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The Paradox of Military Technology

Max Boot

While various setbacks in the war on terror underscore the limits of American power, it is important not to lose sight of the bigger picture: we live in the age of American supremacy. Part of the explanation for U.S. dominance surely lies in America's economic strength. But Europe and Japan are similarly wealthy, yet their global sway lags far behind. What they lack is America's superior military capabilities. In the words of Gregg Easterbrook: "The American military is now the strongest the world has ever known, both in absolute terms and relative to other nations; stronger than the Wehrmacht in 1940, stronger than the legions at the height of Roman power." Although the dominance of U.S. forces can still be challenged when they come into close contact with the enemy on his home turf, they are undisputed masters of the "commons" (sea, air, and space), which allows them to project power anywhere in the world at short notice.

Information technology is central to American military dominance. Not all of the changes wrought by the information age are obvious at first glance, because the basic military systems of the early twenty-first century look roughly similar to their predecessors of the second industrial age—tanks, planes, aircraft carriers, missiles. Military analyst Michael O'Hanlon notes that "basic propulsion systems and designs for aircraft, ships, and internal-combustion vehicles are changing much more gradually than in the early twentieth-century, when two of those three technologies had only recently been invented." The average speed of a U.S. Navy destroyer has not increased in the past 100 years. The U.S. Air Force continues to rely on B-52H bombers last built in 1962. And the Marine Corps still uses helicopters that flew in the Vietnam War. But since the mid-1970s, the communications, targeting, surveillance, and ordnance technologies that make such "legacy" systems considerably more potent have been changing with great rapidity—and to America's great advantage.

Yet in this period of American hegemony, Americans continue to feel vulnerable. As we learned on September 11, and continue learning on the battlefields of Iraq, the most advanced weapons systems and most

Max Boot *is a senior fellow at the Council on Foreign Relations, a columnist for the* Los Angeles Times, *and a contributing editor to* The Weekly Standard. *This article is adapted from his new book* War Made New: Technology, Warfare, and the Course of Modern History, 1500 to Today, *published by Gotham Books (October 2006).*

sophisticated information technology are hardly a perfect shield against other kinds of destructive power. The paradox of our age is that modern technology is both the great *separator* and the great *equalizer* in military affairs: Technological supremacy separates America from the rest of the world, and yet modern technology leaves America vulnerable to vicious groups and gangs armed with AK47s, car bombs, or portable WMDs. To understand the future of warfare, we need to understand both sides of this paradox: specifically, how information technology has increased America's conventional military supremacy (in land, sea, air, and space), and how this military edge may be subverted by determined radicals armed with new technologies of death.

Land Warfare

Advanced armies are still structured, as they have been since the 1940s, around armored forces complemented by light infantry troops who move by vehicle, truck, and aircraft. The best tank in the world is probably the American Abrams (of which the U.S. has 9,000) but the British Challenger II, the German Leopard II, the Israeli Merkava Mk. 4, and the Russian T-80 and T-90 come within striking distance. All modern tanks have stabilized turrets, night-vision capabilities, laser range-finders, and targeting computers that allow them to fight in conditions—on the move or in the dark—that would have stymied earlier models. In addition, composite or reactive armor offers far more protection than in years past, and main guns firing depleted-uranium rounds have far more penetrating power.

While armored vehicles have improved over the years, so have anti-armor weapons. These range from heavy missiles fired from vehicles or aircraft (such as the U.S. Hellfire and Russian Ataka-V) to hand-held versions (such as the U.S. Javelin, the Franco-German Milan, and the Russian Kornet). In addition, even the most advanced tanks can be disabled by other tanks, massive mines, aerial bombs, or artillery shells. The full impact of advances in anti-armor technology has not yet become apparent because most of the forces that have fought modern tanks in recent years—Iraqis, Palestinians, Chechens—have not possessed the latest defensive weapons. But the U.S. success in wiping out Iraqi tanks from stand-off ranges suggests that, in the constant struggle between offense and defense, the advantage may have shifted against heavy armor. The Israelis got a taste of what the modern era has in store when, in August 2006, their tanks and troops ran into a blizzard of advanced anti-tank rockets during their attacks on Hezbollah's strongholds in southern Lebanon.

The U.S. Army is responding to these changes by budgeting at least $124 billion—and possibly a great deal more—to develop a Future Combat System that will replace much of its current armored force with a family of lighter vehicles, manned and unmanned, with stealth designs that will make them harder to detect and hybrid-electric engines that will lessen their fuel requirements. (One of the chief disadvantages of the gas-guzzling Abrams is its heavy dependence on vulnerable supply lines.) Future vehicles will feature advanced composite armor designed to deliver more protection than current models for the same amount of weight, but they will rely for protection less on armor and more on locating and destroying the enemy before they are attacked. Critics believe this places too much faith in "perfect situational awareness," and that these vehicles will not be of much use against guerrillas who can strike with no warning.

As usual, the infantryman's tools have changed least of all. A modern soldier has better protection than his forefathers if he wears Kevlar body armor, but his firepower—which comes primarily from a handheld assault rifle like the M-16 or AK-47 and from a variety of crew-served mortars and machine guns—does not vary significantly from that of a G.I. or Tommy in World War II. Electronic guns that are capable of spitting out a million rounds a minute have been developed, and might permit a soldier to stop an incoming rocket-propelled grenade with a solid wall of lead. But such weapons are years away from being fielded.

Unfortunately for Western soldiers, the proliferation of small arms can put even the most primitive foes on an almost equal footing with the representatives of the most advanced militaries. There are 250 million military and police small arms knocking around the world, and more are being manufactured all the time by at least 1,249 suppliers in 90 countries.

The salvation of information age infantry, at least when they are conducting conventional operations, is their ability to use a wireless communications device to call in supporting fire on exact coordinates. It is doubtful that any military force will again enjoy the preponderance of power of General H. H. Kitchener at Omdurman, but Americans dropping Joint Direct Attack Munitions (JDAMs) on Afghan tribesmen armed with Kalashnikovs—or even on Iraqi soldiers with outdated T-72 tanks—came close. The American edge decreases considerably, however, when its troops have to deploy for peacekeeping or counterinsurgency operations which leave them exposed to low-tech ambushes. "With the possible exceptions of night-vision devices, Global Positioning Systems, and shoulder-fired missiles," writes retired Major General Robert Scales, a former commander of the Army War College, "there is no appreciable technological advantage for an American infantryman when fighting the close battle against even the poorest, most primitive enemy."

Naval Warfare

Navies remain divided, as they have been since the dawn of the second industrial age, into aircraft carriers, submarines, and surface ships. The major difference is that blue-water naval competition has disappeared after more than 500 years. No one even tries to challenge the U.S. Navy anymore on the high seas. Virtually every other navy in the world is little more than a coastal patrol force.

The U.S. has 12 aircraft carriers, nine of them Nimitz-class, nuclear-powered supercarriers that can carry more than 70 high-performance aircraft such as the F/A-18 Super Hornet. A tenth supercarrier is in the works. No one else has a single one. France has the world's only other nuclear-powered aircraft carrier, the *Charles de Gaulle*, but it is half the size of the *Nimitz*. Russia has one aircraft carrier, the *Admiral Kuznetsov*, that rarely leaves port, and it has sold another one, the *Admiral Gorshkov*, to India. Britain has three small Invincible-class aircraft carriers that are used only for helicopters and vertical-takeoff Harrier jets. France, Italy, Spain, Japan, and South Korea have similar helicopter carriers in the works. These ships are comparable to the U.S. Navy's 12 amphibious assault ships, which transport helicopters, jump jets, and Marines.

Whenever they leave port, U.S. capital ships are surrounded by surface and submarine escorts. Twenty-four Ticonderoga-class cruisers and 45 (and counting) Arleigh Burke-class destroyers come equipped with Aegis phased-array radar which can track up to 900 targets in a 300-mile radius. These surface combatants can also operate on their own or in conjunction with smaller vessels such as frigates and minesweepers.

In World War II, ships that didn't carry aircraft were limited to firing torpedoes or heavy guns with a range of less than 30 miles. Starting in the 1960s some submarines were equipped with intercontinental range ballistic missiles, but their targeting was so imprecise that it made no sense to equip them with conventional warheads. Ballistic-missile subs became a mainstay of nuclear deterrence. The development of accurate cruise missiles starting in the 1970s allowed submarines and surface combatants to hit land targets hundreds of miles away with conventional ordnance. Improvements in torpedo design, including the development of rocket-propelled supercavitating torpedoes, also allow submarines to do more damage in their traditional anti-ship role.

The U.S. has the world's largest fleet of nuclear-powered attack submarines (54) and nuclear-powered ballistic-missile subs (16). Russia comes in second with 37 attack submarines and 14 ballistic missile subs. Britain has 15 nuclear-powered submarines, followed by France with 10, and China with six. Not only are U.S. submarines more numerous, they are also more advanced. The most sophisticated are three 1990s-vintage Seawolfs described by one defense analyst as "the fastest, quietest, and most heavily armed undersea vessels ever built."

Because of the growing power of each of its vessels and the lack of competitors, the U.S. Navy has consolidated its high seas hegemony even while its fleet has shrunk from almost 500 ships in the 1980s to fewer than 300 in the early years of the twenty-first century. The potency of U.S. naval vessels is increased by linking together sensors and weapons systems with a tactical computer network known as FORCEnet.

While the U.S. Navy probably will remain unchallenged in blue waters, it faces greater threats as it gets closer to shore. Here water currents, thermal layers, and various obstacles can interfere with even the most advanced sensors, and a variety of defensive weapons systems lurk in wait.

More than 75,000 anti-ship missiles are owned by 70 countries. A few are ballistic, but most are of the cruise-missile variety. Their potency was proved in 1987 when French-made Exocets fired by an Iraqi aircraft crippled the frigate USS *Stark*, killing 37 sailors. Earlier, Argentina used Exocets to sink two British ships during the 1982 Falklands War. Newer anti-ship cruise missiles such as the Russian-made Yakhont, Sunburn, and Uran are even deadlier because they have faster speeds, greater stealth capabilities, and more accurate, GPS-enhanced targeting. Russia is selling these missiles to customers abroad and some nations like China are developing their own versions. Israel suffered the consequences during its recent Lebanon war when an Iranian-provided C-802 cruise missile crippled one of its warships off the coast of Lebanon.

U.S. warships have sophisticated defensive systems to guard against air attack: Incoming missiles can be deflected by electronic countermeasures, flares, or chaff, or destroyed by naval aircraft, sea-to-air Standard missiles, or, as a last resort, by rapid-fire, radar-guided Phalanx guns. But, like the *Stark*, a warship could be caught by surprise or overwhelmed by a flurry of missiles coming from different directions.

Even more worrisome from an American viewpoint is the fact that transport ships and fuel tankers which have to replenish a fleet at sea have no protection when they are outside the defensive range of a battle group. They are as vulnerable as supply convoys on the roads of Iraq. Because a supercarrier has only about a three-day stockpile of JP-5 jet fuel (6,500 barrels a day are needed during combat operations), the most powerful warship in history could be rendered useless if its fuel tankers were sunk.

The threat to shipping, civil and military, is increased by diesel submarines. The latest diesel submarines have ultra-quiet electric engines that make them hard to detect with sonar, and they are much cheaper to buy or produce than a nuclear-powered submarine. Russia has exported Kilo-class diesel-electric subs to China, India, Iran, and Algeria, among others. China is producing its own Song-class diesel submarines in a bid to challenge U.S. naval hegemony using the same strategy that Germany, with its U-boats, once used to challenge British dominion of the waves. U.S. antisubmarine defenses are quite sophisticated, especially in open waters, but even American sensors can have trouble tracking quiet diesel subs in noisy coastal waters.

Mines, which can be scattered by submarines or other vessels, represent another major threat to shipping. More than 300 different varieties are available on the world market. They can be triggered by changes in magnetic fields, acoustic levels, seismic pressure, or other factors. Some come equipped with microelectronics that allow them to distinguish between different types of ships, while others have small motors that allow them to move around. This makes it difficult to certify that a shipping channel is free of mines—it may have been safe an hour ago, but not any more. Demining technology has lagged behind; the U.S. Navy, for one, has never placed much emphasis on lowly minesweepers. It has paid a price for this neglect. In 1987, during operations to prevent Iran from closing the Persian Gulf, an Iranian mine of World War I design nearly sank the frigate USS *Samuel Roberts*. Four years later, in the Gulf War, the cruiser USS *Princeton* and the amphibious landing ship USS *Tripoli* were nearly blasted apart by Iraqi mines. And even a cheap motorboat packed with explosives can pose a significant threat to a modern warship. The USS *Cole*, an Arleigh Burke-class destroyer, was badly damaged in such a terrorist attack in 2000.

All of these threats could be largely negated if U.S. fleets were to stay far out at sea, but they have to approach fairly close to land to launch aircraft or missiles with operational ranges of only a few hundred miles. Moreover, the places where the U.S. Navy is likely to fight in the future are dangerously narrow. The Persian Gulf is only 30 miles wide at its narrowest point, the Taiwan Strait only 100 miles wide.

To maintain its dominance, the U.S. Navy regularly updates the electronics and weapons aboard its warships even as the hulls and propulsion systems remain unchanged. It also plans to build a variety of unmanned vessels along with a CVN-21 aircraft carrier to replace the Nimitz-class, a Zumwalt-class DD(X) destroyer to replace Oliver Hazard Perry-class frigates and Spruance-class destroyers, a CG(X) cruiser to replace the Ticonderoga-class cruisers, and a smaller and speedier Littoral Combat Ship with no direct parallel in today's fleet that would focus on clearing mines, hunting submarines, and fighting terrorists in coastal waters. All of these new vessels will have improved defenses and information-processing tools as well as "plug and play" capacity that will allow them to be quickly reconfigured for different missions. They will also incorporate composite materials, stealthier designs, and electric propulsion to make them harder to detect, though an aircraft carrier with a 4.5-acre flight deck can never exactly hide.

Whether all of these warships are truly needed, given the U.S. Navy's already substantial lead over all competitors, remains an open question. A program to develop giant sea bases—perhaps akin to offshore oil-platforms—that would allow American ground and air forces to operate overseas might be of greater use, given the growing difficulty the U.S. has had in gaining basing and overflight rights from other countries. But what seems clear, on sea as on land, is that the development of new weapons systems will continue to augment American supremacy while leaving American military forces vulnerable to various "low-tech" attacks.

Aerial Warfare

Fighters such as the American F-15 and the Russian MiG-29 were designed in the 1970s for air-to-air combat, but this has become almost as rare as ship-to-ship actions. Since the Israelis destroyed much of the Syrian air force in 1982, and the U.S. and its allies made similarly quick work of the Iraqi air force in 1991, few if any aircraft have been willing to challenge top-of-the-line Western militaries. (The U.S. Air Force hasn't produced an ace—an airman with at least five aerial kills—since 1972.) That may change with the sale to China of the Russian-built Sukhoi Su-30, whose performance characteristics are said to exceed those of the F-15C, but the F/A-22 Raptor, the F-35 Joint Strike Fighter, and the Eurofighter should restore the Western edge. The odds of future aerial dogfights, however, still remain slim.

Modern surface-to-air missiles pose a more immediate danger, because they are cheaper and easier to operate. The U.S. and its allies have developed effective methods of neutralizing most existing air defenses. In addition to jammers, radar-seeking missiles, and decoys, the U.S. employs stealth technology, first used on the F-117 Nighthawk, then on the B-2 Spirit, and now on the F/A-22 and F-35. Future aircraft may be designed with "visual stealth" technology to make them almost invisible even in daylight. No other nation has deployed any stealth aircraft. But advanced sensor networks may now be able to detect first-generation stealth planes. The Serbs actually managed to shoot down an F-117 in 1999.

None of the most sophisticated surface-to-air missiles, such as Russia's double-digit SAMs (SA-10, SA-15, SA-20), was available to Iraq, Serbia, Afghanistan, or other states that the U.S. has fought in recent years, but they are being sold to other customers, including China, Vietnam, Kazakhstan, South Korea, Greece, and Cyprus. So are shoulder-fired anti-aircraft missiles such as the American FIM-92 Stinger, British Starstreak, French Mistral, Chinese Qianwei-2, and the Russian SA-7 Grail, SA-14 Gremlin, SA-16 Gimlet, and SA-18 Grouse. There are at least 100,000 such systems in the arsenals of over 100 states and at least 13 non-state groups such as Hezbollah, the Revolutionary Armed Forces of Colombia (FARC), and the Tamil Tigers. The best models have a range of 23,000 feet.

The potential of hand-carried missiles was demonstrated in the 1980s when Stingers took a significant toll on Soviet aircraft in Afghanistan. The threat is sufficient for the U.S. to rely increasingly on unmanned drones for high-risk missions and to mandate that manned aircraft in war zones stay above 15,000 or 20,000 feet. SAMs pose an especially great threat to helicopters, which don't have the option of flying that high, and for airplanes taking off or landing. Three cargo aircraft leaving Baghdad International Airport have been seriously damaged by missiles, and, while all of them survived, several U.S. helicopters hit with SAMs in Iraq and Afghanistan did not. An Israeli jetliner was almost shot down in Mombasa, Kenya, in 2002 by al Qaeda operatives firing an SA-7. Only the terrorists' targeting error prevented the deaths of 271 passengers and crew. Other civilian airliners are sure to be less lucky.

Assuming that warplanes can reach their destination, the growing precision of bombs and missiles has made it possible to take out targets with fewer and smaller munitions than ever before. (The U.S. Air Force's latest bomb carries only 50 pounds of explosives.) Weapons are getting smarter all the time. The U.S. Sensor-Fuzed Weapon, first employed in the current Iraq War, disperses 40 "skeet" anti-armor warheads that use infrared and laser sensors to find and destroy armored vehicles within a 30-acre area. The Tactical Tomahawk, which entered production in 2004, can loiter up to three hours while searching for targets and receiving in-flight retargeting instructions.

The U.S. preponderance in smart bombs and missiles helps to compensate for the relatively small size of its manned bomber force. As of 2005, the U.S. Air Force had only 157 long-range bombers (B-52s, B-1s, B-2s), a considerable fall not only from World War II (when the U.S. had 34,780) but also from the end of the Cold War (360). While few in number, each B-2 can perform the work of thousands of B-29s by "servicing" 80 "aim points" per sortie.

Tankers such as the KC-10 and KC-135 vastly extend the range and effectiveness of combat aircraft. Cargo-lifters like the U.S. C-5, C-17, and C-130 and the Russian An-70 and An-225 also perform an invaluable, if unglamorous, role in projecting military power around the world. The U.S. owns 740 tanker aircraft and 1,200 cargo aircraft—far more than any other country. A lack of such support aircraft makes it difficult for even the relatively sophisticated European militaries to move their forces very far.

A host of other aircraft, ranging from JSTARS and AWACS to Rivet Joint and Global Hawk, perform surveillance and electronic-warfare missions in support of combat forces. Their numbers have been growing: While there were only two JSTARS in the Gulf War, in the Iraq War there were 15. But commanders have become so reliant on these systems that there never seem to be enough to go around—the so-called LD/HD problem (Low Density/High Demand). These, too, are vital U.S. assets that few other nations have.

Space Warfare

A growing amount of surveillance, communications, and intelligence work is being performed by unmanned aircraft and satellites. In 2001 the U.S. had an estimated 100 military satellites and 150 commercial satellites in orbit, as much as the rest of the world combined. The U.S. spends more than $15 billion a year on military space, perhaps 90 percent of the global total. The most advanced U.S. surveillance satellites can reportedly pick out a six-inch object from 150 miles above. (This is an estimate for Keyhole imaging satellites which can work day or night but cannot penetrate cloud cover. Lacrosse or Onyx systems that use radar imaging can work in all kinds of weather. They can reportedly distinguish objects 3 to 9 feet across. Satellite capabilities are strictly classified; these are only informed guesses.) A new generation of satellites uses stealth technology so that other countries will not be able to track the satellites' movement and thus know when to hide equipment from American eyes.

Yet the advantage the U.S. military derives from mastery of space is slowly eroding. GPS, a system developed by the Defense Department, is now widely available for countless commercial applications that have spawned a $30-billion-a-year industry. A potential enemy could use GPS signals to locate targets in the U.S. the same way the U.S. military uses it to locate targets in Iraq or Afghanistan. The U.S. could jam or degrade GPS signals in wartime, but it would have to do so very selectively for fear of imposing a severe toll on the economy, because GPS devices are now essential for civil aviation, shipping, and other functions. In addition, the European Union in cooperation with China is launching its own GPS constellation, known as Galileo, that would be outside of direct U.S. control.

More and more countries—at least forty to date—are lofting their own satellites. In addition, various multinational organizations such as the Asia Satellite Corp., Arab Satellite Communications Organization, International Telecom Satellite Organization, and European Space Agency have launched their own satellites. But getting access to space no longer requires having your own satellite. A growing number of private firms such as Google, DigitalGlobe, and Space Imaging sell or give away high-resolution satellite photos via the Internet. The best of these offer imagery of sufficient quality to identify objects one and a half feet wide. The Israeli-owned ImageSat International offers customers the opportunity to redirect its EROS-A imaging satellite (launched in 2000 aboard a Russian rocket) and download its data in total secrecy with few if any restrictions. Its CEO boasts: "Our customers, in effect, acquire their own reconnaissance satellite…at a fraction of the cost that it would take to build their own." The private satellite industry is becoming so pervasive that the U.S. military now relies upon it to provide some of its own imaging (typically low-resolution pictures used for mapping) and much of its communications needs.

Targets identified from space could be attacked either with terrorist (or commando) missions or with the growing number of missiles spreading around the world. More than two dozen nations have ballistic missiles and by 2015 at least a dozen will have land-attack cruise missiles. Either type of projectile could be topped with chemical, biological, or nuclear warheads. Eight or nine countries already have nuclear weapons and more are trying to get them, in part to offset the tremendous U.S. advantage in conventional weaponry.

In response, the U.S. is working on a variety of missile defenses. The most advanced are the ground-based Patriot Advanced Capability 3 and the sea-based Standard Missile 3, which have been deployed already to protect U.S. troops overseas. The deployment of a long-heralded system designed to protect the U.S. homeland against long-range missiles began in 2004 with the installation of interceptors in Alaska. Eventually, the U.S. plans to field a multi-layered defense using a variety of sensors and weapons on land, sea, air, and space. Also in the works are systems designed to defeat low-flying cruise missiles, which are hard to distinguish from ground clutter. But whether these systems will protect Americans against the most likely or most deadly types of attacks remains an open question.

Robotic Warfare

The falling size and cost of electronics has made it possible to decrease the number of people needed to operate major weapons systems or, in some instances, eliminated the need for human operators altogether. Maintaining the engines aboard a ship used to require dozens of sailors to work for extended periods in noisy, grimy, cramped quarters. The new DD(X) destroyer will have an engine room controlled entirely by remote sensors and cameras. Or, to take another example, consider the evolution of the long-range bomber from the B-29, which had a crew of 11, to the B-2 which can hit many more targets but has a crew of just two, who spend much of their time supervising the autopilot functions.

The greatest advances in robotics have been made in Unmanned Aerial Vehicles (UAVs), with the U.S. in the lead, Israel following close behind, and at least 40 other countries trying to catch up. By the time of the Iraq War in 2003, the U.S. had fielded six major UAVs: the Air Force's Predator and Global Hawk, the Army's Hunter and Shadow, and the Marines' Pioneer and Dragon Eye. These ranged in size from the 27,000-pound Global Hawk (comparable to a Lear jet) to the five-pound Dragon Eye (more like a model airplane). What they had in common was that they were all designed as surveillance systems. But in a pattern that echoes the history of manned flight, UAVs such as the Predator were soon put to work attacking enemy positions.

Soon to be deployed are drones built especially for combat—Boeing's X-45 and Northrop Grumman's X-47. In Matthew Brzezinski's fanciful description, the former is "flat as a pancake, with jagged 34-foot batwings, no tail and a triangular, bulbous nose" that give it the appearance of "a set piece from the television program *Battlestar Galactica*," while the latter is a "a sleek kite-shaped craft with internal weapons bays for stealth and curved air intakes like the gills of a stingray." Both are designed to be almost invisible to radar and to perform especially dangerous missions like suppressing enemy air defenses. The major difference is that the X-45 is supposed to take off from land like the F-15, while the X-47 is to operate off aircraft carriers like the F-18. Also in development is the Unmanned Combat Armed Rotorcraft which is designed to perform the functions of an attack helicopter like the Apache. An unmanned helicopter, known as Fire Scout, is already being bought by the U.S. Navy and Marine Corps. Unlike the Predator, most of these new UAVs do not require constant control by a human operator; newer UAVs can be programmed to fly themselves and even drop munitions without direct human intervention.

Further into the future may be projects such as a nuclear-powered UAV that could fly at 70,000 feet and stay on station for months or even years at a time; a UAV "tender" that could serve as a mother ship for launching and recovering smaller UAVs; UAV tankers that could refuel other UAVs in flight; and vertical-takeoff UAV cargo-carriers that could supply troops in a combat zone. Many of these UAVs could use smart munitions with their own target-recognition systems, thus introducing another layer of robotics into the process. An existing example is the Low-Cost Autonomous Attack System, a 100-pound bomb with fins and a small turbojet engine that allow it to loiter over an area for up to 30 minutes, using a laser-radar sensor to search for high-priority targets based on programmed algorithms. Once it picks out a target, it can configure its multi-mode warhead into the most appropriate form—fragmentation explosives for unprotected soldiers or an armor-piercing projectile for tanks—prior to impact.

The most revolutionary UAVs are the smallest. The Defense Advanced Research Projects Agency (DARPA) is working on aerial vehicles the size of an insect or a hummingbird that could hover undetected and perch on a telephone pole or a window ledge. Some models have no wings at all; others use flapping, bird-style wings. They are designed to be cheap enough that they could saturate a battlefield with sensors.

Unmanned ground vehicles are not as advanced as UAVs, but they are starting to play a growing role as well. In Iraq and Afghanistan, the U.S. Army and Marine Corps have used robots with names like PackBot, Matilda, Andros, and Swords to search tunnels, caves, and buildings for enemy fighters and explosives. "Some are as big as a backhoe. Others can be attached to a backpack frame and carried by a soldier," writes the trade industry publication *Defense News*. "They move on treads or wheels, climb over obstacles with the aid of flippers, mount stairs, peep through windows and peer into caves with cameras and infrared sensors, sniff for chemical agents, and even operate a small ground-penetrating radar."

As this description indicates, ground-based robots, like their aerial counterparts, are still used mainly for reconnaissance. But weapons are beginning to be mounted on them, too. The Talon, a two-foot-six-inch robot which looks like a miniature tank and was designed for bomb disposal, was sent to Iraq equipped with grenade and rocket launchers as well as a .50-caliber machine gun. It is controlled remotely by a soldier using a video screen and joystick.

Developing more sophisticated unmanned ground vehicles will be tougher than developing better UAVs because there are so many more obstacles that can impede movement on the ground. But progress is rapidly being made. In 2004, DARPA sponsored a race in the Mojave Desert to see if an autonomous robotic vehicle could complete a 132-mile course. That year, the furthest any competitor got was 7.4 miles, but in 2005 four vehicles finished the entire course, with the winner (a souped-up Volkswagen Touareg) claiming the $2 million prize. Buoyed by these results, the Pentagon is pushing ahead with plans for new ground robots such as the MULE (Multifunction Logistics and Equipment Vehicle), a two-and-a-half-ton truck that could carry supplies into battle or wounded soldiers out of it; the Armed Robotic Vehicle, a five-ton mini-tank that could be equipped with missiles or a .30mm chain gun; and the Soldier Unmanned Ground Vehicle, a 30-pound, man-portable scout that comes equipped with weapons and sensors. These are all integral elements of the Army's Future Combat System.

Scientists are also trying to create a self-powered robotic suit—an exoskeleton—that could enable soldiers to carry far heavier loads, move much faster, and conceivably even leap short buildings in a single bound. A prototype developed at the University of California, Berkeley, allows a soldier to carry 180 pounds as if it were less than five pounds.

The U.S. Navy is exploring robotic technology for a variety of its own missions. In addition to carrier-based UAVs (both fixed-wing and rotary), the navy is developing Unmanned Surface Vehicles and Unmanned Undersea Vehicles. Most of these drones would swim but some might crawl along the ocean floor like crabs. They could perform such difficult missions as antisubmarine warfare, mine clearance, undersea mapping, and surveillance in coastal waters.

All drones, whether operating on soil, sea, or sky, offer major advantages over traditional manned vehicles. They can be deployed for longer periods because robots don't need to eat or sleep; they can undertake maneuvers that might put too much stress on the human frame; they can be made much smaller and cheaper because they don't need all sorts of expensive redundancies and life-support systems (no oxygen tanks! no ejection seats!); and they can be much more readily sent on high-risk missions because, should anything go wrong, nobody has to worry about notifying the next of kin. These advantages have persuaded Congress to ratchet up spending on unmanned programs. Lawmakers have mandated that one-third of all U.S. deep-strike aircraft be unmanned by 2010 and that one-third of all ground combat vehicles be unmanned by 2015.

There are two chief limitations on the use of robots at the moment. First, computers and sensors are not yet smart enough to deliver anything close to the "situational awareness" of a human being. Second, a shortage of bandwidth limits the number of drones that can be remotely controlled at any one time. Both problems will become less acute with improvements in computer and communications technology, but there is still little reason to think that robots will be alone on the battlefield of the future. It is doubtful that machines will ever be smart enough to do all of the fighting, even if they can perform some of the dullest, dirtiest, or most dangerous work.

The Limits of Technological Supremacy

Taken together, the changes in military power wrought by the information revolution are still in their early stages, and they still have serious limitations. Even the best surveillance systems can be stymied by simple countermeasures like camouflage, smoke, and decoys, by bad weather, or by terrain like the deep sea, mountains, or jungles. Sensors have limited ability to penetrate solid objects, so that they cannot tell what is happening in underground bunkers such as those that North Korea and Iran likely use to hide their nuclear weapons programs. Urban areas present a particularly difficult challenge: There are far more things to track (individuals) and far more obstructions (buildings, vehicles, trees, signs) than at sea or in the sky. Figuring out whether a person is a civilian or an insurgent is a lot harder than figuring out whether an unidentified aircraft is a civilian airliner or an enemy fighter. It is harder still to figure out how many enemy soldiers will resist or what stratagems they will employ. No machine has yet been invented that can penetrate human thought processes. Even with the best equipment in the world, U.S. forces frequently have been surprised by their adversaries.

Some strategists expect that advances in information technology will greatly diminish if not altogether obliterate some of these difficulties. The Pentagon is creating a Global Information Grid that will pool data from all U.S. assets, whether an infantryman on the ground or a satellite in space. The ultimate goal: to provide a perfect operational picture—a "God's-eye view" of the battlespace.

This ambitious objective could be furthered by the development of better microwave radars that could see through walls, foliage, or soil; cheaper, more pervasive sensors that could provide 24/7 coverage of the battlefield; better data compression and transmission techniques that could allow more bytes to be sent much faster; and more powerful computers that might make it possible to create, for example, a real-time, three-dimensional model of a city showing all the people who reside in it.

Yet no matter how far information technology advances, it is doubtful that the Pentagon will ever succeed, as some utopians dream, in "lifting the fog of war." The fallibility of American soldiers and the cunning of their enemies will surely continue to frustrate the best-laid plans. Moreover, America's growing reliance on high-tech systems creates new vulnerabilities of its own: Future enemies have strong incentives to attack U.S. computer and communication nodes. Strikes on military information networks could blind or paralyze the armed forces, while strikes on civilian infrastructure, such as banking or air control systems, could cause chaos on the home front. Adversaries will almost certainly figure out ways to blunt the U.S. informational advantage. From Operation Anaconda in Afghanistan to numerous misadventures in Iraq, they already have. Whether fighting in the mountains of eastern Afghanistan or in the alleys of Ramadi and Fallujah, U.S. soldiers have been ambushed by insurgents who managed to elude their sensor networks through such simple expedients as communicating via messengers, not cell phones.

Asymmetric Warfare

Given the size and scope of America's military advantage, it is doubtful that any country will mount a full-spectrum challenge to U.S. military capabilities in the foreseeable future. The entry barriers are simply too high, especially for air, sea, and space systems. Virginia-class nuclear submarines cost $2.4 billion, Nimitz-class aircraft carriers go for $6 billion, and the F-35 Joint Strike Fighter program will cost at least $245 billion. The U.S. spends around $500 billion a year on its military, almost as much as the rest of the world combined. In fact, the U.S. spends more simply on the research, development, testing, and evaluation of new weapons—$71 billion in 2006—than any other country spends on its entire armed forces. (By way of comparison, the top three spenders after the U.S. are Russia, whose defense budget in 2003 was estimated at $65 billion; China, at $56 billion; France, at $45 billion; and Japan and the United Kingdom, at $42 billion. These are only estimates; the figures for Russia and China may be considerably higher.)

It is not only U.S. hardware that's hard to replicate; so is the all-volunteer force that makes it work. Operating high-tech military equipment requires long-service professionals, not short-term conscripts. Countries as diverse as Vietnam, China, Germany, and Russia are emulating the Anglo-American model by downsizing their forces and relying less on draftees; many other nations have abolished the draft altogether. The U.S. military's edge lies not simply in recruiting high-quality personnel but in its methods for training and organizing them. Initiatives undertaken in earlier decades, such as setting up realistic training centers to simulate combat conditions and forcing the services to work more closely together (the Goldwater-Nichols Act), continue to bear fruit. Few other armed forces have made comparable reforms.

But a potential adversary does not need to duplicate the U.S. force structure in order to challenge it. The United States faces a growing "asymmetric" threat both from other states and from sub-state groups. As the National Intelligence Council concluded in its recent report "Mapping the Global Future": "While no single country looks within striking distance of rivaling U.S. military power by 2020, more countries will be in a position to make the United States pay a heavy price for any military action they oppose." As we have seen, a variety of off-the-shelf missiles can threaten U.S. tanks, surface ships, and aircraft, especially when they get close to hostile territory. The power of smart munitions is outstripping the protection afforded by speed or armor. After 2010, write defense analysts Michael Vickers and Robert Martinage, "the survivability of aircraft carriers, high-structure surface combatants [e.g., tanks], and non-stealthy aircraft of all types could increasingly be called into question as maritime, over-the-horizon 'area denial' capabilities and extended-range air defense systems continue to mature." In a similar vein, George and Meredith Friedman contend that "the ability of conventional weapons platforms—tanks and aircraft carriers—to survive in a world of precision-guided munitions is dubious."

Also vulnerable are the ports, airfields, and bases which the U.S. uses to project its power overseas. Imagine how much damage Saddam Hussein could have done in 2003 if he had been able to annihilate the one port in Kuwait that was being used to disembark coalition troops or the large desert bases in Kuwait where over 100,000 British and American troops gathered prior to the invasion of Iraq. The Pentagon's 2001 Quadrennial

Defense Review warned that "future adversaries could have the means to render ineffective much of our current ability to project military power overseas."

If the U.S. armed forces could not count on safe, assured access to overseas bases they would need to change radically the way they do business. It would no longer be practical to rely on large land armies or lots of short-range combat aircraft operating out of vulnerable forward bases supplied by equally vulnerable cargo ships, trucks, and aircraft. The U.S. Army might be forced to rely on small numbers of commandos supported by long-range aircraft and missiles—as it did in Afghanistan. The Navy might have to depend more on submarines and the Air Force on stealth aircraft. All the services might have to make greater use of unmanned vehicles. The battlefield, which has been becoming less crowded for centuries, might empty out even further as small units try to conceal themselves from ubiquitous sensor networks, emerging only briefly to launch lightning strikes before they go back into hiding.

This has become known as the "swarming" scenario, and it has attracted support from the likes of military historian Alexander Bevin. "Large concentrations of troops and weapons are targets for destruction, not marks of power," he writes, "and [in the future] they no longer will exist.... Military units, to survive, must not only be small, but highly mobile, self-contained, and autonomous." Even if these predictions are accurate, however, it isn't clear when they would become reality, and timing matters tremendously. The key to winning future wars is knowing when to move from one form of military to another: A premature decision to change (such as the U.S. Army's flawed Pentomic design in the 1950s) can leave one unprepared to fight and win the wars that actually occur, Vietnam being the classic example.

In any case, it is doubtful that a complete switchover to "swarming" will ever occur. Winning wars, as opposed to winning battles, will continue to require controlling territory, which in turn will require a substantial presence of ground troops, as the U.S. has learned in Afghanistan and Iraq. No wonder-weapon will alter this fundamental reality, which means even the most high-tech military force will always remain vulnerable to the less sophisticated but still deadly technology of its adversaries on the ground.

American Hiroshima?

Even as strategists look to the future, armed forces must not lose sight of the threats of the moment, and they do not come for the most part from traditional militaries. They come largely from terrorist groups—some with state sponsorship, others without—that use the fruits of modern military technology to their perverse advantage.

"Irregular" attacks carried out by tribes, clans, or other non-state actors are as old as warfare itself; they long predate the development of modern armed forces and the nation-state. The religious fanaticism which animates so many of today's terrorists and guerrillas is equally ancient. But technological advances have made such attacks far more potent than in the distant past. The progeny of the second industrial revolution—assault rifles, machine guns, mortars, rocket launchers, landmines, explosives—long ago spread to the remotest corners of the globe. Fighters who a century ago might have made do with swords and muskets now have access to cheap and reliable weapons such as the AK-47 capable of spewing out 100 bullets a minute. More advanced technologies, from handheld missiles to chemical, biological, and nuclear weapons, give even a small group of insurgents the ability or potential ability to mete out far more destruction than entire armies could unleash just a century ago. And thanks to modern transportation and communications infrastructure—such as jumbo jets, the Internet, and cell phones—insurgents have the capability to carry out their attacks virtually anywhere in the world.

September 11 showed the terrifying possibilities of such unconventional warfare. It is easy to imagine that in the future super-terrorists will be able to kill hundreds of thousands, even millions, with effective weapons of mass destruction. All of the materials, as well as the know-how needed to craft such devices, are all too readily available.

The proliferation of nuclear weapons has the greatest ability to trump U.S. military hegemony. The atomic bomb is more than sixty years old. It belongs to an age of rotary-dial telephones and fin-winged cars. It is a miracle that it has not been used by maniac dictators or political radicals since 1945, but that streak won't last forever. And while information age technology offers a reasonable chance of stopping a nuclear-tipped missile, there is much less probability of stopping a terrorist with a nuclear suitcase. There is little in theory to prevent al Qaeda from carrying out its oft-expressed desire to create an "American Hiroshima." In the words of Eugene Habiger, a retired four-star general who once ran antinuclear terror programs for the Department of Energy, "it is not a matter of if; it's a matter of *when.*"

The most important challenge for the U.S. armed forces and their allies in the post-9/11 world is to "leverage" their advantage in conventional weaponry to deal with today's unconventional threats. Information technology can be an important part of this task. Embedded microchips can track the 18 million cargo containers moving around the world and help prevent terrorists from using them to smuggle weapons. Computerized cameras scanning a crowd may be able to pick out a terrorist based on facial recognition patterns. Dog-like sniffing machines may be able to recognize suspects by their body odor. Powerful computers utilizing artificial intelligence programs can sift vast reams of Internet data to pick out information about terrorist plots—if concerns about violating the privacy of innocent people do not get in the way. A variety of unobtrusive sensors can detect the presence of explosives or chemical, biological, or nuclear weapons. Handheld computer translating devices such as the Phraselator, already in use by U.S. troops, can bridge some of the language gap between Western operatives and the regions where they operate.

But in the final analysis, having the best technology is not enough to defeat the most committed terrorists armed with the deadliest weapons. Some of the most expensive weapons systems being purchased by the United States and its allies are irrelevant to fighting and winning the war against terrorism. And the combination of moral restraint and bureaucratic sluggishness that defines America's military culture may leave the U.S. at a comparative disadvantage against nimble, networked, nihilistic enemies like al Qaeda, who will deploy whatever weapons they have with urgent brutality. To deal with the essential paradox of the information age—that the march of advanced technology may decrease our security in some areas while increasing it in others—we need not just better machines but also the right organizations, training, and leadership to take advantage of them. That's where the U.S. has lagged badly behind; its industrial-age military bureaucracy remains configured primarily for fighting other conventional militaries, rather than the terrorist foes we increasingly confront. Changing the culture and structure of our armed forces—to say nothing of the CIA or State Department—is a far more daunting task than simply figuring out which weapons systems to buy. Yet even if we rise to that bureaucratic and political challenge, there will likely be times, tragically, when our military supremacy is no match for the technology-enhanced savagery of our inferior enemies.