precise and sometimes stealthy capabilities – and if the offense-defense dynamic becomes more balanced – quantity may become a very significant element of future conflict. Put another way, mass may reemerge as a central element of future high-end contingencies.

Humans should remain the ultimate arbiters of using force, even as technologies continue to develop.

These types of dynamics would likely cause the United States and high-end adversaries to apply concepts of mass (e.g. swarming) to emerging capabilities, such as unmanned autonomous systems. In a reversal of the qualitative bias toward larger platforms that emphasize range, persistence and stealth, a focus on the quantitative dimension of unmanned systems would incentivize investing in smaller platforms that are highly networked and extremely autonomous. These relatively cheap and expendable platforms could combine to overwhelm advanced defensive systems.[47]

A New Escalation Ladder?

Emerging technologies may alter the decision-making process before or during a crisis. New technologies often provoke a discontinuous shift in the nature of military competition and in the way new systems are employed to shape a geopolitical environment.[48] Several new technologies are changing the way deterrence and escalation operate between the United States and other actors. Cyber capabilities, particularly the emergence of offensive weapons, are reshaping the way policymakers in the United States think about thresholds for using force – whether provocations or attacks in cyberspace warrant a response in cyberspace or in other domains.[49] And the use of offensive cyber weapons, most notably the Stuxnet virus that attacked elements of Iran's nuclear program, will have consequences as the source code – essentially a blueprint for how to construct an offensive cyber weapon – continues to be better understood by international experts and presumably potential adversaries.[50]

Whereas the effect of cyber weapons on deterrence is at least being investigated, the impact of the emerging robotics revolution on war is worryingly underexplored. A future is fast approaching in which the United States or one of its adversaries could conduct offensive operations primarily through unmanned and robotic systems. Policymakers and analysts do not yet fully grasp how a potential adversary would react to intrusive surveillance by unmanned systems. Most worrisome, they do not yet understand how potential adversaries would view U.S. thresholds for using force. For instance, would China assume that shooting down a U.S. unmanned system over the South China Sea would not elicit an escalatory response? Would U.S. policymakers believe that China would not escalate if a U.S. manned aircraft shot down a Chinese unmanned system? How will the United States and other actors internalize the loss of unmanned systems in the early stages of a crisis or conflict? Participants in war games inside and outside the U.S. government are beginning to grapple with these key questions, and the implications for policymaking and decisionmaking are very unclear.

Humans "in the Loop"

Several emerging technologies also raise the critical question of what role humans will play in determining why, when and how to employ these technologies. The profound destructive power of nuclear weapons, combined with the speed of their potential use, dominated decades of decisionmaking processes at the highest levels of government.[51] Today, cyber weapons influence high-level decisionmaking in a similar way.[52] The exponential pace of the development and proliferation of unmanned systems – particularly autonomous systems – will cause another surge in thinking regarding how to ensure that humans remain a critical part of the decisionmaking process. The need to decide whether and how to use cyber technology or unmanned autonomous capabilities in near real time is once again compressing the amount of time available to decisionmakers.

Humans should remain the ultimate arbiters of using force, even as technologies continue to develop.[53] This is not a foregone conclusion shared across the national security enterprise. There is emerging evidence that policymakers are concerned with cyberspace capabilities and the need to plan for defense and counteroffensives at "netspeed" – an arguably deeply problematic concept implying the need to preauthorize cyberspace actions.[54] These types of arguments are very likely to emerge as other technologies begin to proliferate in key theaters, potentially compressing the time available for decisionmakers to react. Yet civilian policymakers must ensure that the president alone retains the right to authorize the initial use of force in a crisis – particularly in situations that pose substantial risks of miscalculation and escalation.

VI. INNOVATION BARRIERS

The tremendous potential of these game-changing technologies requires consistent investment and attention by defense policymakers as well as more robust collaboration between DOD and leading-edge innovators in the commercial sector. Yet the Pentagon does not seem to be postured adequately to do this. Instead, it seems to be focused entirely on identifying the budgetary cuts necessary to deal with sequestration. Although sequestration is admittedly a very tough challenge, the singular focus on today's cuts may be obscuring the need to invest in tomorrow.

Several other barriers also put needed investments at risk. First, as alluded to above, the military often strongly resists serious investments in technologies that may threaten perceived "core" weapons platforms and traditional concepts for their employment. As former Defense Secretary Robert Gates said at the end of his tenure, there is a "… nostalgia that can too often consume the institutional culture of any large, successful organization. This is a problem for all the services. Each has had a traditional orientation – rooted originally in World War II and the Cold War, and then reinforced in the 1991 Persian Gulf campaign – that has been, to varying degrees, neglected in the Iraq and Afghanistan campaigns."[55] The military services typically focus their attention and investments on incremental improvements to traditional platforms at the expense of more forward-looking investment and procurement.[56]

Second, making big bets on new, unproven technologies entails a great deal of risk and potential for failure. Risk aversion is a deeply rooted facet of Pentagon culture – and not unreasonably so for uniformed planners. Military commanders are charged with being ready to face today's plausible contingencies. Thus, they are naturally wary of investing in game-changing technologies, the benefits of which exist somewhere in the mid- to long-term future (if at all). Commanders will almost always favor guaranteed additional capacity today over potential capability tomorrow. Civilian and military defense leaders must therefore ensure that investment in next-generation and potential game-changing technologies continues during the current downturn.

The tremendous potential of these game-changing technologies requires consistent investment and attention by defense policymakers as well as more robust collaboration between DOD and leading-edge innovators in the commercial sector.

VII. RECOMMENDATIONS

We propose several modest recommendations that can help ensure that needed investments in potential game-changing technologies are prioritized and protected during the next five years or more of relatively austere defense spending. These recommendations focus primarily on ensuring that senior civilian and military leaders are provided with sufficient information to enable guidance development and dissemination, robust oversight and strong bureaucratic incentives toward maintaining a healthy technological edge over plausible competitors.

Congress should:

- Require the Secretary of Defense to issue annual reports on the state of defense research and development across the enterprise. This would help ensure that the Office of the Secretary of Defense (OSD) and the military services maintain a consistent focus on the issue and provide Congress and the public with an annual baseline for oversight and analysis.
- Form temporary or permanent subcommittees of the Senate and House Armed Services Committees tasked with ensuring dedicated oversight of defense research and development spending. As an alternative, annual hearings by the most relevant current subcommittees may be sufficient.

The Secretary of Defense should:

- Task the Deputy Secretary of Defense to create a standing next-generation technology task force, perhaps modeled after the Defense Science Board Task Force. It should be charged with three priorities: ensuring that investments in game-changing technologies are not disproportionately targeted for cuts during the downturn; ensuring that experimentation efforts continue to encourage an innovative organizational culture that accepts the possibility of failure; and facilitating active coordination between the Under Secretary of Defense for Policy (OSD-P), the Under Secretary of Defense for Acquisitions, Technology and Logistics, the Joint Staff and the military services.
- Task OSD-P to ensure that the standing set of long-range defense planning scenarios takes full account of plausible next-generation game-changing technologies. This would help counter the often substantial pressure for long-term scenarios to be built around today's platforms, technologies and concepts of operation.
- Commission a series of studies exploring how best to retain adequate human decisionmaking and oversight of the use of emerging technologies (particularly autonomous systems) in plausible potential future crises.
- Initiate a multiyear series of war games designed to increase understanding of how current and plausible future advances in military and commercial technology may alter military competitions in Asia, the Middle East and elsewhere.
- Ask the Chairman of the Joint Chiefs of Staff to task the military service chiefs and the regional combatant commanders to consider ways to integrate and better collaborate on development and potential employment of next-generation technology.

Finally, the White House should:

- Create a standing joint interagency policy committee (IPC) to examine the state of national security research and development priorities, policies and funding. This committee should be co-chaired by senior representatives from the White House Office of Science and Technology Policy, the Office of Management and Budget and the National Security Staff. The IPC should be tasked to ensure that multiagency, multiservice approaches are taken to preserving robust research and development programs across the government.
- Establish a standing forum, through the Office of Science and Technology Policy, to help increase the number and scale of public-private partnerships designed to apply advanced technology to tough national security problems.

VIII. "LOCKING IN" AMERICA'S PRIVILEGED TECHNOLOGICAL POSITION

Today's emerging technologies have tremendous potential to coalesce in ways that could spark another military-technical revolution. Unfortunately, neither DOD nor the broader national security establishment has devoted adequate attention to understanding the strategic implications of emerging technologies and ensuring that the right investments are being made and sustained during a deep decline in defense spending.

America's privileged position in military technology is not an inherent right.

For decades, American defense strategy has focused on maintaining a clear technological lead – in the capabilities used to defend U.S. interests; the concepts of operation that can maximize effectiveness on the battlefield; and the human capital that can create, design and innovate ahead of other countries. If not managed properly, reduced defense spending – and especially the extremely short-sighted sequestration mechanism – may erode both the investment capital and human capital needed to realize the full potential of the game-changing technologies described above. America's privileged position in military technology is not an inherent right. Regardless of the years of constrained defense spending to come, policymakers must ensure that they build on the legacy of technological dominance left by previous generations.

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Center for a New American Security
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