Wired for War?
Robots and Military Doctrine

By P.W. SINGER

Marines in Iraq employ remote-controlled robot to detect improvised explosive devices and weapons caches

U.S. Marine Corps (William Skelton)

The growth in our use of unmanned systems has taken place so rapidly that we often forget how far we have come in just a short time. While U.S. forces went into Iraq with only a handful of drones in the air (all of V Corps had just one), by the end of 2008, there were 5,331 unmanned aircraft systems in the American inventory, from vigilant Global Hawks and armed Predators that circle thousands of feet overhead to tiny Ravens that peer over the next city block. A similar explosion happened on the ground, where zero unmanned ground vehicles were used in a tactical sense during the 2003 invasion; by the end of 2008, the overall inventory crossed the 12,000 mark, with the first generation of armed ground robotics arriving that year as well. And notably, these are just the first generation, much like the iPod, already outdated by the time they hit the marketplace and battlespace.

In many ways, the most apt historic parallel to this era may well turn out to be World War I. Back then, strange, exciting new technologies, which had been science fiction a few years earlier, were introduced and then used in greater numbers on the battlefield. They did not really change the fundamentals of the war, and in many ways the technology was balky and fighting remained frustrating. But these early models did prove useful enough that it was clear that the new technologies were not going away and militaries had better figure out how to use them most effectively. It also became clear with such new technologies that their effects would ripple out, reshaping areas that range from the experience of the soldier at war and how the media reports war to asking troubling new questions about the ethics and laws of war. Much the same is just starting to happen with our unmanned systems today.

Doctrine, Schmoctrine

Beyond these major questions of what happens when the robots of science fiction become political reality over the next few decades, there is a worry that force planners must start to pay attention to *doctrine*. A concern is that the United States is in a position similar to the British toward the end of World War I. It has developed an exciting new technology, which may well be the future of war. And it is even using the technology in growing quantities (the number of unmanned ground systems in Iraq today is just above the number of tanks the British had at the end of World War I). But the United States does not yet have an overall doctrine on how to use them or how they fit together.

"There is no guiding pattern, no guiding vision," is the assessment of Colonel Robert Bateman, an Army officer in the Pentagon's Net Assessment office tasked with this area. A survey of U.S. military officers taken by Defense Advanced Research Projects Agency (DARPA) researchers backs him up. When the officers were questioned about robots' future in war, they identified developing a strategy and doctrine as the third *least* important aspect to figure out (only ahead of solving inter-Service rivalry and allaying allies' concerns).[1] One commentator described how the military's process of purchasing systems, despite not having fully developed operational plans for them, "smacked of attention deficit disorder."[2]

The issue is not that we are not buying these systems or arguing over who controls them, but rather that we are not dealing with the broader question of where and how it all fits together. As an Army sergeant complained, "Every time we turn around they are putting some new technology in our hands." When his unit in Iraq was given a Raven unmanned aerial vehicle (UAV), no one instructed them on how, when, or where best to use it, or how it integrated into broader operations. So his unit tried the drone out on their own, putting a sticker on it that said in Arabic, "Reward if you return to U.S. base." A few days later, they "lost it somewhere in Iraq" and never saw the drone again. (In 2008, two U.S.-made Ravens were found hidden in Iraqi insurgent caches, which not only points to how our adversaries are exploring these technologies, but also shows that insurgents operate under a "finders keepers" ethic).[3]

The makers of these systems concur. iRobot executives (the team behind the Packbot) complain that the military is actually "behind" the technology in how it conceptualizes its use in the field, especially in ignoring robots' growing smarts and autonomy: "They still think of robots as RC [remote control] cars."[4] Similarly, at Foster-Miller (the team behind the TALON and SWORDS), executives point to the lack of an overall plan for support structures as evidence of the gap. They note that there is "nothing yet on logistics to support or maintain robots. . . . The Army is just bootstrapping it."[5]

robot executives complain that the military is "behind" the technology in how it conceptualizes its use in the field, especially in ignoring robots' growing autonomy

The Mothership Has Landed

Developing the right doctrine for using unmanned systems is thus essential to the future of the force. If the U.S. military gets it right, it will win the wars of tomorrow. If it does not, it might instead be on the way to building what one Army officer called "the Maginot Line of the 21st century."[6]

Akin to the intense interwar doctrinal debates over how to use new technologies such as tanks and airplanes, there is not yet agreement on how best to fight with unmanned systems. But the contours are coming to light. Much as early armor proponents argued over whether tanks should only support infantry versus being massed together, or the debate over aviation's strategic versus tactical roles, there appear to be two directions in which the doctrines of unmanned systems might shake out, with a degree of tension between the operating concepts. The first is the idea of the *mothership*, perhaps best illustrated by the tack the U.S. Navy is unconsciously moving toward with unmanned systems at sea.

The sea is becoming a much more dangerous place for navies in the 21st century. Drawing comparisons to the problems that traditional armies are facing with insurgencies on the land, Admiral Vern Clerk, former Chief of Naval Operations, believes that "the most significant threat to naval vessels today is the asymmetric threat."[7] The United States may have the largest blue water fleet in the world, numbering just under 300 ships, but the overall numbers are no longer on its side. Seventy different nations now possess over 75,000 antiship missiles, made all the more deadly through "faster speeds, greater stealth

P.W. Singer is Senior Fellow and Director of the 21st Century Defense Initiative at the Brookings Institution. This article is derived from his upcoming book *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (Penguin, 2009).

capabilities, and more accurate, GPS [global positioning system]-enhanced targeting."[8]

The dangers are even greater in the brown water close to shore. Here, small, fast motor boats, like those that attacked the USS *Cole*, can hide among regular traffic and dart in and out. Relatively cheap diesel-powered submarines can silently hide among water currents and thermal layers. More than 300 varieties of undersea mines are available on the world market today, ranging from those that detonate by simple contact to a new generation of smart mines, stealthy robotic systems equipped with tiny motors that allow them to shift positions, so as to create a moving minefield.

As evidenced by the intense work with robotics at the Office of Naval Research, the Navy is increasingly turning toward unmanned systems to face this dangerous environment. Describing the "great promise" that unmanned systems hold for naval warfare, one report told how "we are just beginning to understand how to use and build these vehicles. The concepts of operations are in their infancy, as is the technology. The Navy must think about how to exploit the unmanned concepts and integrate them into the manned operations."[9]

One of the early ideas for trying to take these technologies out to sea comes in the form of the Navy's littoral combat ship (LCS) concept. Much smaller and faster than the warships used now, the ships are to be incredibly automated. For example, the crew on the prototype ship in the series is only about one-fourth the size of the previous equivalent ship's crew. But less important than the automation of the ship itself is the concept of change it represents. Besides the crew on board, there is also a crew on shore, sitting at computer cubicles and providing support from thousands of miles away.[10] The LCS has a modular plug-and-play capacity, allowing various unmanned systems and the control stations to be swapped in and out, depending on the mission.

If the ship is clearing sea lanes of mines, it might pack onboard a set of mine-hunting robotic mini-subs. If the ship is patrolling a harbor, it might carry mini-motorboats that would scatter about, inspecting any suspicious ships. Or, if it needs to patrol a wider area, it might carry a few UAVs. Each of these drones is controlled by crew sitting at control module stations, who themselves only join the ship for the time needed. The manned ship really is a sort of moving mothership, hosting and controlling an agile network of unmanned systems that multiply its reach and power.

The mothership concept is not just planned for new, specially built ships like the LCS. Older ships all the way up to aircraft carriers might be converted to this mode. Already serving as a sort of mothership for manned planes, the aircraft carrier would add up to 12 unmanned planes to each carrier under the Navy's current plan. This number should grow if we are interested in actual combat effectiveness. In a 2006 wargame, which simulated a battle with a "near-peer competitor" that followed the mode of fighting an asymmetric war with submarines, cruise missiles, and antiship ballistic missiles (that is, China), Navy planners hit upon a novel solution. Because unmanned planes take up less deck space and have far greater endurance and range than manned planes, they reversed the ratio, offloading all but 12 of the manned planes and loading on 84 unmanned planes. Their "spot on, almost visionary" idea reportedly tripled the strike power of the carrier and gave it a reach that a standard mix of F–35s and F–18s would lack.[11] As UAVs shrink in size, even more drones could fly off such flattops. In 2005, one of the largest aircraft carriers in the world, the USS *Nimitz*, tested Wasp Micro Air Vehicles, drones that are only 13 inches long.[12]

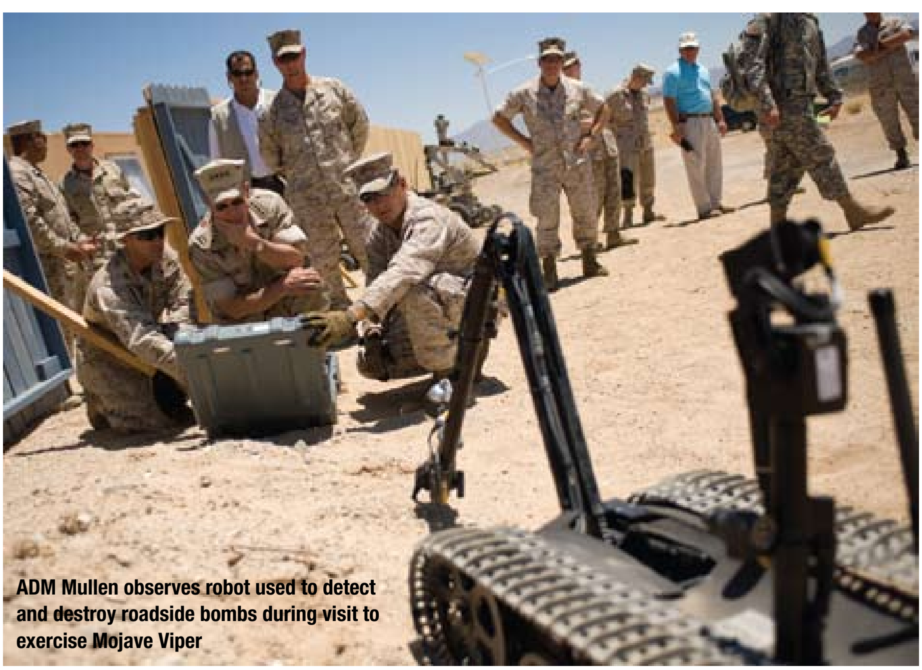
The same developments with mothership concepts are starting to take place under the sea. In 2007, a Navy attack sub shot a small robotic sub out of its torpedo tubes, which then carried out a mission. The robotic mini-sub drove back to the mother submarine. A robotic arm then extended out of the tube and pulled the baby sub back inside,

the Navy's current plan for aircraft carriers entails adding up to 12 unmanned planes to each carrier

whereupon the crew downloaded its data and fueled it back up for another launch. It all sounds simple enough, but the test of a robotic underwater launch-and-recovery system represented "a critical next step for the U.S. Navy and opens the door for a whole new set of advanced submarine missions," according to one report.[13]

The challenge the Navy is facing in undersea warfare is that potential rivals such as China, Iran, and North Korea have diesel subs that remain absolutely quiet. When these subs hide in littoral waters close to shore, many advantages held by America's nuclear subs disappear.

Unmanned systems, particularly those snuck in by a fellow submarine, "turn the asymmetry around by doing [with unmanned craft] what no human would do." For example, sonar waves are the traditional way to find foes under the sea. But these active sensors are akin to using a flashlight in the dark. They help us find what we are looking for, but they also let everyone nearby know exactly where we are.



ADM Mullen observes robot used to detect and destroy roadside bombs during visit to exercise Mojave Viper

U.S. Navy (Chad J. McNeeley)

Manned submarines instead usually quietly listen for their foes, waiting for them to make a noise first. By contrast, unmanned systems can be sent on missions and blast out their sonar, actively searching for the diesel subs hiding below. An enemy might be able to strike back, but it would only reveal its presence and not kill any Sailors.

Having its own fleet of tiny subs also multiplies the reach of a submarine. For example, a mother-submarine able to send out just a dozen tiny subs can search a grid the size of the Persian Gulf in a little over a day. A submarine launching a UAV that can fly in and out of the water (like Lockheed Martin's Cormorant design) extends the mothership's reach farther, even ashore.

Such capabilities will lead to new operating concepts. One naval officer talked about how the robotic mini-subs would be like the unmanned "whiskers." He continued, "They would act as 'force multipliers,' taking care of programmable tasks and freeing up manned warships to take on more complex ones. And they could be sent on the riskiest missions, to help keep Sailors and Marines out of harm's way." [14] For example, the robotic subs could be sent in to clear minefields from below, lurk around enemy harbors, or track enemy subs as they leave port.

By pushing its robotic whiskers (and "teeth," as the systems can also be armed) farther away from the body, the mothership does not even have to be a warship itself. For example, with foreign nations increasingly unwilling to host U.S. bases ashore, the Navy is moving to a doctrinal concept of seabasing. These would be large container ships that act like a floating harbor. But such ships are slow, ungainly, and certainly not stealthy; hence, they are vulnerable to attack. A plan to protect them is called Sea Sentry.[15] The seabase would not only provide a supply station for visiting ships and troops ashore, but also host its own protective screen of unmanned boats, drones, and mini-subs. Similar plans are being developed for other vulnerable targets at sea, such as civilian merchant ships, oil tankers, and even oil rigs.[16]

The concept of the mothership is not limited to the sea. For example, one firm in Ohio has fitted out a propeller-powered C–130 cargo plane so it can not only launch UAVs, but also recover them in the air. The drones fly in and out of the cargo bay in the back, turning the plane into an aircraft carrier that is actually airborne.[17]

Rethinking War with Mother

Such motherships will entail a significant doctrinal shift in how militaries fight. One report explained that its effect at sea would be as big a transformation as the shift to aircraft carriers, projecting that it would be the biggest "fork in the road" for the U.S. Navy in the 21st century.[18]

Naval war doctrine, for example, has long been influenced by the thinking of the American Admiral Alfred Thayer Mahan (1840–1914). Mahan did not have a distinguished career at sea (he reputedly would get seasick even on a pond), but in 1890 he wrote *The Influence of Sea Power Upon History*, which soon changed the history of war at sea.

Navies, Mahan argued, were what shaped whether a nation became great (an argument likely to appeal to any sailor). In turn, the battles that mattered were the big showdowns of fleets at sea, "cataclysmic clashes of capital ships concentrated in deep blue water."[19] Mahan's prescripts for war quickly became the doctrine of the U.S. Navy, guiding Teddy Roosevelt to build a "Great White Fleet" of battleships at the turn of the 20th century and shaping the strategy the Navy used to fight the great battles in the Pacific in World War II, as well as how it planned to fight the Soviets if the Cold War ever turned hot.

The future of war at sea, however, bodes to look less and less like what Mahan envisaged. With the new asymmetric threats and unmanned responses, any future confrontations will not merely take place between two fleets, made up of the biggest ships, concentrated together into one place. Moreover, where ships fight will not simply be the blue waters far from shore; these battles are predicted to take place closer to shore. The fleet would comprise not a number of ships "concentrated" together as Mahan wanted, but rather would be made up of many tiny constellations of smaller, often unmanned systems, linked back to their host motherships. These ships, in turn, might be much smaller than Mahan's capital ships of the past.

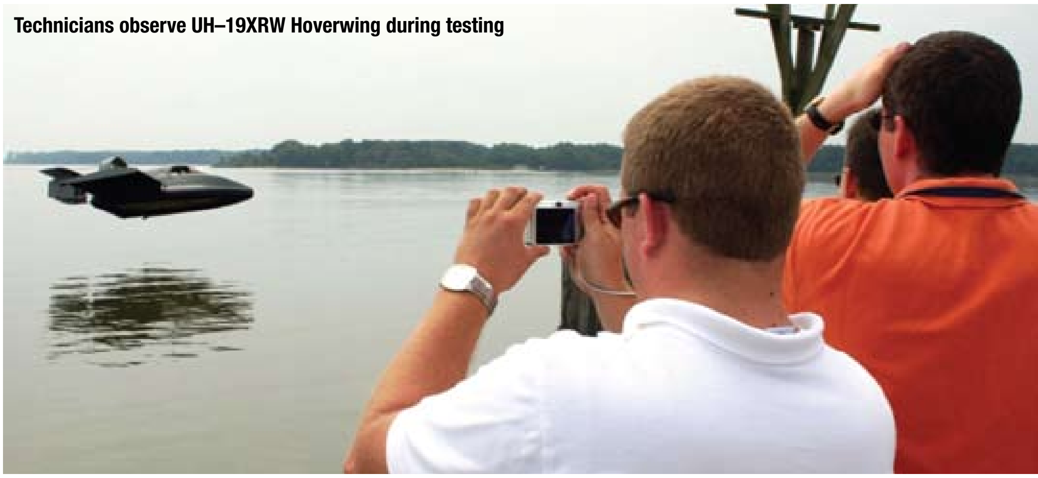
ships will not be "concentrated" together as Mahan wanted, but rather be made up of many tiny constellations of smaller, often unmanned systems

With Mahan's vision looking less applicable to modern wars and technology, a new thinker on 21st-century naval war doctrine may have to come into vogue in planning. The only twist is that he was born just 14 years after Mahan.

Sir Julian Stafford Corbett (1854–1922) was a British novelist turned naval historian. Notably, Corbett was a friend and ally of naval reformer Admiral John "Jackie" Fisher, who introduced such new developments as dreadnaughts, submarines, and aircraft carriers into the Royal Navy. While he and Mahan lived in the same era, Corbett took a completely different tack toward war at sea. They both saw the sea as a critical chokepoint to a nation's survival, but Corbett thought that the idea of concentrating all ships together in the hope of one big battle was "a kind of shibboleth" that would do more harm than good. The principle of concentration, he declared, was "a truism—no one would dispute it. As a canon of practical strategy, it is untrue."[20]

In his masterwork on naval war doctrine, modestly titled *Some Principles of Maritime*

Technicians observe UH–19XRW Hoverwing during testing



U.S. Navy (John Joyce)

Strategy, Corbett opined that the idea of putting all one's ships together into one place did not induce all enemies into one big battle. Only the foe that thought it would win such a battle would enter it. Any other sensible foe would just avoid the big battle and disperse to attack the other places where the strong fleet was not (a theory that was borne out later by the German strategy in World War II). Moreover, the more a fleet concentrated in one place, the harder it would be to keep its location concealed. So the only thing Mahan's big fleet doctrine accomplishes in an asymmetric war, Corbett felt, is to make the enemy's job easier.

Instead, argued Corbett, the fleet should spread out and focus on protecting shipping lanes, blockading supply routes, and generally menacing the enemy at as many locales as possible. Concentrations of a few battleships were not the way to go. Rather, much like how the Royal Navy policed the world's oceans during the 1700 and 1800s, it was better to have a large number of tiny constellations of mixed ships, large and small, each able to operate independently. In short, it is a doctrine far more apt for motherships.

Even more shocking at the time, Corbett emphasized that a navy should think about not just operations in the blue waters in the middle of the ocean, but also what role it could play in supporting operations on land. Offers one biographer, "Well before it was fashionable, [Corbett] stressed the interrelationship between navies and armies."[21] This seems much more attuned to the role of the U.S. Navy today, which must figure out not merely how to deter major state conflict and protect shipping lanes, but also how to aid the fight on the land (for instance, it carried out over half of the 15,000 airstrikes during the 2003 invasion of Iraq).

Mahan won the first round in the 20th century, but Corbett's doctrine may well come true through 21st-century technology.

Swarming the Future

The concept of motherships comes with a certain built-in irony, however. It entails a dispersion, rather than concentration, of firepower. But the power of decision in this doctrinal concept is still highly centralized. Like the spokes in a wheel, the various unmanned systems may be far more spread out, but they are always linked back to the persons sitting inside the mothership. It is a top-down, "point and click" model of war, where it is always clear who is in charge. General Ronald Keys, the Air Force chief of air combat, describes a typical scenario that might take place in such a model applied to war in the air: "An [enemy] air defense system pops up, and I click on a UCAS [unmanned combat air system] icon and drag it over and click. The UCAS throttles over and jams it, blows it up, or whatever."[22]

This philosophy of unmanned war is very mechanical, almost Newtonian, and certainly not one in which the robots will have much autonomy. It is not, however, the only possible direction that we might see doctrines of war move in, much as there were multiple choices on how to use tanks and airplanes after World War I. Places such as DARPA, the Office of Naval Research, and the Marine Corps Warfighting Laboratory are also looking at "biological systems inspiration" for how robot doctrine might take advantage of their growing technologic smarts and autonomy. As one analyst pointed out, "If you look at nature's most efficient predators, most of them don't hunt by themselves. They hunt in packs. They hunt in groups. And the military is hoping their robots can do the same."[23]

rather than being centrally controlled, swarms are made up of highly mobile, individually autonomous parts

The main doctrinal concept that is emerging from these programs is an alternative to motherships called *swarming*. Rather than being centrally controlled, swarms are made up of highly mobile, individually autonomous parts. Like birds in a flock or wolves on a hunt, each decides what to do on its own, but somehow still manages to organize into highly effective groups. After the hunt, they disperse. Individually, each part is weak, but the overall effect of the swarm can be powerful.

Swarming does not only happen in nature. In war, it is actually akin to how the Parthians, Huns, Mongols, and other mass armies of horsemen would fight. They would spread out over vast areas until they found the foe, and then encircle them, usually wiping them out by firing huge numbers of arrows into the foe's huddled army. Similarly, the Germans organized their U-boats into "wolfpacks" during the Battle of the Atlantic in World War II. Each submarine would individually scour the ocean for convoys of merchant ships to attack. Once one U-boat found the convoy, all the others would converge, first pecking away at the defenses, and then, as more and more U-boats arrived on the scene, overwhelm them. And it is a style of fighting that is fairly effective. In a RAND study of historic battles going back to the time of Alexander the Great, the side using swarm tactics won 61 percent of the battles.[24]

Notably, 40 percent of these wins were battles that took place in cities. Perhaps because of this historic success of urban swarms, this same style of fighting is increasingly used by insurgents in today's asymmetric wars. From the "Black Hawk Down" battle in Somalia (1993) and the battles of Grozny in Chechnya (1994, 1996) to the battles of Baghdad (2003, 2004) and Fallujah (2004), the usual mode is that insurgents hide out in small, dispersed bands until they think they can overwhelm some exposed unit. The various bands, each of which often has its own commander, then come together from various directions and try to encircle, isolate, and overwhelm the enemy unit. This echoes T.E. Lawrence's account of how his Arab raiders in World War I used their mobility, speed, and surprise to become "an influence, a thing invulnerable, intangible, without front or back, drifting about like a gas."[25]

Swarms, whether of buzzing bees or insurgents with AK–47s, are made up of independent parts and have no one central leader or controller. So the self-organization of these groupings is a key to how the whole works. The beauty of the swarm, and why it is so appealing for unmanned war, is how it can perform incredibly complex tasks by each part following incredibly simple rules.

A good example is a flock of birds. Hundreds of birds can move together almost as if they have a single bird in charge, speeding in one direction, then turning in unison and flying off in a different direction and at a different speed, without any bird bumping into the other. They do not just operate this way for what one can think of as tactical operations, but also at the strategic level, with flocks migrating in unison over thousands of miles.

As one Army colonel asks, "Obviously the birds lack published doctrine and are not receiving instructions from their flight leader, so how can they accomplish the kind of self-organization necessary for flocking?"[26] The answer actually comes from a researcher, Craig Reynolds, who built a program for what he called "boids," or artificial birds.[27] As an Army report on the experience described, all the boids needed to do to organize themselves together as a flock was for each individual to follow three simple rules: "1. Separation: Don't get too close to any object, including other boids; 2. Alignment: Try to match the speed and direction of nearby boids; and 3. Cohesion: Head for the perceived center of mass of the boids in your immediate neighborhood."[28] This basic boid system worked so well that it was also used in the movie *Batman Returns* to create the realistic bat sequences.

Just as birds and boids follow simple rules to carry out complex operations, so might an unmanned swarm in war. Each system would be given a few operating orders and let loose, each robot acting on its own, but also in collaboration with all the others. The direction of the swarm could be roughly guided by giving the robots a series of objectives ranked in priority, such as a list of targets given point-value rankings. For instance, much like a bird might have preferences between eating a bug or a Saltine cracker, a robot's operating code might note that taking out an enemy tank is more useful than taking out an enemy outhouse. The swarm would then follow Napoleon's simple credo about what works best in war: "March to the sound of the guns."

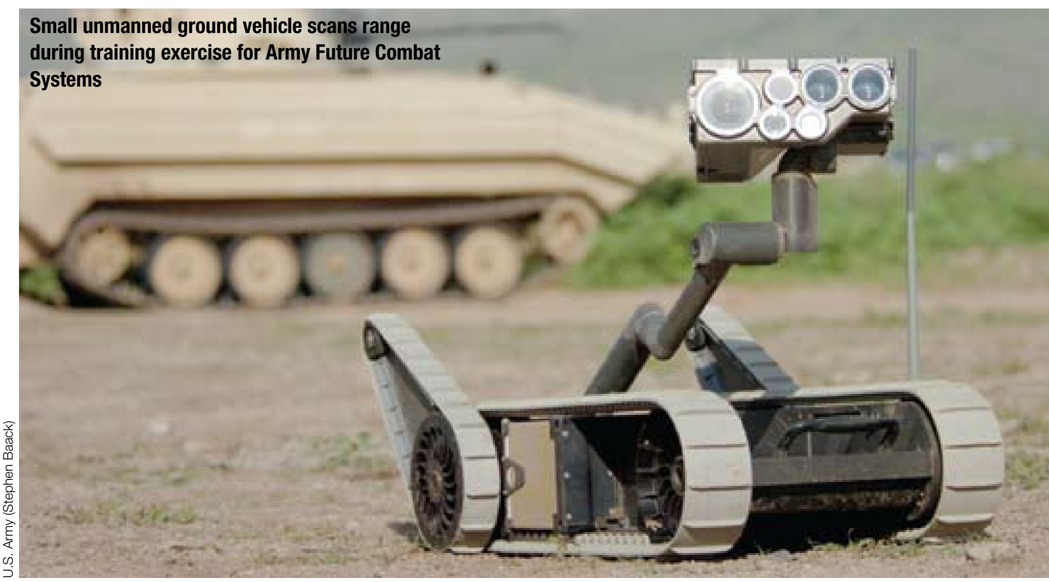
The Santa Fe Institute carried out a study on these proliferated autonomous weapons (PRAWNS), which shows how this concept might work in robotic warfare (Lockheed Martin has a similar program on robot swarms funded by DARPA, called the "Wolves of War").[29] Very basic unmanned weapons would use simple sensors to find enemy targets, an automatic targeting recognition algorithm to identify them, and easy communications such as radio and infrared (as the scientists thought the military's current idea of using the Internet to coordinate operations was flawed because the Internet would be too easy to jam) to pass on information about what the other robots in the swarm were seeing and doing. The robots would be given simple rules, which mimic birds that flock or ants that forage for food. As the PRAWNS spread around in an almost random search, they would broadcast to the group any enemy targets they find. Swarms would then form to attack the targets. But each individual robot would have knowledge of how many fellow robots were attacking the same target, so if there were already too many PRAWNS attacking one target, the other systems would move on to search for new targets. In much the same way as ants have different types (soldiers and workers) operating in their swarms, the individual PRAWNS might also carry different weapons or sensors, allowing them to match themselves to the needs of the overall swarm.[30]

While each PRAWN would be very simple, and almost dumb (indeed, their artificial intelligence would be less than the systems already on the market today), the sum of their swarm would be far more effective than any single system. Why drive a single SWORDS or Packbot into a building, room by room, to see if an enemy is hiding there, when a soldier could let loose a swarm of tiny robots that would scramble out and automatically search on their own?

Mom against the Bees

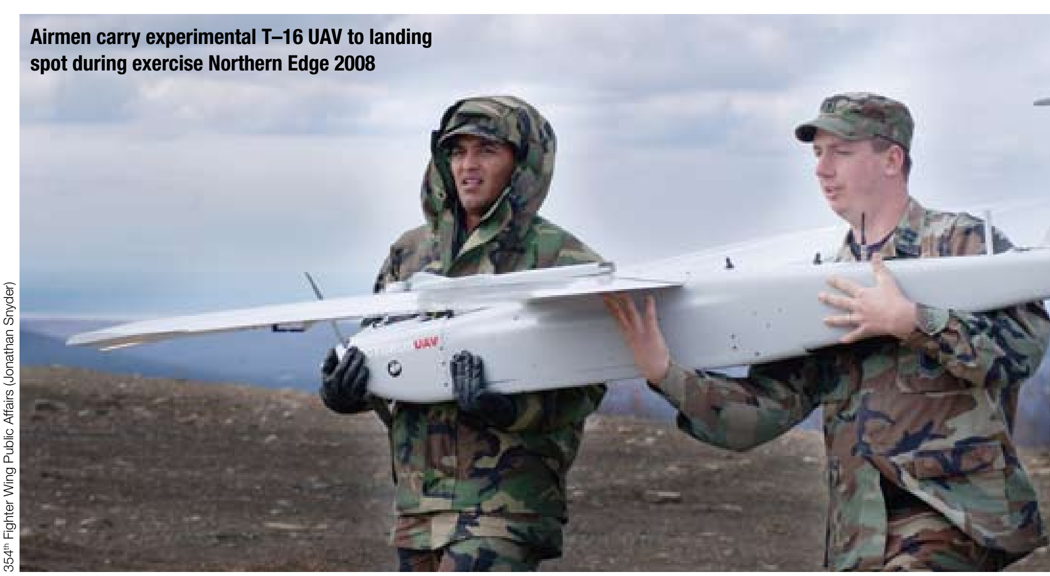
Swarms are thus the conceptual opposite of motherships, despite both using unmanned systems. Swarms are decentralized in control but concentrate firepower, while motherships are centralized but disperse firepower. If we imagine a system of motherships laid out on a big operational map, it would look like a series of hubs, each with spokes extending. Like checker pieces, each of these mothership hubs could be moved around the map by a human commander, much as each of their tiny robotic spokes could be pointed and clicked into place by the operators sitting inside the motherships. With swarms, the map would instead look like a meshwork of nodes. It would almost appear like drawing lines between the stars in the galaxy or a "map" of all the sites in the Internet. Every tiny node would be linked with every other node, either directly or indirectly. Where

robots would be given simple rules, which mimic birds that flock or ants that forage for food



Small unmanned ground vehicle scans range during training exercise for Army Future Combat Systems

U.S. Army (Stephen Baack)



Airmen carry experimental T–16 UAV to landing spot during exercise Northern Edge 2008

354th Fighter Wing Public Affairs (Jonathan Snyder) the linkages cluster together is where the action in battle would be taking place, but these clusters could rapidly shift and move.

Every doctrine would seem to have its advantages and disadvantages. The mothership style of operations has specific roles for specific units, as well as central lines of communications. Chop off one limb and the task might not get done. By contrast, self-organizing entities such as swarms come with built-in redundancies. Swarms are made up of a multitude of units, each acting in parallel, so there is no one chain of command, communications link, or supply line to chop. Attacking a swarm is akin to going after bees with a sword. Similarly, swarms are constantly acting, reacting, and adapting, so they have a feature of perpetual novelty built in. It is hard to predict exactly what they will do next, which can be a very good thing in war.

The disadvantages of swarm systems are almost the inverse. Swarms may not be predictable to the enemy, but neither are they exactly controllable or predictable for the side using them, which can lead to unexpected results. Instead of being able to point and click and get the immediate action desired, a swarm takes action on its own, which may not always be exactly where and when the human commander wants it.

The above is almost like what Gandhi said while sitting on the side of the road as a crowd went by. "There go my people. I must get up and follow them, for I am their leader!"[31] The human commander's job with a swarm will be to set the right goals and objectives. They may even place a few limits on such things as the "radius of cooperation" of the units. Then, other than perhaps parceling out reserves and updating the point values on each of the enemy's target types to reflect changing needs, the human commanders would, as Naval Postgraduate School expert John Arquilla describes it, "basically stay the hell out of the way of the swarm."[32] This type of truly "decentralized decision making," says one Marine general, "flies in the face of the American way of war. . . . But it works."[33]

Whether it is motherships, swarms, or some other concept of organizing for war that we have not yet seen, it is still unclear what doctrines the U.S. military will ultimately choose to organize its robots around. In turn, it is also unclear which doctrine will prove to be the best, as it is fully possible that, like the British and French in the interwar years, America's Armed Forces could make choices that seem brilliant at the time but later prove utterly wrong.

Indeed, just as the optimum with tanks turned out to be combined arms units, the choices may also mix and mingle. The concepts of swarms and motherships could be blended, with human commanders inserting themselves at the points where swarms start to cluster. It would not be the same as the direct control of the mothership's hub and spoke system, but it would still be a flexible way to make sure the leader was influencing events at the major point of action.

Whatever doctrine prevails, it is clear that the American military must begin to think about the consequences of a 21st-century battlefield in which it is sending out fewer humans and more robots. Just as the technologies and modes of wars are changing, so must our concepts of how to fight and win them. **JFQ**

NOTES

1 Robert Finkelstein and James Albus, "Technology Assessment of Autonomous Intelligent Bipedal and Other Legged Robots," Defense Advanced Research Projects Agency, 2004.

2 Bill Sweetman, "UCAVs Offer Fast Track to Stealth, Long Range, and Carrier Operations," *Jane's International Defence Review* 40 (2007), 41.

3 U.S. Army Soldier, interview by author, Washington, DC, November 2, 2006; "American Drone Discovered in Baghdad Cache," June 20, 2008, available at <http://blog.wired.com/defense/2008/06/insurgents-unma.html>.

4 iRobot executive, interview by author, November 16, 2006.

5 Foster-Miller executive, interview by author, November 17, 2006.

6 John A. Gentry, "Doomed to Fail: America's Blind Faith in Military Technology," *Parameters* 32, no. 4 (2002), 88.

7 Joris Janssen Lok, "Navies Look for Ways to Tackle the Ever-changing Close-in Threat," *Jane's International Defence Review* 37 (2004).

8 Max Boot, "The Paradox of Military Technology," *The New Atlantis* 14 (2006), available at <www.thenewatlantis.com/archive/14/boot.htm>.

9 F.W. LaCroix and Irving N. Blickstein, *Forks in the Road for the U.S. Navy* (Santa Monica, CA: RAND, 2003), ix.

10 Scott Truver, "Mix and Match," *Jane's Defence Weekly*, March 16, 2005, 24.

11 Bill Sweetman, "U.S. Finally Looks Beyond the B–2 for Long-Range Strike Capability," *Jane's International Defence Review* 39 (2006), 44.

12 Christian Lowe, "Itsy-bitsy Drone," April 5, 2005, available at <www.defensetech.org/archives/001467.html>.

13 "Boeing Achieves First Submerged Unmanned Undersea Vehicle Recovery by a Submarine," press release, November 26, 2007, available at <www.boeing.com/news/releases/2007/q4/071126b_nr.html>.

14 Carl Posey, "Robot Submarines Go to War. Part 2: The Navy's AUVs," *Popular Science*, March 2003, available at <www.popsci.com/popsci/science/6327359b9fa84010vgnvcm1000004eecbccdrcrd.html>.

15 Michael Fetsch, Chris Mailey, and Sara Wallace, "UV Sentry," paper presented at the Association for Unmanned Vehicle Systems International, 34th Annual Symposium and Exhibition, Washington, DC, August 6–9, 2007.

16 Lok.

17 David Pugliese, "Launch and Recover UAV System Tested," *Defense News*, February 19, 2007, 14.

18 LaCroix and Blickstein, ix.

19 Ibid.

20 See "Julian Corbett," Wikipedia, available at <http://en.wikipedia.org/wiki/Julian_Corbett>. Quotation from Robert Cowley and Geoffrey Parker, *Reader's Companion to Military History* (Boston: Houghton Mifflin, 2004).

21 Frank G. Hoffman, "The Fleet We Need: A Look at Alternative—and Affordable—Futures for the U.S. Navy," *Armed Forces Journal* (August 2006), 49.

22 David A. Fulghum and Michael J. Fabey, "F–22: Unseen and Lethal," *Aviation Week & Space Technology* 166, no. 2 (2007), 46.

23 Noah Shachtman, quoted in the Discovery Military Channel documentary *Warbots*, which aired January 26, 2006.

24 Sean J.A. Edwards, "Swarming and the Future of Warfare," Ph.D. diss., Pardee RAND Graduate School, 2005, 83.

25 Ibid., 64.

26 Thomas K. Adams, "The Real Military Revolution," *Parameters* 30, no. 3 (2000).

27 Craig W. Reynolds, "An Evolved, Vision-based Model of Obstacle Avoidance Behavior," in *Proceedings*, ed. C. Langton (Redwood City, CA: Addison-Wesley, 1994).

28 Adams.

29 "UCAR—The Next Generation of Unmanned Aerial Vehicles," August 17, 2003, available at <www.gizmag.com/go/2118/>.

30 Dave Frelinger et al., *Proliferated Autonomous Weapons: An Example of Cooperative Behavior, Documented Briefing* (Santa Monica, CA: RAND, 1998), 6.

31 Gregory A. Jackson, "'Follow the Money' and Other Unsolicited Advice for CIOs," *Cause and Effect* 22, no. 1 (1999).

32 As quoted in Joel Garreau, *Radical Evolution: The Promise and Peril of Enhancing Our Minds, Our Bodies—And What it Means to Be Human* (New York: Doubleday, 2005), 217.

33 U.S. Marine Corps general, interview by author, January 16, 2007.