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20YY
Preparing for War in the Robotic Age

By Robert O. Work and Shawn Brimley

Center for a New American Security

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About the Authors

Robert O. Work is the CEO at the Center for a New American Security.

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

20YY: PREPARING FOR WAR IN THE ROBOTIC AGE

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I. EXECUTIVE SUMMARY

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Over the past several decades, the United States has been an aggressive first mover in a war-fighting regime centered on guided munitions and integrated battle networks. These innovations have allowed U.S. forces to operate relatively uncontested in space, in the air, and on and under the sea, and to dominate conventional force-on-force land combat. For a variety of reasons – the geopolitics of rising powers, the global diffusion of technology and counter-reactions by its adversaries chief among them – the preeminence enjoyed by the United States in this regime is starting to erode.

As a result, U.S. defense strategists and force planners are confronted by a rapidly approaching future in which guided munitions and battle networking technologies have proliferated widely and are employed by both state and non-state actors across the full range of military operations. While senior force planners and policymakers at the Pentagon, White House and Capitol Hill increasingly recognize the potential challenges and costs of operating against adversaries with such sophisticated weapons, much remains to be done to prepare the U.S. military for fighting against adversaries capable of firing dense, accurate salvos of guided munitions.

But the shift to something resembling guided munitions parity is only a predicate challenge to a potentially deeper revolution afoot – a move to an entirely new war-fighting regime in which unmanned and autonomous systems play central roles for the United States, its allies and partners, and its adversaries. U.S. defense leaders should begin to prepare now for this not so distant future – for war in the Robotic Age.[1]

Unmanned systems are familiar to the U.S. military, which has employed them in extensive and sometimes dramatic fashion during the last decade in Iraq, Afghanistan and elsewhere. But these largely remotely piloted air and ground vehicles will soon be replaced by increasingly autonomous systems in all physical operating domains (air, sea, undersea, land and space) and across the full range of military operations. The United States will be driven to these systems out of operational necessity and also because the costs of personnel and the development of traditional crewed combat platforms are increasing at an unsustainable pace.

Unlike during the Cold War, when advanced technologies such as missiles, guided munitions, computer networking, satellites, global positioning and stealth stemmed largely from government-directed national security research and development strategies, the movement toward the Robotic Age is not being led by the American military-industrial complex. While defense companies are pursuing advanced stealth systems, electric weapons and protected communications, companies focused on producing consumer goods and business-to-business services are driving many other key enabling technologies, such as advanced computing and "big data," autonomy, artificial intelligence, miniaturization, additive manufacturing and small but high density power systems. All of these technologies – largely evolving in the thriving commercial computing and robotics sectors – could be exploited to build increasingly sophisticated and capable unmanned and autonomous military systems.

A new war-fighting regime in which guided munitions and battle networking has fully proliferated and unmanned and autonomous systems have become central to combat will take some time to manifest fully. Accordingly, we call this the "20YY" regime to avoid needless debate over what decade or year it might occur. Nevertheless, some of its implications are already becoming clear.

A warfare regime based on unmanned and autonomous systems has the potential to change our basic core concepts of defense strategy, including deterrence, reassurance, dissuasion and compellence. These systems will have different characteristics than their manned counterparts and will reshape how the U.S. military postures and bases its forces around the world and how senior decision-makers consider decisions about the use of force. Managing stability during periods of tension may become far more difficult. The integration of manned and unmanned systems in the armed services will spur profound debates regarding U.S. military roles and missions, the operational concepts necessary to take full advantage of new technologies, and the ethical and moral implications of doing so. Even fundamental military concepts such as the relationship between offensive and defensive military strategies or the interplay of range, speed and mass will be greatly affected by a shift toward unmanned and autonomous systems.

The 20YY war-fighting regime is not the realm of science fiction. This report outlines why we believe this shift is coming, what it heralds for U.S. defense strategy and national security, and why and how the Department of Defense (DOD) should take advantage of this inevitable transition. There are profound opportunities to properly posture the U.S. armed services for this future if policymakers can make smart choices during the ongoing defense downturn. There are equally great risks, however, that poor decisions and a slow recognition of these powerful trends will put tomorrow's U.S. military at unnecessary risk.

II. A PERIOD OF POTENTIAL DISCONTINUOUS CHANGE

While U.S. military planners have always sought a technological advantage over their potential adversaries, achieving and maintaining technological superiority became a central element of U.S. grand strategy during the Cold War. This edge was considered vital to help the U.S. armed forces overcome the significant quantitative advantage in conventional forces enjoyed by the Soviet military. Ultimately, America's technological offset strategy underwrote its conventional (as well as its nuclear) deterrent and helped to win the Cold War.[2] It then provided the U.S. military with unchallenged military superiority for the first two decades after the fall of the Soviet empire. As a result, technological superiority over potential state adversaries is now considered a foundational aspect of any U.S. defense strategy.

Today, however, many of the innovations spurred by the intense military-technical competition with the Soviet Union – in missilery, space systems, guided munitions, stealth and battle networking – have proliferated widely enough to pose challenges to traditional forms of U.S. power projection. As such, military planners must now assume that in some future scenarios U.S. armed forces may be forced to fight for theater access and freedom of maneuver in ways not seen since World War II. The ramifications of this emerging anti-access-power projection competition is now an important part of various high-level debates at the Pentagon, forcing senior leaders to reconsider America's global defense posture and revise its contingency plans and procurement priorities.

Planning for a world of widely proliferated anti-access weapons would be challenging under any circumstances. The challenge is compounded by the need to account for an emerging set of new, potentially disruptive technologies that may create sharp discontinuities in the conduct of warfare.

Technological superiority over potential state adversaries is now considered a foundational aspect of any U.S. defense strategy.

Chief among them is the rise and rapid proliferation of unmanned systems. Unmanned systems have already profoundly reshaped U.S. defense strategy and procurement priorities and are growing increasingly important in militaries worldwide. Thousands of unmanned systems of various types are now found in the U.S. inventory. At least 75 countries are investing in unmanned systems.[3] Other emerging technologies may disrupt the global military balance as well, such as offensive cyber warfare tools; advanced computing; artificial intelligence; densely interconnected, multi-phenomenology sensors; electric weapons such as directed energy, electromagnetic rail guns and high-powered microwave weapons; additive manufacturing and 3-D printing; synthetic biology; and even technologies to enhance human performance on the battlefield.[4] All of these technologies – driven primarily by demand and advances in the commercial sector – are emerging today and hold the potential to spark a new "military-technical revolution."

A military-technical revolution (MTR) occurs when new military technologies, operational concepts, and organizations combine to produce dramatic improvements in military effectiveness and combat potential.[5] As argued by military theorists, MTRs are often associated with broader revolutions in warfare – periods of sharp, discontinuous change that render obsolete or subordinate existing military regimes or the most common means for conducting war. These changes may

The Navy experimental unmanned aircraft, the X-47B, taxis to it's launch position on the flight deck aboard the nuclear powered aircraft carrier *USS Theodore Roosevelt,* off the Virginia coast, Sunday, Nov. 10, 2013. The Navy says the tests have demonstrated a drone's ability to integrate with the environment of an aircraft carrier.

(STEVE HELBER/Associated Press)

apply to militarily relevant technologies, concepts of operation, methods of organization, available resources, or a combination of several of these things. They are also often linked with broader political, social, economic and scientific transformations. The development of an MTR may be rapid or it may evolve more gradually before a revolutionary threshold is reached. Once this occurs, existing military regimes are often upended by new more dominant ones, leaving old ways of warfare behind.[6]

The premise of this paper is that the next several decades may see a period of discontinuous change in both technology and warfare. This premise is based on four perceived trends. First, as the guided munitions-battle network regime continues to mature, the monopoly long enjoyed by the United States in this regime will likely continue to erode as the associated technologies proliferate to both state and non-state actors alike. This will require the armed forces to develop new ways and means to operate and survive on ever more lethal battlefields. Second, the increasing lethality of guided munitions warfare, coupled with the rising costs of manpower and crewed combat systems and commensurate reduction in their numbers, will likely lead to a smaller U.S. military, which, while qualitatively superior, may not have sufficient quantity to prevail against sophisticated adversaries. Third, rapid advances in computing power, big data, artificial intelligence, miniaturization, robotics and additive manufacturing, among others, will make unmanned systems increasingly capable, autonomous and more cost-effective. Fourth, as more and more adversaries begin to employ guided munitions and as large numbers of effective and low-cost unmanned systems proliferate, mass will likely once again become more prominent in U.S. military force-on-force calculations. And, because

On Military Revolutions

A number of commentators have written about military-technical revolutions, revolutions in war, revolutions in warfare and revolutions in military affairs.[7] While these terms are often used interchangeably, they should not be.

We prefer and use the term "military-technical revolution" to describe dramatic improvements in military effectiveness and combat potential due to the application of new technologies or combat systems. We adopt Eliot Cohen's term "revolution in warfare" to describe periods of discontinuous change that upend existing military regimes or, as argued by Richard Hundley, existing military core competencies. We believe that even as the ways and means of warfare evolve over time, the fundamental nature of war remains immutable. Moreover, we see these two terms as related but distinct. As Hundley argues, not all revolutions in warfare are technology driven. Similarly, not all military-technical revolutions lead to broader revolutions in war. Finally, we avoid using "revolution in military affairs" altogether, a term that came to vogue in U.S. defense circles in the 1990s, because it is associated with two ideas we categorically reject: that technology will lead to "dominant battlespace awareness" and "dominant battle knowledge," essentially lifting the fog and friction of war; and that the combination of battle networks and guided munitions will make future wars short, sharp, clean and relatively casualty free.

Like Barry Watts, we subscribe to the notion that "the fundamental nature of war is essentially an interactive clash – a *Zweikampf* or two-sided 'duel,' as Carl von Clausewitz characterized it – between independent, hostile, sentient wills dominated by friction, uncertainty, disorder and highly nonlinear interactions."[8] Nothing about technology – bullets, bombs, or robots – alters the fact that war is a human endeavor, with decidedly deadly consequences for warfighters and civilians once the forces of war are unleashed. Technology does not make war more clinical; it makes it more deadly. Precision does not make the battlefield more sterile, but rather makes it increasing lethal. The technologies and trends explored in this report will make future battlefields more complex for defense leaders, and more dangerous for those in harm's way.

of the high cost of people and manned platforms, the impetus toward greater battlefield mass is more likely to be reflected in greater numbers of unmanned systems rather than in more or larger manned units or crewed systems.

We hypothesize that these four trends may spark a new unmanned military-technical revolution, and perhaps even a broader revolution in warfare. In order to maintain its technological superiority during and after the transition from one war-fighting regime to another, the Department of Defense must begin now to prepare for it. However, the U.S. armed forces are just coming to grips with the operational and organizational ramifications of the steadily maturing guided munitions-battle network regime. Thinking about the successor robotic regime likely following closely in trail is even less mature. As a result, DOD is in danger of making poor decisions during the coming defense drawdown, during which the Pentagon must make disciplined, prioritized programmatic choices if it hopes to prepare the U.S. armed forces for a future characterized by ubiquitous unmanned and autonomous systems. To allow the U.S. military both to weather these buffeting winds of change and to capitalize on real opportunities to extend America's technological edge, DOD must urgently spur new thinking and research on the changing nature of warfare and the types of new systems, organizations, and operational concepts needed to conduct it.

III. THE RISE OF GUIDED MUNITIONS WARFARE

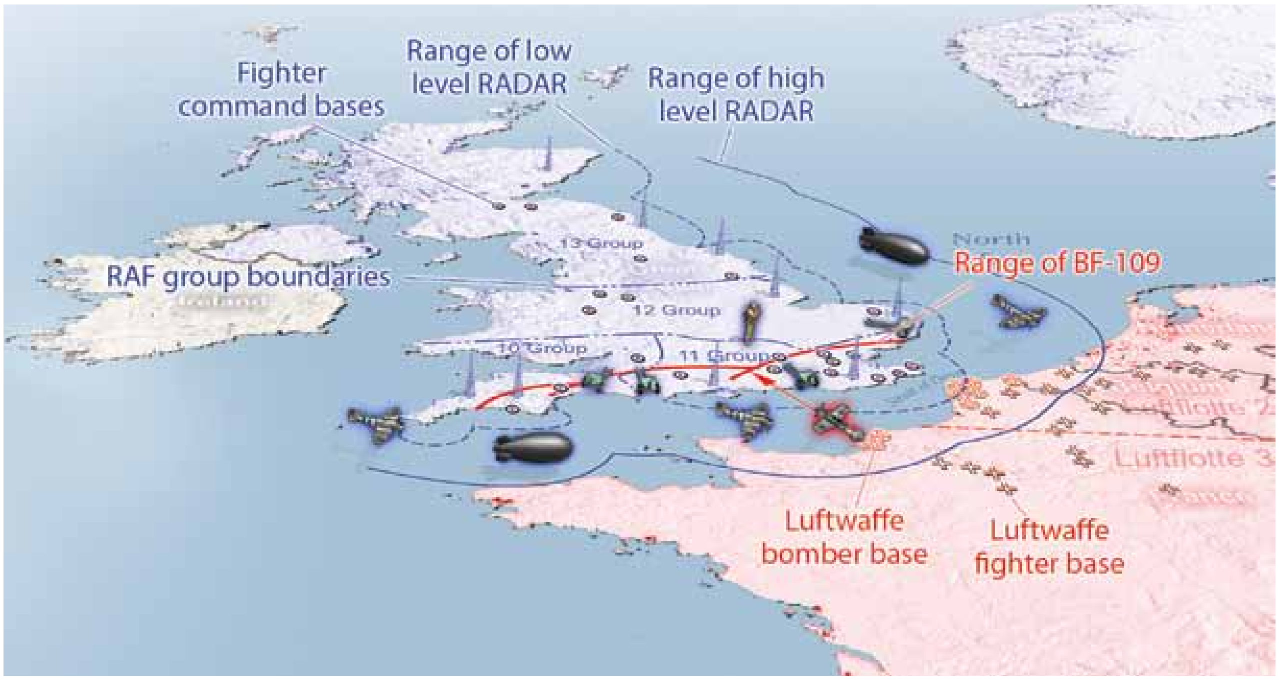
Before exploring the contours of any potential future revolution in warfare, however, it is important to understand fully the current war-fighting regime, in which combat will be dominated increasingly by guided munitions and the battle networks that employ them.

Since the first caveman picked up a club, extending one's reach to strike the enemy from standoff distances has been critical in warfare. Once rocks and spears were thrown in battle, and especially after slings and bows and arrows appeared, the contested zone between opposing forces expanded to hundreds of yards wide. With the development of modern firearms and machine guns, contested zones expanded to more than a thousand yards; with artillery, tens of miles; and with air-dropped bombs, hundreds of miles. The key characteristic of combat using unguided, ballistic munitions – even over relatively short ranges – was that most munitions that were thrown, shot, fired, launched, or dropped ultimately missed their targets. Moreover, miss distances increased rapidly as the range to target increased. Consequently, especially when firing at targets that first moved freely in two dimensions (e.g., maneuvering troops, cavalry, vehicles or ships) and later in three (e.g., aircraft, missiles, submarines, etc.), or while firing at fixed or moving targets from a moving platform (e.g., horses, tanks, aircraft, submarines, ships, etc.), a force had to mass hundreds of platforms or weapons systems, release thousands of projectiles, bombs, or munitions, or both, to achieve the desired battlefield effects or accept the risks of closing the range.[9] Similarly, to maximize success at the point of an attack, maneuver forces would often seek to aggregate forces in order to achieve a local superiority in numbers and to increase the effectiveness of their preliminary bombardments. As a result, unguided weapons warfare had an inherent bias toward mass.

During World War II, two technical alternatives to unguided weapons warfare presented themselves, both with latent revolutionary effects. The one with the most immediate, visceral impact was the atomic bomb – a weapon with enough sheer explosive power to destroy all but the most hardened targets, even with relatively large aiming errors. Given their great destructive potential, for a time atomic weapons upended the tactics associated with unguided weapons warfare. Military planners assumed they would have to disperse their forces for survivability, mass only when necessary to achieve effects, and then quickly re-disperse before being subject to atomic strike. However, the command and control and mobility challenges associated with continually dispersing, massing and re-dispersing forces under the threat of atomic attack vexed military planners throughout the 1950s.[10] Consequently, once the United States and Soviet Union achieved nuclear parity and the likelihood of tactical nuclear warfare faded, military planners generally reverted to the familiar massed conventional tactics of the unguided weapons era.

The second technical alternative to unguided weapons warfare came in the form of guided conventional weapons – weapons that actively corrected their trajectories and flight paths to home in on their targets or aim points after being fired, released, or launched.[11] These weapons made their combat debut in 1943. That year, German submarines launched the first passive acoustic homing torpedoes against two allied convoys, sinking several merchant ships in the process. U.S. Navy patrol aircraft scored the first U-boat kill using the Mark 24 FIDO air-dropped acoustic homing "mine." And German bombers used six Fritz X radio-controlled guided glide bombs to sink the Italian battleship *Roma*.[12] As even these early weapons proved, guided munitions often achieved direct hits on their targets even when fired singly or in small salvos. Moreover, guided

FIGURE 1: BRITISH TACTICAL BATTLE NETWORK DURING 1940 BATTLE OF BRITAIN



During the Battle of Britain, defending forces employed a tactical battle network consisting of radar and spotters (a surveillance grid), hardened operations centers connected by radio and underground cables (a command, control and coordination grid), and a series of battlefield systems including anti-aircraft guns and fighter squadrons (an effects grid). The use of this tactical battle network decreased the element of surprise, allowing the outnumbered defenders to mass at the point of German attack.

weapons had the same accuracy whether fired at their minimum or maximum engagement ranges. In other words, conventional guided munitions introduced a new combat engagement paradigm: *weapons accuracy independent of range.*

Having munitions able to correct for aiming errors and reduce miss distances to near zero even across great engagement ranges sparked additional technological adaptation. Since having an advantage in reach over an adversary is useful in almost any force-on-force combat situation and in any operating domain, soon after the first guided weapons appeared, tactical users naturally sought munitions with greater and greater maximum effective ranges. Indeed, in 1945 – just two years after the first guided weapons were employed – a U.S. patrol aircraft struck and nearly sunk a Japanese destroyer at a range of 20 nautical miles with a radar-guided anti-ship glide bomb, all while operating safely beyond the range of the destroyer's defensive battery.[13] Obviously, these types of "over-the-horizon" engagements required some type of cueing and aiming system. The quest for increased effective weapon ranges thus spurred the co-development of new *battle networks* – sensing, tracking, targeting and planning networks – designed to direct long-range salvos of guided munitions.[14]

The first battle networks actually came before the development of guided weapons. For example, in 1940 during the Battle of Britain, the outnumbered British air and air defense forces opposed attacking German bombers with a tactical battle network consisting of: a *surveillance grid* with both long- and short-range sensors (radar and spotters); a dedicated *command, control and coordination (C3) grid* consisting of distributed and hardened operations centers connected by radio and buried telephone cables; and an *effects grid* that employed an array of battlefield systems, including radar-controlled anti-aircraft guns, British fighter squadrons, barrage balloons and electronic combat forces.[15] However, this battle network primarily helped take surprise out of the equation. This was an important development, allowing the outnumbered and outgunned Royal Air Force to effectively counter German attacks. At the point of interception, however, massed British fighter formations armed with machine guns firing unguided rounds still hurled themselves against massed German bomber streams defended by bomber crewmen and defending fighters shooting unguided rounds. It was not until the effects grids of subsequent air defense networks included guided surface-to-air and air-to-air missiles that massed collisions of defending and attacking air forces began to change. Accordingly, the development of ever more capable guided weapons and battle networks has been forever inextricably linked.

Together, the combination of guided weapons and battle networks sparked a period of relatively rapid change in warfare. After 1945, war-fighting community after war-fighting community adopted guided weapons and assembled the tactical battle networks to employ them, spurring tactical innovations and improvements in combat performance in all operating domains. The first-movers consisted of those communities forced to engage targets that moved freely in three dimensions, such as the air defense, air-to-air fighter and anti-submarine warfare communities. During the 1950s, many of the early generations of guided munitions had atomic warheads to offset deficiencies in their terminal accuracy. By the Vietnam War, however, most tactical munitions were armed with conventional warheads, due both to improvements in terminal guidance systems and concerns over nuclear escalation. Moreover, the U.S. air-to-ground community began experimenting with a new generation of offensive guided weapons, including bombs and missiles with electro-optical, laser or anti-radiation guidance. These weapons proved to be extremely accurate, allowing U.S. tactical air forces to attack a wide array of targets with unerring precision.[16]

The Vietnam War was followed by the 1973 Yom Kippur War, which punctuated the increasing lethality of guided munitions on the battlefield.[17] The dramatic effectiveness of these weapons spurred American defense thinkers to begin exploring new operational concepts that linked long-range sensors and guided munitions to counter the Soviet conventional numerical superiority in Europe. These new operational concepts, highlighted during experiments and exercises, demonstrated great promise. Indeed, by the mid-1980s, they caused Soviet military theorists to conclude that the linking of wide-area sensors, new methods of command and control, and long-range conventional guided munitions would represent a new military technical revolution, as the resulting "reconnaissance-strike complexes" would be able to achieve destructive effects equivalent to tactical nuclear weapons.[18]

As was the case for nuclear weapons, the culmination of guided munitions and battle networks employed in reconnaissance-strike complexes promised to alter fundamentally the requirement for battlefield massing in large force-on-force engagements – but in a more elegant and tactically useful way than nuclear weapons. Since a single guided weapon had a good chance of destroying or neutralizing its intended target, instead of having to mass enough weapons to ensure a single target was hit, an attacker had only to fire enough weapons to saturate an opponent's defenses. And, when firing munitions blessed with accuracy independent of range, forces could now *mass effects by fire* from great distances while operating from a dispersed posture, using far less ammunition. Consequently, a smaller defending force employing

A Tomahawk cruise missile lights up the night sky as it is fired from the *USS Wisconsin* in a January 1991 file photo. The effectiveness of guided munitions during the war led the U.S. military to make a concerted move toward a new war-fighting regime.

(JOHN MCCUTCHEON/Associated Press File Photo)

guided munitions might defeat a larger attack force that employed only unguided munitions.[19] Similarly, offensive forces firing guided munitions could be made much smaller and could conduct distributed attacks across wide fronts or along multiple axes, further adding to the burden of the defense. Accordingly, in collisions between conventional forces, a smaller force employing guided weapons might be capable of defeating a much larger force that employed unguided ones.

This type of thinking appeared to be validated in the 1990-91 Persian Gulf War, when a U.S.-led coalition attacked an Iraqi army built in the Industrial Age for unguided munitions warfare. Even though guided munitions represented less than 10 percent of all American munitions expended during the war, their astounding accuracy and battlefield effectiveness seemed to confirm Soviet theorizing about the revolutionary effects of new operational guided-weapon battle networks which would render unguided weapons warfare subordinate in large force-on-force engagements. Consequently, one can think of Operation Desert Storm as the "defining battle" of the guided munitions-battle network revolution, spurring the American military – particularly its air forces – to make a concerted move toward guided munitions.[20]

This move was made easier because the U.S. components for effective operational battle networks had been assembled during the Cold War. The American space-based strategic intelligence, surveillance and reconnaissance (ISR) grid, originally designed to support national leaders, was reconfigured to provide direct support to theater commanders and their forces. The U.S. global command, control, communications, computer and intelligence (C4I) grid,

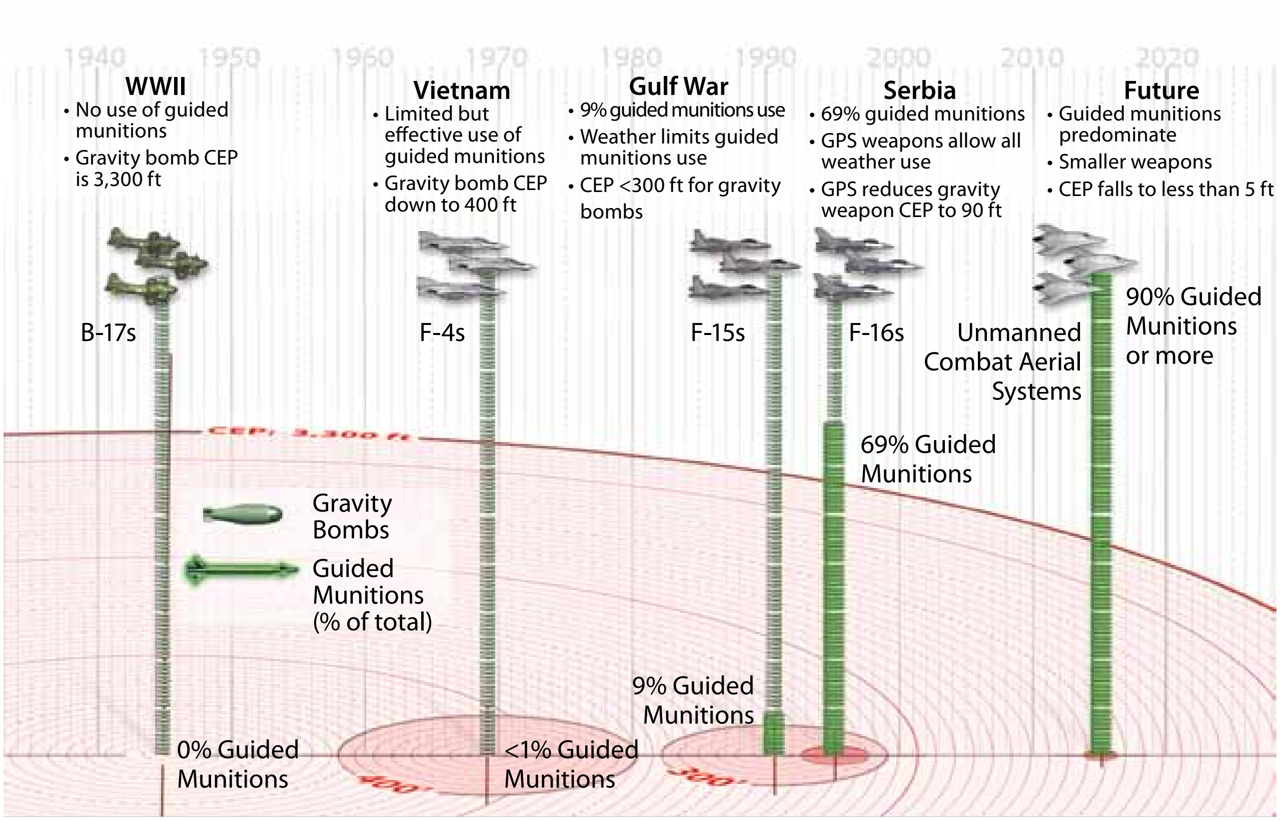
A fighter from the Tawhid Brigade, which operates under the Free Syrian Army, fires an anti-tank missile in Aleppo, Syria in November 2013. (MOLHEM BARAKAT/Reuters)

designed to continue operations during and after a nuclear exchange, was similarly reconfigured to support theater campaigns. Under the banner of "C4I for the Warfighter," the C4I grid gradually transitioned from mainframe computers to distributed servers and desktops in regional operating centers around the globe, utilizing new Internet protocols. This transition helped combat forces fighting in distant theaters of operations to form common operating pictures and conduct interactive, collaborative planning at all levels. Finally, U.S. effects grids were improved with the development of bombs and missiles with reliable Global Positioning System (GPS) and inertial navigating systems, which could be employed day or night and in all weather conditions, allowing sustained 24-hour-a-day guided munitions bombardment.

These moves all contributed to the formation of very powerful Joint multidimensional battle networks that employed greater and greater percentages of guided munitions. Indeed, by 1999, approximately 30 percent of all air-to-ground weapons employed against Serbian forces during Operation Allied Force were guided. Four years later, during Operation Iraqi Freedom, the percentage of guided weapons rose to nearly 65 percent of all munitions expended.[21] The effectiveness of these weapons spurred other war-fighting communities to begin developing an array of battlefield guided rockets, artillery, mortars and missiles (often referred to as G-RAMM), many of them employed to great effect later in Iraq and Afghanistan.

As an opportunistic and aggressive first mover in the guided munitions-battle network regime, the United States accrued significant combat advantages in conventional force-on-force engagements, as seen in Operation Desert Storm, the initial stages of Operation Enduring Freedom, and the early conventional phase of Operation Iraqi Freedom. These advantages were so pronounced, and so difficult to duplicate on the scale produced

FIGURE 2: ACCURACY AND EMPLOYMENT OF AIR-DROPPED GUIDED MUNITIONS BY UNITED STATES



CEP, a measure of accuracy, defines the radius of a circle in which 50% of a salvo's munitions fall. Since WWII, CEPs for guided munitions have fallen precipitously. The above image illustrates falling CEPs for air-dropped munitions since World War II and the increasing employment of guided munitions since the Vietnam War.

by American forces, that potential adversaries quickly sought means to blunt the effectiveness of U.S. guided munitions-battle networks.

One approach for an opposing force was to deny or hinder the American's ability to find and attack targets by practicing deception, going underground or hiding in caves. These tactics were practiced effectively by the Serbian army during Operation Allied Force, al Qaeda and the Taliban in Afghanistan and Pakistan, and the North Koreans and Iranians.[22] Another effective variant of this target denial strategy was for an enemy to hide "amongst the people" and conduct close-in ambush attacks, as practiced by Islamist terrorist groups in both Iraq and Afghanistan.[23] A different approach was to try to deter attacks by a U.S. multidimensional conventional battle network by pursuing nuclear weapons, as practiced by North Korea and now threatened by the Iranians. Another was to use guided munitions and battle networks in discrete combat situations in order to even the odds and inflict heavy casualties on technologically superior militaries. This tactic was employed by the Vietnamese Peoples Air Force against U.S. tactical air forces in the skies over North Vietnam and the Egyptian Army against the Israeli Defense Forces in 1973, and by Hezbollah against the Israelis in the 2006 Lebanon War.[24] And, of course, opponents could try limit the effectiveness and operational relevancy of guided munitions and battle networks by avoiding large force-on-force confrontations altogether and waging long-term insurgencies designed to exhaust American power and will, as seen in Iraq and Afghanistan.

All these approaches represent strategies of weaker powers, however. It seemed reasonable to assume that at some point in the future the U.S. military might confront a more formidable adversary capable of competing directly in the new war-fighting regime on far more equal terms. This eventuality was explored as early as November 1993 in a draft thought piece written by Michael G. Vickers for the Office of Net Assessment (ONA) in the Pentagon. The premise of *A Concept for Theater Warfare in 2020* was that the guided munitions-battle network revolution would likely transform the conduct of war between large state adversaries during the next two to three decades. The paper envisioned new systems, organizations and concepts of operations to construct a single, coherent vision of how war might be fought in a new, discontinuous military regime characterized by warfare between adversaries *with conventional guided munitions-battle network parity.* The intent was to identify potential new strategic, operational and tactical problems posed by the emerging military revolution for further analysis, computer simulation and war-gaming, in order to stimulate the development of new concepts and organizations within the U.S. armed forces.[25]

Vickers' paper spurred rich debate and thinking about the potential future of interstate war in a war-fighting regime characterized by widely proliferated long-range precision strike capabilities. It also prompted ONA to sponsor a war game series called Future Warfare 20XX. The 20XX games, which began in 1995 and continued through December 2000, were waged in an alternate future where the key technological and strategic trends described in *A Concept for Theater Warfare in 2020* had fully played out. Game conflict scenarios were set in the unspecified year of "20XX" to avoid needless debate over the precise time frame during which the postulated forces and capabilities might become available. In practice, however, players assumed the games were set sometime between 2025 and 2030 (approximately 30 years in the future).[26]

The purpose of the war games was to analyze the 20XX MTR regime and its associated force capabilities; evaluate candidate MTR operational and organizational concepts; and identify operational and organizational issues that merited further exploration and investigation.[27] To reach these aims, the games explored in detail mid- to high-intensity warfare in a fully mature guided munitions war-fighting regime in which the United States and its allies waged advanced, multidimensional campaigns against a large peer competitor and its allies. The large peer competitor was presumed to have rough guided munitions and battle network parity with the U.S. military, albeit with asymmetrical capabilities. Game play included operations within and across all operating domains and employment of advanced biological weapons.[28]

By the end of the series, game players and observers concluded that three key drivers would establish the basic contours of the envisioned 20XX regime. These drivers were:

- Nuclear weapons and deterrence would continue to truncate conventional war below the strategic level;
- Guided munitions warfare was offensive dominant, meaning offensive striking capabilities would tend to dominate defensive ones; and
- Stealth, broadly defined, would not only remain practicable, but would also become central to survival in the guided munitions-battle network regime.[29]

IV. IMPLICATIONS OF A MATURE GUIDED MUNITIONS-BATTLE NETWORK REGIME

The Future Warfare 20XX war game series was considered a great success within the Office of Net Assessment. The hope was that the insights and thinking developed over the course of the series would help prompt and inform a thorough transformation of the U.S. armed services, with new sensors, weapons systems and operational concepts in better alignment with the guided munitions war-fighting regime. During the decade after the attacks of September 11, 2001, however, the U.S. military headed in a direction that at first appeared much different from that posited in Future Warfare 20XX. Having found itself in two long-term irregular campaigns in Iraq and Afghanistan, the U.S. armed forces naturally focused their attention on counterinsurgency and counterterrorist operations instead of conventional force-on-force combat. Indeed, the nature of these two campaigns caused many to openly question or disparage the thinking behind the "revolution in military affairs" touted in the 1990s.[30]

Nevertheless, while the specific form of theater warfare envisioned in the Future Warfare 20XX games did not immediately come to pass (nor did the games project this to happen), many of the fundamentals foreseen by the game have, perhaps surprisingly, borne fruit even as the U.S. military found itself waging irregular conflicts. As terrorists and insurgents began hiding among the people and in complex and urban terrain, they were hounded by a patient and relentless man-hunting campaign, facilitated by sophisticated human tracking sensor grids, a highly integrated interagency C3 and targeting grid, and an effects grid including special operations forces and progressively smaller guided munitions capable of striking individuals accurately with very little collateral damage. Indeed, given the discrete lethality of the effects grid, the balance of effort in U.S. counterterrorism operations has focused much more on "finding" and "fixing" bad actors – with "finishing" generally the least time-consuming aspect of any operation. This is precisely the same type of intense "hider-finder" competition foreseen in high-intensity guided munitions warfare, if different in kind.[31]

The effect has been that the dominance enjoyed by the United States in the late 1990s/early 2000s in the areas of high-end sensors, guided weaponry, battle networking, space and cyberspace systems, and stealth technology has started to erode. Moreover, this erosion is now occurring at an accelerated rate.

Meanwhile, in the 13 years since the last 20XX game, foreign nation-state C4I, surveillance and reconnaissance systems, and guided munitions-battle network capabilities have become increasingly sophisticated and capable. Indeed, these systems now form the very robust and advanced "anti-access and area denial" (A2/AD) capabilities envisioned in the 20XX war game series.[32] The effect has been that the dominance enjoyed by the United States in the late 1990s/early 2000s in the areas of high-end sensors, guided weaponry, battle networking, space and cyberspace systems, and stealth technology has started to erode. Moreover, this erosion is now occurring at an accelerated rate.[33]

A fully armed MQ-9 Reaper unmanned aerial vehicle taxis down the runway at an air base in Afghanistan in 2007, on its way to another wartime mission. Unmanned systems will evolve from largely remotely-piloted vehicles to increasingly autonomous systems. Dozens of countries are investing in unmanned systems of all types.

(STAFF SGT. BRIAN FERGUSON, USAF/Associated Press)

- Emblematic of what is possible with advanced battle networks is the People's Republic of China's (PRC) assembly of a multidimensional, land-based reconnaissance-strike complex, which aims to deter, forestall and ultimately defeat any outside military intervention into the Western Pacific region. Whereas the preferred effectors in U.S. operational battle networks are currently shorter-range air-delivered munitions, the PRC military emphasizes longer-range ballistic and cruise missiles. Indeed, the ballistic missiles of the People's Liberation Army's Second Artillery Corps can already reach American forward bases throughout East Asia and carrier strike forces operating at sea inside the "second island chain." The missiles may soon be capable of reaching U.S. bases on Guam.[34]
- Beyond advanced competitors such as China and Russia, as guided munitions and battle networking technologies have become less expensive and more widely proliferated, second-tier states such as Iran have also begun to pursue ballistic missiles and guided munitions. Additionally, Iran has also transferred increasingly sophisticated guided weapons to its non-state proxies, including Hezbollah.[35]
- Guided rockets, artillery, mortar rounds and

missiles are now increasingly found in the order of battle of most modern militaries and even some non-state actors.[36]

- Finally, irregular adversaries can create their own simple guided munitions simply by appropriating commercially available technologies such as small unmanned aerial vehicles and packing them with explosives. Or, as was the case on September 11, 2001, by hijacking an aircraft and employing it as a heavy cruise missile.

This discussion is not meant to imply that the future of warfare will be characterized solely by collisions between battle networks employing guided munitions. Because of the nuclear overhang, the chance of direct wars with advanced states is relatively low. Far more likely will be conflicts with their regional proxies or other regional powers. Even then, direct force-on-force battles may be rare, with irregular warfare, insurgencies, and terrorism more prevalent. Such conflicts will continue to be messy, deadly affairs, with more deaths caused by small arms or even machetes than guided munitions. But that does not mean that the maturation of the guided munitions-battle network regime can or should be ignored. Given the foregoing observable trends and the demonstrated lethality of combat with guided munitions, future U.S. military interventions are likely to be increasingly costly across the full range of military operations. As retired Lieutenant General George Flynn, U.S. Marine Corps, noted, " … the prospect of even non-state actors being able to hit more or less everything they aim at with precision guided mortars, artillery and short-range rockets is not only worrisome, but unavoidable as relatively inexpensive guided weaponry proliferates world wide."[37]

V. NEEDED: A CONCERTED RESPONSE

Just as the U.S. military begins grappling with the implications of the steadily maturing guided munitions-battle network revolution, however, the United States finds itself on the leading edge of its fifth major defense drawdown since the end of World War II, and it could be a prolonged one. The 2012 Strategic Review, the 2013 Strategic Choices and Management Review and the follow-on Quadrennial Defense Review represent DOD's first attempts to balance its current and future military capabilities and capacities with reduced defense resources. They will not be the last. It may take three to five years – if not longer – before the department settles on a stable, balanced defense program, and the decisions made during this period are certain to have a lasting impact on the pace and direction of U.S. force modernization.

The key force design challenge will be to make this smaller future fighting force one that is as or more effective than the larger legacy force, and one that is capable of operating against and defeating adversaries with advanced capabilities.

Given current U.S. global security responsibilities, the natural tendency will be to give preference to military capabilities that are perceived to be more affordable or "good enough" for today's adversaries, rather than making new investments in research and development or pursuing more expensive, advanced systems focused on potential future high-tech warfare. In addition, as the services necessarily downsize to manage shrinking budgets, there will be a tendency to retain as much capacity in legacy platforms and approaches as possible, rather than reduce traditional platforms even further to pursue new, arguably untested concepts and technologies. Meanwhile, both first-tier states like China and Russia and second-tier states like Iran are exporting state-of-the art guided munitions and battle networking technologies to their allies or willing buyers, hastening their proliferation. And, as previously discussed, even non-state actors could introduce innovative and lethal military systems simply by buying and modifying commercially available technologies and systems. Moreover, China and Russia are investing heavily in even more advanced technologies such as cyber warfare tools, stealth and counter-stealth, and in capabilities designed specifically to exploit perceived vulnerabilities in U.S.-made systems. There is thus a real danger that traditional U.S. advantages will be negated or overtaken by future adversaries.

To avoid losing its technical edge and to account for the increased lethality of guided munitions warfare, the U.S. armed forces must first begin to develop new operational concepts aimed at securing and maintaining access, freedom of action, and tactical effectiveness during future power projection and battlefield operations. Such concepts will aid in identifying the new core tactical competencies, operational and organizational constructs, and combat systems needed to survive and thrive in a fully mature guided munitions-battle network regime. This is already starting to happen. The new Air-Sea Battle concept represents the first real attempt by U.S. defense planners to come to grips with fighting against potential adversaries capable of firing dense guided munitions salvos at range.[38] But much more work needs to be done. For example, the U.S. armed forces will need to update their thinking about Joint Forcible Entry Operations and AirLand Battle to account for fighting against adversaries that employ G-RAMM and the increasingly sophisticated tactical battle networks that employ them. Irregular warfare, counterterrorist and counterinsurgency concepts must also be updated to account for adversaries armed with advanced weaponry. Guided by these new concepts, DOD must next increase research and development spending and force designers must develop new combat systems, units and organizations. Service planners must then develop the tactics, techniques and procedures to best exploit them. The U.S. military must do all these things to preserve its technical and tactical edge into the future.

While updating and changing its operating concepts and tactics, techniques and procedures to account for a maturing and steadily more lethal guided-munitions battle network regime, U.S. force planners and designers must confront and deal with two dominating institutional trends. These are:

- **The high and steadily increasing cost of personnel.** Recruiting, training and retaining high-quality individuals for the American all-volunteer force have proved to be quite expensive, especially after a decade of war. Indeed, between FY 2001 and FY 2012, compensation costs per active-duty service member grew 57 percent. Adjusted for inflation, this equates to 4.2 percent real annual growth. Over the same time period, the share of the base DOD budget devoted to military personnel-related costs grew from 30 percent in FY 2001 to 34 percent in FY 2012. Even if the cost per service member returns to its historical norm of 2.6 percent real annual growth during the upcoming period of flat or declining overall defense budgets, by FY 2021 total military personnel-related costs (including active and reserve component forces) could consume nearly half (46 percent) of the DOD budget, crowding out both investment and operations and training dollars.[39] Unless this trend is arrested, personnel costs will inevitably create a system-wide end strength governor for the American all-volunteer force. Said another way, because of high and steadily increasing associated costs, future U.S. military forces will most likely have far fewer active duty personnel.
- **The high and steadily increasing costs for crewed combat platforms.** Similarly, U.S. armed forces will be unable to replace their current front-line combat systems and platforms on a one-for-one basis. To survive against steadily improving guided munitions and battle networks, crewed combat platforms of all types will need to be stealthy, able to fight from standoff ranges, or have highly capable active and passive defenses able to defeat repeated salvos of guided munitions – or some combination of all of these characteristics. However, these capabilities will come with a steep price. The F-22 Raptor and F-35 Lightning II Joint Strike Fighter both are exquisite air combat systems. But their procurement costs are much higher than the nonstealthy aircraft they replace.[40] Similarly, the new Flight III *Arleigh Burke*-class guided missile destroyer with its advanced Air and Missile Defense Radar, the Joint Light Tactical Vehicle, Ground Combat Vehicle and Amphibious Combat Vehicle will all likely to be far more expensive than their analogous legacy platforms. Moreover, the operations and maintenance costs for these new, more technologically advanced platforms will all likely be higher than the legacy systems they replace.

Barring a major increase in planned military spending during the next decade, then, the combination of these two trends means the U.S. armed forces will likely shrink in the coming years. The key force design challenge will be to make this smaller future fighting force one that is as or more effective than the larger legacy force, and one that is capable of operating against and defeating adversaries with advanced capabilities.

VI. THE RISE OF UNMANNED AND AUTONOMOUS SYSTEMS

One potential answer to this daunting force design challenge is increased use of unmanned systems. While attempts to build such systems stretch back all the way to ancient Greece, the first practical unmanned systems were self-propelled weapons, particularly underwater torpedoes. Developed by English engineer Robert Whitehead, these unguided, "straight-running" weapons were powered by compressed air and equipped with an internal mechanism able to maintain the weapon at a preset depth. Torpedoes were later followed by radio-controlled or wire-guided motorboats, stuffed with enough explosives to seriously damage or sink ships, and "land torpedoes," remote-controlled armored tractors meant to transport a half-ton of high explosives into enemy trenches.[41]

From these first early inventions, unmanned systems evolved along several different lines, including: aerial target drones; unmanned aerial systems; unmanned surface and underwater vehicles; unmanned ground vehicles; unmanned decoys; robotic rescue systems; remote logistics delivery systems; and unguided and guided munitions such as torpedoes, cruise missiles and guided bombs, which are now considered a separate category all their own.[42] The early impetus for many of these systems was to take over duties performed by humans or manned systems that were "dull" (involving long duration or repetitious operations), "dirty" (involving operations in contaminated environments), or "dangerous" (involving operations in which the danger to humans and manned systems was deemed unacceptably high, such as minesweeping, explosive ordnance disposal and attacks against battle networks employing guided weapons).[43]

Today, the U.S. armed forces operate many thousands of unmanned aerial vehicles of different types, suggesting the transition to a future unmanned war-fighting regime is well underway.[44] However, these numbers are quite deceiving. Because most of these unmanned systems were conceived, designed and built with the "dull, dirty and dangerous" paradigm in mind, they are more often than not viewed merely as adjuncts to manned systems. Moreover, many were designed to operate in uncontested environments with rudimentary battle networks and few guided munitions. This observation is not meant to imply unmanned systems do not perform valuable missions. It is simply to convey that despite their large numbers, the use of unmanned combat systems in the air, on land and on and under the sea is still very much in its operational infancy in the U.S. armed forces. Indeed, current concepts of operation barely scratch the surface of the potential for today's unmanned systems, much less future generations of far more advanced unmanned and increasingly autonomous platforms. The potential of the current generation of unmanned systems derive primarily from the performance advantages gained from removing a person from a platform, such as increased speed, maneuverability and endurance, and from the ability to take increased risk with unmanned platforms. The potential of future unmanned systems promises to be both more profound and possibly revolutionary in nature.

Current concepts of operation barely scratch the surface of the potential for today's unmanned systems, much less future generations of far more advanced unmanned and increasingly autonomous platforms.

Afghan residents look at a robot that is searching for IEDs (improvised explosive devices) during a road clearance patrol by the U.S. Army in Logar province, eastern Afghanistan in November 2011.

(UMIT BEKTAS/Reuters/Corbis)

The revolutionary potential of future unmanned systems is tied directly to several interrelated rapid advances in the technology sector, chief among them trends in communications and information technologies. Among the most important are:

- **Cyber warfare.** Cyber operations are a rapidly advancing dimension of warfare that will intersect heavily with warfare in the robotics age. Cyber is likely to be the new "high ground" in future warfare. An actor who dominates in cyber conflict can infiltrate command-and-control networks, generate misinformation and confusion, and potentially even shut down or usurp control over physical platforms. This will be especially true for unmanned systems, especially when operating remotely at a distance from their operators and maintainers. Moreover, as the "Internet of things" evolves and the Internet continues to colonize physical space, even more physical objects will be networked and remotely manipulable. Therefore, developments in cyber warfare are intimately tied to the development of the Internet, which is continually evolving at a rapid rate. How these co-developments play out over time will have an enormous impact on the pace and scope of the shift to unmanned and robotic systems.[45]
- **Protected communications.** Because of the threat of cyber warfare and advances in electronic combat, a common complaint heard

about unmanned systems is they are limited by the need for robust and reliable communications links to their human operators. However, the U.S. military is investing heavily in various forms of high-bandwidth, protected communications, such as advanced extremely high frequency satellites, laser and free-space optical communications, and with a new generation of small, low-cost receiving terminals. Together, these technologies will address the long-standing U.S. military demand for robust, anti-jam, and secure communications for tactical forces and platforms on the move in distant theaters. As these technologies become more available, many of today's concerns about being able to communicate reliably with unmanned systems over long ranges seem likely to be ameliorated. At the same time, redundant and secure line-of-sight communication links will allow groups and swarms of unmanned systems and platforms to maintain communications among themselves in even the most contested electromagnetic environments.[46] Because of their increased endurance, unmanned systems are in fact uniquely suited to perform the role of communications relays themselves, either in the air or undersea.

- **Advanced computing and big data.** Computers have always overmatched humans in crunching numbers. Today, they already make millions of calculations a second, and future computers will have even higher computational speeds. This will inevitably improve the performance of sensors, tactical decision aids, and weapons systems. At the same time, the amount of data available to users in many competitive domains, including military activity, is exploding.[47] The sheer amount of data now available is far beyond any human's ability to process, correlate and act upon it. Analysis of large data sets – now known as big data – will become a key basis of economic, scientific and military competition, as high-speed computers increasingly tap into enormous open source (or classified), cloud-based information repositories and make sense of it in ways heretofore considered impossible.[48] For the foreseeable future, human intelligence will continue to be required to apply context and judgment to data analysis and to account for qualitative insights.[49] However, future advances could lead to discontinuous jumps in computer processing and engineering that could allow computers to process huge data sets and portray the data in ways that mimic human intuition and judgment, leading to a new generation of powerful campaign and tactical decision aids.
- **Autonomy.** The ongoing fusion of sensor technology with advanced computational and processing power has enabled commercial and military platforms to become more aware of their environment and interact with it in the absence of human control. Early and significant steps in this regard include unmanned aerial systems able to take off, navigate to predetermined waypoints and land autonomously, as well as land-based counter-GRAMM and shipboard close-in defense systems capable of fully automatic operations. The future will see more revolutionary capabilities, up to and including the ability for platforms – singularly or in "swarms" – to perform a host of missions, including autonomous ISR, jamming, decoys, communications relay and cargo resupply. While human decision-making will likely retain advantages in situations that are complex, ambiguous, require understanding of context or require judgment for some time, steadily improving autonomous logic will certainly be useful in situations where simple, predictable tasks are being performed, where reaction time is critical, or where communications links with human controllers are fragile. For some types of target sets in relatively uncluttered environments, it is already possible to build systems that can identify, target and engage enemy forces, although current DOD guidelines direct that a human be in the loop for offensive lethal force decisions.[50]

- **Artificial intelligence.** The number of instances where humans must remain in the loop will likely shrink over time. Advances in computing power coupled with access to big data are sure to make future computers increasingly "smarter." Today, computers employing early forms of artificial intelligence can perform better than humans in specific, isolated tasks such as driving cars and flying airplanes and can defeat humans in games such as chess and Jeopardy. In the near future, artificial intelligence will likely continue to be context-specific and confined to specific problems, with human insight needed to understand the broader context or step outside the frame of a particular problem. As machine intelligence advances, however, the functional worldview of artificial systems will increase, with intelligent systems able to operate in increasingly complex and cluttered environments. In the far future, computers may "not only understand our world, they will be able to communicate that understanding to us and make it look easy."[51] They might be able to make diagnoses, provide recommended courses, or make decisions of their own based on preprogrammed guidance or rules of engagement. Maximizing the use of advances in artificial intelligence will depend on finding the optimal mix of machine and human intelligences for any given problem, leveraging the unique advantages of their differing cognitive abilities.

In addition to advances in information technology, several supporting enabling technologies will also play a key role in the development of an unmanned warfare regime. How these technology areas develop may make a significant difference in the way the current guided munitions-battle network regime evolves, the viability and cost of unmanned and autonomous systems, as well as potential countermeasures to them.

- **Commercial robotics.** The commercial robotics industry is thriving. The International Federation of Robotics estimate there are over 1.4 million robots of one form or another in today's global production facilities. For example, Japan's FANUC Robotics produces an industrial fleet of over fifty different production robots. The largest of these lifts and cuts up to a ton of large rolls of materials; the smallest picks and places either pills or batteries along an assembly line. However, robots are proliferating throughout the commercial workplace. For example, new robots are being produced for stack and sort and automated distribution warehouse operations, in the agricultural sector, and for work on deep-sea oil rigs. Sales of domestic robots topped 12 million robots in 2012 alone. As the demand for commercial robotic systems goes up in sector after sector, control and autonomous logic will inevitably improve along with the dexterity and capability of the systems.[52] Many of these robots might have or could be modified to provide military utility.
- **Miniaturization.** Small, high-density power and propulsion systems will lead to smaller guided munitions as well as unmanned systems of all types. These smaller weapons and systems will be quite capable, as new manufacturing techniques allow the fabrication of ever smaller electronic and mechanical devices and systems. For example, the exponential increases in aggregate computing power predicted by Moore's Law, with the resulting decreasing size and increasing density of microprocessors, has generally reduced the size of the sensors and guidance and control systems, as well as the overall size of many commercial and military platforms. At the same time, increasing guidance accuracy allows the development of smaller and smaller guided munitions, designed to limit collateral damage. Similarly, with no need to account for human support systems, miniaturization is rapidly occurring for unmanned systems, offering the potential for military forces to operate undetected for extended durations – potentially

A technician works with Baxter, an adaptive manufacturing robot created by Rethink Robotics at The Rodon Group manufacturing facility, Tuesday, March 12, 2013, in Hatfield, Pa.

(MATT ROURKE/Associated Press)

hiding in plain sight masquerading as birds, insects or inanimate objects.[53] Moreover, miniaturization of robotic systems would enable the rapid deployment of massive numbers of platforms – saturating an adversary's defenses and enabling the use of swarming concepts of operation that have powerful potential to upend more linear approaches to war-fighting.[54]

- **Additive manufacturing.** Technologies that create objects through a sequential layering process, such as 3D printing, can be used for both prototyping and distributed manufacturing. This will make it possible for extremely rapid prototyping of new systems and potentially rapid scaling of production.[55] This technology is also likely to alter how U.S. forces are deployed and resupplied. Consider the ability of deployed units to print replacement parts for key equipment sets without having to depend on long-range (and vulnerable) logistics infrastructure. Consider how U.S. naval operations and deployment tempos would be affected by the ability for deployed ships to print parts while underway – potentially lengthening the time between needed port calls. This could result in reduced operational costs in peacetime, and increased operational independence in wartime.

- **Small, high-density power generation systems.** The rise of unmanned and increasingly autonomous systems is leading to platforms and concepts of operation that can take full advantage of the ability to loiter in geographic areas for long periods – sometimes measured in days, and eventually in weeks or months. A limiting factor for range, endurance and payload is the fuel necessary to power the platform. Along with additive manufacturing techniques that can help decrease weight and better fuel efficiency techniques, the introduction of new high-power generation systems like fuel cells and high-density batteries will be necessary to take full advantage of emerging unmanned systems that could conceivably operate for extended periods in denied environments. Alternative power systems such as radioisotope power may be particularly suited to certain environments, such as underwater, but also raise policy challenges that must be addressed.

- **Electric weapons.** As guided munitions and battle networks proliferate, legacy power projection platforms and bases will be vulnerable to saturation attack from large numbers of long-range guided weapons, such as ballistic and cruise missiles, unless defenders can find interception methods with favorable cost-exchange ratios. As previously discussed, the guided munitions-battle network regime is offensive dominant, which imposes both great burdens and costs on a defender. Shooting two $10 million to $15 million interceptors against a single inbound ballistic missile to ensure a successful engagement is a losing proposition over the long run in a guided munitions salvo competition. This will be even more true when defending against future swarming attacks by unmanned systems. Electric weapons, such as electromagnetic rail guns and high-energy lasers, with high rates of fire and low cost per shot, could help redress both near-term and far-term problems. As such, military planners are aggressively pursuing them.[56] High-powered microwave weapons that disrupt electronics likewise have tremendous potential. Such weapons could disable enemy weapons and electronic systems through non-lethal means and could potentially be employed with a greater degree of autonomy in unmanned systems.[57] With the development of smaller, high-density power generation systems, these systems could be made much more compact, making them available on future battlefields in increasing numbers.

- **Human performance modification.** Leveraging technology to enhance human ability – physical or cognitive – has the potential to play a significant role in enabling militaries to cope with the fast-paced, data-rich environment of a robotics warfare regime. Pharmaceutical drugs such as Modafinil and Adderall already have the potential to sustain or increase cognitive performance but raise challenging ethical issues, particularly for their use in military populations who may be subject to coercion or pressure from leadership. Potential adversaries, on the other hand, may have less ethical concerns with using performance-modifying drugs. Advances in synthetic biology may also hold the potential for adversary use of weapons to degrade human performance or even directly attack civilian populations.[58] There are also active programs underway designed to produce capable exoskeletons for U.S. military personnel. For example, the U.S. Army and U.S. Special Operations Command are developing a Tactical Assault Light Operator Suit (TALOS) that aims to integrate advanced armor, command and control computers, power generators and enhanced mobility exoskeletons. Such systems have the potential for truly revolutionary change in infantry warfare, which has been limited since the beginning of war by the amount of weight a person can carry.[59]

VII. 20YY: WARFARE IN THE ROBOTIC AGE

When confronting the increased lethality of future battlefields and the high costs of personnel and crewed combat systems, force planners and designers seem certain to exploit the above technological advances and increasingly turn to unmanned systems in an effort to improve the combat effectiveness and lethality of a smaller U.S. military. As these advances make unmanned systems more capable and reliable, they are likely to give rise to a new Age of Robotics. Current unmanned systems and robots are capable of making some rudimentary decisions on their own. However, with steady advances in computing, big data, artificial intelligence, automation, miniaturization and new power generation systems, future systems will likely be capable of acting with increasing autonomy and replicating the performance of humans in many situations. These future advanced systems will also be able to take on roles humans simply cannot, such as undertaking more dangerous missions or reacting with greater speed, precision and coordination than humans are capable of. These characteristics are likely to make unmanned systems and robots of all shapes and capabilities more and more attractive to force designers, and more central to tactics and operations. As just one example, consider the words of retired Navy Captain Wayne P. Hughes as he contemplated the future of naval warfare:

> …we may be on the leading edge of a new age of tactics. Call it the "age of robotics." Unpeopled air, surface, and subsurface vehicles have a brilliant, if disconcerting, future in warfare. To appreciate the possibilities, think of future unmanned aerial vehicles in the same relationship to the manned combat aircraft as the present precision-guided Tomahawk land-attack vehicle has with respect to the scarcely aimed V-1 cruise missiles of late World War II….[T]he most likely [revolution in warfare] is not in information acquisition, transfer, and processing, the beginnings of which are already fifty years behind us insofar as naval tactics are concerned. The revolution will be in uninhabited robots that search and shoot under amazing modes of self-control.[60]

By relying on smaller size and superior numbers, unmanned systems can be built to be lost in combat, making survivability a characteristic not of any individual platform but of a swarm of systems, operating together.

As Captain Hughes portends, by leveraging their unique attributes, unmanned and autonomous systems offer potentially revolutionary new concepts of operation and approaches. While platform costs for some high-end unmanned systems designed to operate in contested airspace and land and maritime environments may in some cases be comparable to manned variants, increased autonomy may still yield significant savings in training, operations, and total lifecycle costs. Furthermore, because there have no crew, unmanned systems offer an entirely different approach to survivability. Instead of building ever-smaller numbers of exquisite crewed platforms to penetrate an enemy's battle networks, large quantities of low-cost, expendable unmanned systems can be produced to allow U.S. forces to overwhelm enemy defense with favorable cost-exchange ratios. By relying on smaller size and superior numbers, unmanned systems can be built to be lost in combat, making survivability a characteristic not of any individual platform but of a swarm of systems, operating

An octocopter (a drone with eight rotors) hovers in front of vapour trails left by aircraft during a presentation, to showcase the potential use of drones in the video and photography industries, in Pirnice, Slovenia in May 2013.

(SRDJAN ZIVULOVIC/Reuters)

together. This approach also allows graceful degradation of a capability rather than the complete loss of a capability if an exquisite manned multimission platform is disabled or destroyed.

Networked, cooperative swarms of unmanned systems that can maneuver and engage targets collectively also have the potential to achieve reaction times much faster than that of human operators. Intelligent swarms can overwhelm adversary defenses, autonomously jamming, spoofing and employing non-lethal disruptive weapons such as high-powered microwaves, while relaying the position of enemy targets to human controllers who can authorize lethal engagements. Human controllers, safely removed from harm's way, would provide mission-level control over the swarm, but the leading edge of the battlefront across all domains would be unmanned, networked, intelligent and autonomous. The resulting *reconnaissance-strike swarm* could achieve speed, synchronization and coordination of maneuver far surpassing that possible with manned platforms, rendering previous methods of warfare obsolete.

Even at the low end of the conflict spectrum, U.S. military planners will likely be forced to consider how to best employ unmanned systems. For example, a smaller U.S. military is unlikely to achieve the desired counterinsurgent-to-population ratio in future counterinsurgency campaigns except in instances where the population is quite small.[61] One response might be to try and avoid these types of operations together. Another, better approach might be to develop new counterinsurgency concepts that exploit the advantages of an integrated manned-unmanned unit. This was precisely the type of thinking that informed a crowd control demonstration conducted by Naval Air Warfare Center Weapons Division engineers and the iRobot

Corporation. In this demonstration, unmanned ground and aerial vehicles worked together to effectively disperse a simulated crowd of people.[62] While many consider unmanned warfare as being "high-end," a central premise of the 20YY research agenda is that it will span the full range of military operations.

While many consider unmanned warfare as being "high-end," a central premise of the 20YY research agenda is that it will span the full range of military operations.

In such a regime, the "winners" will likely be those who best leverage the unique advantages of both machine and human intelligences. The character of this new war-fighting regime is hinted at in Tyler Cowen's book *Average Is Over.* In the book, Cowen posits how the American economy may change over time as society continues to accommodate the ever-growing presence of computers, machines and robots. Cowen observes that we take as a matter of faith that computers will beat humans in games of knowledge and insight. Cowen points out, however, that the most successful chess champions are not machines or humans but rather human-machine teams working together in what is called "free play" chess.[63] In a future war-fighting regime dominated by guided munitions and unmanned and autonomous systems, those who master "free play" combat by harnessing the relative cognitive advantages of both humans and machines will likely dominate the battlefield as well.

We are convinced that the transition to this new war-fighting regime is no longer a matter of if, but only a matter of when. Taking a cue from the 20XX Future Warfare games, we therefore refer to this logical potential successor to the guided munitions-battle network regime as the "20YY regime," so as to avoid pointless debates over what decade or year the new regime may arrive. Our focus must be only on preparing for it.

VIII. THE 20YY REGIME: IMPLICATIONS FOR MILITARY STRATEGY, ORGANIZATION AND OPERATIONS

It is important that defense analysts, planners and policymakers begin to contemplate the contours of this successor 20YY war-fighting regime sooner rather than later. Unlike the military-technical revolution sparked by guided weapons and battle networks, *advances in the commercial sector* will likely trigger the MTR associated with unmanned, robotic and autonomous attack systems. This means there could be a variety of regime first movers and a high likelihood of strategic, operational or tactical surprise.

There are other good reasons to begin contemplating the 20YY regime beyond hedging and preparing for potential surprises, however. In addition to discerning the potential military ramifications and consequences of advances in such things as computer and big data, artificial intelligence, robotic systems and additive manufacturing, there are a number of conceptual issues that must be seriously considered. Indeed, a war-fighting regime dominated by robotic and unmanned and autonomous systems is likely to challenge our basic core concepts of defense strategy, including deterrence, reassurance, dissuasion and compellence. Examples of the kinds of things that merit careful analysis by defense policymakers, technologists and the analytic community include, but are not limited to:

Deterrence

For all the reasons outlined above, a war-fighting regime centered on unmanned and autonomous systems will rapidly spread to the point where one or more actors achieve – or more likely perceive – degrees of parity in the military-technical competition. In essence, the 20YY regime is more likely to feature contests between actors that are fielding roughly similar types of offensive and defensive capabilities, making it much harder to perceive and capitalize on technical advantages. Conventional deterrence relationships in a 20YY regime may begin to become far more dynamic – depending more on actual or perceived advantages in particular regions or subregions, where speed, mass, deception and geography could play more central roles than in the recent past.

Crisis Stability

An unmanned and autonomous systems-centered war-fighting regime will have profound implications for how political leaders and military commanders interpret adversary behavior, make judgments on how to posture forces, decide whether and how to use force, and determine how best to manage escalation if conflict erupts. Decades of military interactions between manned submarines, ships and aircraft have spurred the evolution of general norms of behavior that have helped maintain stability even during times of high tension between actors. However, the introduction of unmanned and autonomous systems into crisis-prone regions will complicate efforts at maintaining crisis stability. For example, in September 2013, a Chinese military drone flew toward the Japanese-controlled Senkaku islands that are at the center of a territorial dispute. Japan responded by scrambling F-15 fighter jets and both nations engaged in heated rhetoric regarding future use of force. In a future in which unmanned or potentially autonomous systems may be confronting each other, the prospects for miscalculation and inadvertent escalation in places like the South and East China Seas seem quite high – and potentially undermine crisis stability.[64] New norms of behavior will need to be developed as leaders adapt to the unique attributes and challenges of unmanned and autonomous systems in crisis situations.

Force Posture

New military capabilities naturally spur revisions to how military forces are deployed and stationed

Chief Aerographer's Mate Trung Freed, from Naval Mine and Anti-Submarine Warfare Command, Corpus Christi, Texas, monitors the deployment of a Bluefin Autonomous Underwater Vehicle (AUV) during a day of at-sea testing being conducted as part of AUV Fest 2007, sponsored by the Office of Naval Research, and hosted by the Naval Surface Warfare Center Panama City.

(U.S. NAVY PHOTO)

around the world and within key regions.[65]

In recent years we have seen how long-range unmanned vehicles have created opportunities to leverage smaller, more austere, locations from which to engage in surveillance and counter-terrorism operations. We should expect that a war-fighting regime centered on unmanned and autonomous systems would impact how U.S. forces posture overseas. For instance, the emergence of long endurance large-diameter unmanned underwater vehicles might significantly alter how U.S. submarine forces are postured and stationed in key theaters. Longer-range unmanned aerial systems will provide new opportunities to station capabilities farther afield from key subregions (e.g., Diego Garcia, Australia). Technology also impacts how militaries conceive of the importance of particular geographic locations. For example, Guam and the Pacific Islands are more important to U.S. strategy given the increasing range of precision ballistic missiles. It remains unclear how a 20YY-type regime will reshape conceptions of military posture and basing, but given the length of time needed for repositioning U.S. military forces and negotiating with allies and partners, U.S. policymakers would be wise to start thinking and planning now.

Alliances and Partnerships

Perhaps unlike recent shifts in defense technology and war-fighting paradigms, a move toward a regime featuring large numbers of unmanned and increasingly autonomous systems might play to the strengths of some key U.S. allies. For

A researcher from the Biomimetic Millisystems Lab from the University of California Berkeley with his flying H2Bird robot, at the Drones and Aerial Robotics Conference (DARC), held at New York University on October 11, 2013.

(KIKE CALVO/Associated Press)

example, Japan and South Korea are market leaders in computer technology and particularly in the integration of robotics into both domestic manufacturing and service industries. The opportunities to harness the increasingly commercial-centric innovations into advanced military platforms could incentivize greater defense planning collaboration, research and development strategy, and interoperability for fielded systems. Defense leaders should expect challenges however, as even though the procurement and training costs for adopting elements of the 20YY regime will likely be lower than the outlays required for procuring future high-end crewed platforms and the personnel to employ them, the organizational changes that would be required might create substantial adoption barriers.[66] Operationally, the ability of smaller states (e.g. Singapore, Qatar, Bahrain, some NATO partners) to leverage additive manufacturing and other advanced industrial techniques may enhance their ability to create next generation capabilities, produce them at scale, and field military forces at a level well above historical norms. In fact, a fully realized robotics warfare regime may decouple military power from the population base, traditionally a significant metric of potential military power. The challenge for U.S. defense planners will be to help allies and partners determine their unique requirements, the possibilities inherent in developing niche capabilities, and ways they might be integrated into multilateral partnerships, alliance structures and military operations.

Roles and Missions

The 20YY regime will have a powerful influence on how U.S. armed forces are organized, trained and equipped. We are seeing only the beginnings of this shift currently, but they are significant. A good example is how the U.S. Navy is beginning to integrate unmanned systems into current force design. The maritime surveillance and reconnaissance community is actively integrating unmanned systems into manned P-8A Poseidon squadrons.[67] This early form of free play operations, which sees the integration of manned and unmanned platforms at the unit level, suggests a powerful future inflection point that in most cases will likely enhance operational effectiveness and reduce risk to manned platforms. In other cases, there may be cultural or institutional antibodies to unmanned systems, particularly if they are perceived to threaten traditional manned roles and missions in various communities.[68]

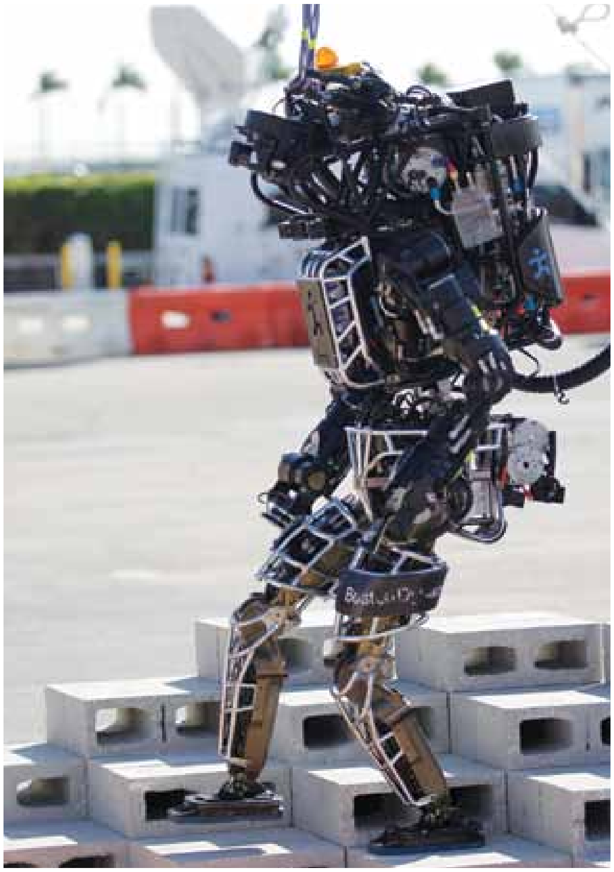
Operational Concepts

The 20YY regime might upend traditional ways

U.S. analysts have conceived of contemporary military competitions and regional balances of power, necessitating new ways to project and sustain military power into and within large contested zones. Two plausible shifts to operating concepts are most acute, and others might become clear as the regime matures.

First is the relationship between offense and defense. Since the end of the Cold War and the near-monopoly U.S. forces have enjoyed in the guided munitions-battle network regime, offensive forms of warfare have been dominant. Missile defenses and integrated air defense networks have generally been judged insufficient against a long-range strike complex in which guided munitions can overcome defensive systems – certainly insofar as defending against U.S. military operations are concerned. This has spurred China and other potential competitors to invest heavily in offensive strike systems of their own – in China's case long-range ballistic missiles that can hold U.S. air bases and aircraft carriers at risk. This maturation of the guided munitions regime – away from an outright U.S. monopoly to something less – means the stability of the military competition in Asia will begin to erode, as first strike incentives become more pronounced at the conventional level of war. The emergence of a 20YY regime centered on unmanned and increasingly autonomous systems will alter the contours of the offense-defense balance even further – the specifics of which are difficult to perceive but critical to explore.

Second is the balance between quality and quantity in the 20YY regime. During the Cold War, U.S. military strategy centered on establishing qualitative military dominance as a means to counter the quantitative advantages of the Soviet Union. We produced fewer platforms than the Soviet Union, but we ensured they were generally more capable on the battlefield. As discussed earlier, this approach ultimately undermined



Boston Dynamics' Atlas, a high-mobility, humanoid robot designed to negotiate rough terrain, takes on an irregular surface in this terrain negotiation exercise in Homestead, Florida in December 2013.

(ANDREW INNERARITY/Reuters)

Warsaw Pact military strategy in Europe and rapidly eroded the Soviet conventional deterrent. This strategy has continued throughout the post-Cold War period and into the present, with U.S. forces enjoying a qualitative advantage over any conceivable adversary. However, once precision munitions have fully proliferated, it is possible that quantity – or mass – begins to re-emerge as a critical discriminator for actors vying for military advantage. If such incentives exist, we are likely to see actors pursue concepts designed to leverage large quantities of relatively low-cost unmanned and autonomous systems to employ "swarms" to overwhelm an adversary during offensive or defensive operations. Such an approach could quickly affect the perceived or actual military balance of power in key regions.

Unlike the Cold War – when government research and development spending spurred most military innovations (e.g., stealth, precision navigation and timing, satellites, computer networking, etc.) – the technical enablers of the 20YY regime (e.g., autonomy, big data, additive manufacturing, miniaturization, etc.) are largely driven by the commercial world.

Accelerated Diffusion and Strategic Surprise

The 20YY regime will take time to develop, but given the pace and scale of globalization and the diffusion of military technology, it is likely to evolve far more rapidly than the guided munitions regime of the mid-to-late 20th century. Unlike the Cold War – when government research and development spending spurred most military innovations (e.g., stealth, precision navigation and timing, satellites, computer networking, etc.) – the technical enablers of the 20YY regime (e.g., autonomy, big data, additive manufacturing, miniaturization, etc.) are largely driven by the commercial world. These commercial drivers will tend to reduce both the fiscal and organizational costs for militaries attempting to procure and integrate these capabilities, as much of the development costs will be incurred and incentivized by the private sector.[69] This dynamic will likely increase the speed of adoption, potentially increasing the threat that the United States will be surprised by an adversary's ability to field advanced military capabilities. For example, the Japanese recently dominated a competition to build rescue robots sponsored by the Defense Advanced Research Projects Agency.[70] There is no reason to believe that other countries less friendly to the United States will be unable to surprise the United States by introducing militarily useful robotic systems – especially since their development and testing might be far more difficult to detect than that for manned systems.

IX. WE MUST PREPARE NOW FOR 20YY

Since the end of the Cold War, the United States military has enjoyed a virtual monopoly in the guided munitions-battle network regime. U.S. warfighters have benefited enormously from a long series of affirmative strategic decisions made by defense policymakers in the Department of Defense and on Capitol Hill – spurring investments in game-changing technologies that essentially "locked in" America's technological advantage for a generation.

Now, however, as the United States' ability to project power and to dominate force-on-force encounters begins to erode as more and more opponents become able to effectively employ guided weapons, defense planners must begin to shift their gaze from the current war-fighting regime to the coming one dominated by proliferated sensors, electric weapons, and ubiquitous unmanned and autonomous systems in all operating domains. Unfortunately, as they do so, there is a very real danger that today's environment – featuring declining budgets with increasing internal cost drivers, a desire to look inward after more than a decade of war and interservice rivalries centering on preserving legacy capabilities and outdated operational concepts – will make it challenging to spur and sustain the thinking, development of new operational concepts, research, experimentation and investments needed to prepare today's U.S. military for the demands of the 20YY future.

The United States must overcome this challenge. If it hopes to maintain its technological superiority, the U.S. armed forces must begin to conceptualize how a maturing guided munitions-battle network regime and advances in technologies driven primarily by the civilian sector may coalesce and combine in ways that could spark a new military-technical revolution. It cannot afford to defer the time, thinking and investments needed to prepare for warfare in the Age of Robotics. This is especially true given the speed of globalization and the diffusion of military capability to potential future adversaries large and small. To a degree that U.S. force planners are simply not accustomed to, other global actors are in a position to make significant headway toward a highly robotic war-fighting future in ways that could outpace the much bigger and slow-moving U.S. defense bureaucracy.

The United States cannot allow this to happen. It must ensure that the Soldiers, Airmen, Sailors and Marines of tomorrow's wars are prepared to fight and win. Preparing now for the 20YY war-fighting regime is a key means toward this end.

ENDNOTES

1. We believe there are two foundational readings that illuminate both the history of the guided munitions war-fighting regime as well as the ongoing evolution into a Robotic Age: Barry D. Watts' *Six Decades of Guided Munitions and Battle Networks: Progress and Prospects* (Center for Strategic and Budgetary Assessments, 2007), and P.W. Singer's *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (New York: Penguin Press, 2009).

2. In 1975, when writing the summary to the Long-Range Research and Development Planning Program, Albert Wohlstetter conceptualized new reconnaissance strike capabilities based on advanced sensors and conventional munitions with "near zero miss" accuracy. In 1978, William Perry, then the director of research and engineering in DOD, initiated the Assault Breaker program to explore the viability of this concept. This program helped to underwrite the new AirLand Battle concept then being developed by the U.S. Army and Air Force. Less than six years later, the head of the Soviet General Staff, Marshal N. V. Ogarkov concluded that "automated reconnaissance-and-strike complexes" with accurate, terminally guided conventional munitions would make it possible to achieve effects approaching those of nuclear weapons. For a good description of this period, see Watts, "Six Decades of Guided Munitions and Battle Networks: Progress and Prospects," 10-12.

3. P.W. Singer, "The Global Swarm: Drones are not only spreading to other countries, they're becoming smaller and smarter," *Foreign Policy* (March 13, 2013), http://www.foreignpolicy.com/articles/2013/03/11/the_global_swarm. The Department of Defense's updated *Unmanned Systems Roadmap: FY2013-2038* (December 2013): http://www.defense.gov/pubs/DOD-USRM-2013.pdf, inventories the number of unmanned aerial systems at 10,964. The roadmap does not inventory systems in other domains, but were unmanned ground systems, unmanned submersible prototypes, and emerging "micro-UAVs," to be included the number of unmanned systems in DOD's inventory would likely approximate 20,000.

4. These technologies are explored in depth in Shawn Brimley, Ben FitzGerald and Kelley Sayler, "Game Changers: Disruptive Technology and U.S. Defense Strategy" (Center for a New American Security, September 2013).

5. Andrew F. Krepinevich Jr., "The Military Technical Revolution: A Preliminary Assessment" (Center for Strategic and Budgetary Assessments, October 2002), 14.

6. For the purposes of this paper, a military regime encompasses the weapons, strategies, tactics, and operational and organizational constructs that together define the aggregate military capabilities during a readily identifiable historical period, and the way these capabilities are used to generate combat power. Put more simply, it is the way war is conducted over a strategically coherent period of time. This definition is derived from the one set forth by Michael G. Vickers and Robert C. Martinage, in "The Revolution in War" (Center for Strategic and Budgetary Assessments, December 2004), 2.

7. See for example Vickers and Martinage, "The Revolution in War"; Richard O. Hundley, "Past Revolutions; Future Transformations" (National Defense Research Institute, RAND, 1999); and Eliot Cohen, "A Revolution in Warfare," *Foreign Affairs* (March/April 1996).

8. Barry D. Watts, "The Maturing Revolution in Military Affairs" (Center for Strategic and Budgetary Assessments, 2011), 34.

9. Much of the thinking about unguided and guided weapons warfare reflected in this paper came from a year-long discussion between co-author Robert O. Work and Barry D. Watts while colleagues at the Center for Strategic and Budgetary Assessments in 2006. This discussion was later captured, developed and refined in Watts, in "Six Decades of Guided Munitions and Battle Networks: Progress and Prospects."

10. For a good description of Army thinking in the early atomic age, see A.J. Bacevich, *The Pentomic Era: The U.S. Army Between Korea and Vietnam* (Washington: National Defense University Press, 1986).

11. Christopher J. Bowie, as cited in Watts, "Six Decades of Guided Munitions and Battle Networks: Progress and Prospects," 1.

12. Watts, "Six Decades of Guided Munitions and Battle Networks: Progress and Prospects," 3-5.Although called a "mine," the Mark 24 was the first passive acoustic homing torpedo in the U.S. inventory. "Torpedo Mk 24 "FIDO," http://www.uboat.net/allies/technical/fido.htm.

13. David R. Mets, "The *Force* in U.S. Air Force," *Aerospace Power Journal* (Fall 2000), 58, 62.

14. Battle networks consist of three vertically linked subnetworks (or grids) that operate together as a single cooperative and adaptive fighting entity. A sensor grid correlates all information about the environment and friendly and enemy forces to give all those plugged into the network a *common battle network picture*. A C3 grid shares relevant information about the common battle network picture among all network users, facilitates operational planning based on this picture, distributes relevant orders and tasks to achieve a desired effect and makes changes to them as events unfold. An effects grid selects and directs the platforms, units, offensive and defensive weapons and offensive and defensive network attack systems to achieve specific combat effects. A battle network is thus best conceived as being a network of networks that employ a variety of *effectors* to achieve tactical or operational objectives or outcomes. Tactical battle networks are designed to engage specific targets operating in a specific operating domain, while operational battle networks employ networks of tactical battle networks in a coherent way to achieve campaign-level effects. The former can be operated under human or computer control, while the latter require a combination of both (at least up to this point in time). This description is adapted from Captain Wayne P. Hughes Jr., USN (Ret.), *Fleet Tactics and Coastal Combat* (Annapolis, MD: Naval Institute Press, 2000), 285.

15. Watts, "Six Decades of Guided Munitions and Battle Networks: Progress and Prospects," 17-18.

16. From February 1972 to February 1973, U.S. tactical air forces dropped 10,500 laser-guided bombs throughout Southeast Asia. Of these, 5,107 were

assessed as direct hits; another 4,000 hit with 25 feet of their intended targets. Watts, "Six Decades of Guided Munitions and Battle Networks: Progress and Prospects," 9.

17. Both the Egyptian and Syrian armies were equipped with Soviet-made SA-6 surface-to-air missile and AT-3 antitank guided missiles. The effectiveness and lethality of both missiles surprised the Israeli Defense Forces, causing much higher than anticipated losses to Israeli aircraft and tanks.

18. Marshal N.V. Ogarkov, as cited in Watts, "Six Decades of Guided Munitions and Battle Networks: Progress and Prospects," 25. Descriptions of reconnaissance-strike complexes can be found on p. 25.

19. This was exactly the thinking behind the U.S. Army and Air Force AirLand Battle Doctrine and NATO's Follow-on Forces Attack (FOFA) concept, developed in the 1980s to offset the great quantitative advantage in conventional forces then enjoyed by the Soviets and their Warsaw Pact allies along the Central European Front. For a discussion of both, see Manfred R. Hamm, "Military Doctrine, Force Postures, and Arms Control in Europe: The AirLand Battle Doctrine and NATO's FOFA Concept," in *Alternative Conventional Defense Postures in the European Theater, Vol. 3,* eds. Hans Gunter Brauch and Robert Kennedy (Bristol, PA: Taylor and Francis, 1993).

20. MTRs are often realized by a defining battle in which the revolutionary force or forces waging it demonstrate the dominance of the new way of war. See Vickers and Martinage, "The Revolution in War," 3.

21. Watts, "Six Decades of Guided Munitions and Battle Networks: Progress and Prospects," 20.

22. The Serbian army was particularly effective in "withholding" its forces from attack. See Martin Andrew, "Revisiting the Lessons of Operation Allied Force," Airpower Australia Analysis, June 14, 2009, http://www.ausairpower.net/APA-2009-04.html. This was only one form of force employment discussed by Stephen Biddle in his superb book *Explaining Victory and Defeat in Modern Battle* (Princeton University Press, 2004).

23. General Rupert Smith, *The Utility of Force: the Art of War in the Modern World* (Random House, 2005).

24. See Mark Mazzetti and Thom Shanker, "Arming of Hezbollah Reveals U.S. and Israeli Blind Spots," *The New York Times,* July 19, 2006.

25. Office of Net Assessment, Office of the Secretary of Defense, *A Concept for Theater Warfare in 2020* (draft dated November 1993), 1.

26. Michael Vickers and Robert Martinage, "Future Warfare 20XX Wargame Series: Lessons Learned Report" (Center for Strategic and Budgetary Assessments for the Office of Net Assessment, December 2001), 1-2.

27. Ibid., 1.

28. Ibid., 7.

29. Ibid., 6.

30. For example, one respected analyst argued that revolutionary war theorists had failed to identify a single period of truly revolutionary change in warfare since 1918. See Stephen Biddle, "Military Power: A Reply," *The Journal of Strategic Studies* (June 2005), 457.

31. Michael G. Vickers, "The Revolution in Military Affairs and Military Capabilities: Broadening the Planning Parameters of Future Conflict," School of Advanced International Studies, Johns Hopkins University, 1996, 11.

32. See for example Barry D. Watts, "The Maturing Revolution in Military Affairs" (Center for Strategic and Budgetary Assessments, 2011), 9-12. This excellent short monograph explains the potential ramifications of the maturing guided munitions-battle network regime between now and 2050.

33. Ibid., 5-7. See also Andrew F. Krepinevich Jr., "The Pentagon's Wasting Assets," *Foreign Affairs* (July/August 2009), http://www.foreignaffairs.com/articles/65150/andrew-f-krepinevich-jr/the-pentagons-wasting-assets; Arend G. Westra, "Radar versus Stealth: Passive Radar and the Future of U.S. Military Power," *Joint Force Quarterly*, 55 no. 4 (2009), 136-143; Randy Huiss, "Proliferation of Precision Strike: Issues for Congress," R42539 (Congressional Research Service, May 14, 2012), http://www.fas.org/sgp/crs/nuke/R42539.pdf; and Laura Grego, "A History of Anti-Satellite Programs," (Union of Concerned Scientists, January 2012), http://www.ucsusa.org/assets/documents/nwgs/a-history-of-ASAT-programs_lo-res.pdf.

34. Watts, "The Maturing Revolution in Military Affairs," 9. For an excellent overview of the role of long-range missiles in the Asia-Pacific and the implications for U.S. strategy, see Jim Thomas, "Why the U.S. Army Needs Missiles," *Foreign Affairs* (May/June 2013).

35. For example, press reports indicate Iran has mated advanced guidance systems on its Fateh-110 short-range rocket, allowing it to strike both land and naval targets with great accuracy out to 300 kilometers. See Nasser Karimi, "Iran Fateh Missile Unveiling Showcases Upgraded Short-Range Rocket," The Huffington Post*,* August 21, 2012, http://www.huffingtonpost.com/2012/08/21/iran-fateh-missile_n_1816802.html. Israel continues to try to prevent the transfer of advanced guided weaponry to Hezbollah. See for example, Farnaz Fassihi, Julian E. Barnes and Sam Dagher, "Israeli Jets Blast Arms Shipment Inside Syria," *The Wall Street Journal*, January 30, 2013, http://online.wsj.com/news/articles/SB10001424127887323701904578273861863731082.

36. Such weapons include those like the Army's Guided Multiple Launch Rocket System; Excalibur 155-millimeter guided artillery round; the Precision Guidance Kit, which adds GPS guidance to "dumb" artillery rounds; guided tank rounds; and guided mortar rounds. Watts, "The Maturing Revolution in Military Affairs," 11.

37. As cited by Watts in "The Maturing Revolution in Military Affairs," 11. Also see Dan Lamothe, "More Accurate Artillery Concerns General," *The Military Times* (April 20, 2010): http://www.militarytimes.com/article/20100420/NEWS/4200305/More-accurate-artillery-concerns-general.

38. See Department of Defense, *Air-Sea Battle: Service Collaboration to Address Anti-Access & Area Denial Challenges* (May 2013).

39. Todd Harrison, "Looking Beyond the Fog Bank: Fiscal Challenges Facing Defense" (Center for Strategic and Budgetary Assessments, April 2013).

40. See Jeremiah Gertler, "Air Force F-22 Fighter Program," RL31673 (Congressional Research Service, July 11, 2013), http://www.fas.org/sgp/crs/weapons/RL31673.pdf; and Jeremiah Gertler, "F-35 Joint Strike Fighter (JSF) Program," RL30563 (Congressional Research Service, February 16, 2012), https://www.fas.org/sgp/crs/weapons/RL30563.pdf. Some high-end unmanned systems designed to operated in contested airspace and land and maritime environments will also be quite expensive. But removing the human from the platform will likely save significant costs.

41. P.W. Singer, "Drones Don't Die – A History of Military Robotics," Historynet.com, May 5, 2011, http://www.historynet.com/drones-dont-die-a-history-of-military-robotics.htm. Also see Singer's *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (New York: Penguin Press, 2009), which is a foundational text.

42. Mike Hammer, "A Few God Bots," in *Rise of the Robots*, ed. Neil Fine (New York: Time Home Entertainment, 2013).

43. Ibid.

44. See Department of Defense, *Unmanned Systems Integrated Roadmap* (2013): http://www.defense.gov/pubs/DOD-USRM-2013.pdf.

45. For an excellent recent overview see P.W. Singer and Allan Friedman, *Cybersecurity and Cyberwar: What Everyone Needs to Know* (New York: Oxford University Press, 2013).

46. For good overviews of the importance of secure military communications and their enabling architectures see: Todd Harrison, *The Future of MILSATCOM* (Washington: Center for Strategic and Budgetary Assessments, 2013). For the communications requirements and challenges associated with unmanned systems see chapter 4 of Department of Defense, *Unmanned Systems Integrated Roadmap FY2013-2038* (Washington: 2013).

47. See David Bjerklie, "Machines That Think," in *Rise of the Robots*, ed. Neil Fine (New York: Time Home Entertainment, 2013). Also see James Manyika et al., *Big Data: The next frontier for innovation, competition, and productivity* (McKinsey Global Institute, May 2011).

48. See Kenneth Neil Cukier and Viktor Mayer-Schonberger, *Big Data: A revolution that will transform how we live, work, and think* (New York: H.M. Harcourt, 2013).

49. Bjerklie, "Machines That Think," in *Rise of the Robots*.

50. For example, the Israeli Harpy anti-radiation unmanned aerial vehicle detects, targets, and engages enemy radars without any human oversight or supervision. The United States does not have a system comparable in terms of degree of autonomy. See Department of Defense, *Autonomy in Weapon Systems,* Directive 3000.09 (November 21, 2012), http://www.dtic.mil/whs/directives/corres/pdf/300009p.pdf; and Defense Science Board, *The Role of Autonomy in DoD Systems* (July 2012), http://www.fas.org/irp/agency/dod/dsb/autonomy.pdf.

51. Bjerklie, "Machines That Think."

52. See Keith Wagstaff, "No Sweat!", Michael Q. Bullerdick, "Home is Where the Hardware Is," and Gary Belsky, "Welcome to Roboburgh," in *Rise of the Robots.* Also see James Manyika et al., *Disruptive Technologies: Advances that will transform life, business, and the global economy* (McKinsey Global Institute, May 2013): particularly chapter five, "Advanced Robotics."

53. This idea is explored—as fiction—in Daniel Suarez, *Kill Decision* (New York: Dutton / Penguin Group, 2012). Moreover, miniaturized electronics have even allowed the development of crude "cyborg" animals, controlled by electrical signals. See "The Roboroach" from the company Backyard Brains, which developed a cheap commercial harness designed to control the movements of the common cockroach by stimulating the antenna nerves. Accessed at https://backyardbrains.com/products/roboroach.

54. See John Arquilla and David Ronfeldt, "Swarming and the Future of Conflict" (RAND Corporation, 2000); John Arquilla, "Killer Swarms," ForeignPolicy.com, November 26, 2012, http://www.foreignpolicy.com/articles/2012/11/26/killer_swarms; Luca Petricca, Per Ohlckers and Christopher Grinde, "Micro- and Nano-Air Vehicles: State of the Art," *International Journal of Aerospace Engineering* (February 2011), and Adam Piore, "The Rise of the Insect Drones," *Popular Science* (December 2013): http://www.popsci.com/article/technology/rise-insect-drones.

55. See Chris Anderson, *Makers: The New Industrial Revolution* (New York: Crown Business, 2012); and Neil Gershenfeld, "How to Make Almost Anything," *Foreign Affairs* (November/December 2012).

56. The best overview of how electric weapons might change battlefield dynamics and strategy can be found in Mark Gunzinger and Christopher Dougherty, "Changing the Game: The Promise of Directed-Energy Weapons" (Center for Strategic and Budgetary Assessments, 2012).

57. DOD Directive 3000.09, *Autonomy in Weapon Systems,* which establishes DOD policy for autonomy in the use of force, allows for autonomous use of "non-lethal, non-kinetic force … against materiel targets." It restricts use, however, of autonomous lethal force outside of very narrow, human-supervised defensive roles.

58. See Brimley et al., "Game Changers: Disruptive Technology and U.S. Defense Strategy," for a brief discussion of human performance modification issues. Also see National Intelligence Council, *Global Trends 2030: Alternative Worlds* (2012): 67.

59. See David Axe, "Combat Exoskeleton Marches Toward Afghanistan Deployment," *Wired.com* (May 23, 2012): http://www.wired.com/dangerroom/2012/05/combat-exoskeleton-afghanistan/, Roger Teel, "Army Explores Futuristic Uniform for SOCOM," *U.S. Army.Mil* (May 28, 2013): http://www.army.mil/article/104229/Army_explores_futuristic_uniform_for_SOCOM, U.S. Special Operations Command, "U.S. SOCOM Seeks Ideas for Advanced Assault Suit Development,"(August 20, 2013): http://www.socom.mil/News/Pages/USSOCOMSeeksIdeasforAdvancedAssaultSuitDevelopment.aspx.

60. Captain Wayne P. Hughes Jr., U.S. Navy (retired), *Fleet Tactics and Coastal Combat,* second edition (Annapolis, MD: Naval Institute Press, 2000), 4-5.

61. Current counterinsurgency doctrine calls for a minimum of 20 counterinsurgents per 1,000 civilian residents in an area of operations. See US Army, Field Manual 3-24, *Counterinsurgency* (Washington: Headquarters Department of the Army, 2006), 1-13. However, in a study conducted by the U.S. Army, analysis suggested the minimum counterinsurgent force is 2.8 soldiers per 1,000 residents, with more forces required as the violence level increases. Stephen M. Goode, "A Historical Basis for Force Requirements in Counterinsurgency," *Parameters* (Winter 2009-2010)." Even using the lower number, a relatively non-violent counterinsurgent operation in a country of just 20 million people would require a force of 56,000 counterinsurgents. A country of 40 million would require double that number. A smaller U.S. Army and Marine Corps would be hard pressed to sustained such numbers over long periods of time.

62. "iRobot Crowd Control Demonstration (2010)," in *Arming the Fleet, 1943-2011: Providing our Warfighters the Decisive Advantage*, (China Lake and Point Mugu, CA: Naval Air Warfare Center Weapons Division, 2013): p. 105.

63. Tyler Cowen, *Average Is Over: Powering America Beyond the Age of the Great Stagnation* (New York: Dutton, 2013).

64. See Hiroko Tabuchi, "Japan is Open to Placing Officials on Disputed Islands," *The New York Times,* September 10, 2013: A3. Also see Shawn Brimley, Ely Ratner and Ben FitzGerald, "The Drone War Comes to Asia: How China Sparked a Dangerous Unmanned Arms Race," *Foreign Policy* (September 24, 2013).

65. See Andrew Krepinevich and Robert O. Work, "A New Global Defense Posture for the Second Transoceanic Era" (Center for Strategic and Budgetary Assessments, 2007). Also see Stacie Pettyjohn, *U.S. Global Defense Posture, 1783-2011* (Arlington, VA: RAND Corporation, 2012), Michèle Flournoy and Janine Davidson, "Obama's New Global Posture: The Logic of U.S. Foreign Deployments," *Foreign Affairs* (July/August 2012), Carnes Lord, ed. *Reposturing the Force: U.S. Overseas Presence in the 21st Century* (Newport, RI: Naval War College Press, 2006), and Kurt Campbell and Celeste Ward, "New Battle Stations?" *Foreign Affairs* (September/October 2003).

66. Michael Horowitz explores this issue at length in *The Diffusion of Military Power: Causes and Consequences for International Politics* (Princeton, NJ: Princeton University Press, 2010).

67. See a good overview by Lieutenant Commander Guy M. Snodgrass, U.S. Navy, "Naval Aviation's Transition Starts With Why," *U.S. Naval Institute Proceedings Magazine* (September 2013). Also see Admiral Jonathan W. Greenert, U.S. Navy, "Payloads over Platforms: Charting a New Course," *U.S. Naval Institute Proceedings Magazine* (July 2012).

68. For the classic treatment of how culture shapes military perceptions, see Carl Builder, *The Masks of War: American Military Styles in Strategy and Analysis* (Baltimore: Johns Hopkins University Press, 1989). The ongoing debate over the role of unmanned systems in the carrier air wing is another one to watch closely. See Bryan McGrath, "UCLASS – Don't Get Your Hopes Up," Information Dissemination blog on InformationDissemination.net, June 1, 2013, http://www.informationdissemination.net/2013/06/uclass-dont-get-your-hopes-up.html.

69. See Michael Horowitz, *The Diffusion of Military Power*. See also James Manyika et. al., *Disruptive Technologies: Advances that will transform life, business, and the global economy* (McKinsey Global Institute, May 2013).

70. John Markoff, "Japanese Team Dominates Competition to Create Generation of Rescue Robots," *The New York Times,* December 22, 2013: A20.

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Center for a New American Security
1152 15th Street, NW
Suite 950
Washington, DC 20005

TEL 202.457.9400
FAX 202.457.9401
EMAIL info@cnas.org
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1152 15th Street, NW
Suite 950
Washington, DC 20005

TEL 202.457.9400
FAX 202.457.9401
EMAIL info@cnas.org

www.cnas.org

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