The Drone Revolution Revisited:

An Assessment of Military Unmanned Systems in 2016

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September 2016

The Center for the Study of the Drone at Bard College is an interdisciplinary research institution founded in 2012 that examines the novel and complex opportunities and challenges presented by unmanned technologies in both the military and civilian sphere.

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Holland Michel, Arthur and Dan Gettinger. “The Drone Revolution Revisited: An Assessment of Military Unmanned Systems in 2016.” *Center for the Study of the Drone at Bard College*, September 6, 2016.

We would like to thank the Bard College students whose outstanding research formed the basis for this report.

We would like to express our gratitude to Thomas Keenan, with whom we co-taught the seminar “The Drone Revolutions,” which gave rise to this report.

We would like to thank Peter W. Singer for his participation and support.

Madi Garvin and Erin O’Leary provided editorial support for this report.

Cover photo by Staff Sgt. Manuel J. Martinez/U.S. Air Force.

The Drone Revolution Revisited

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Introduction

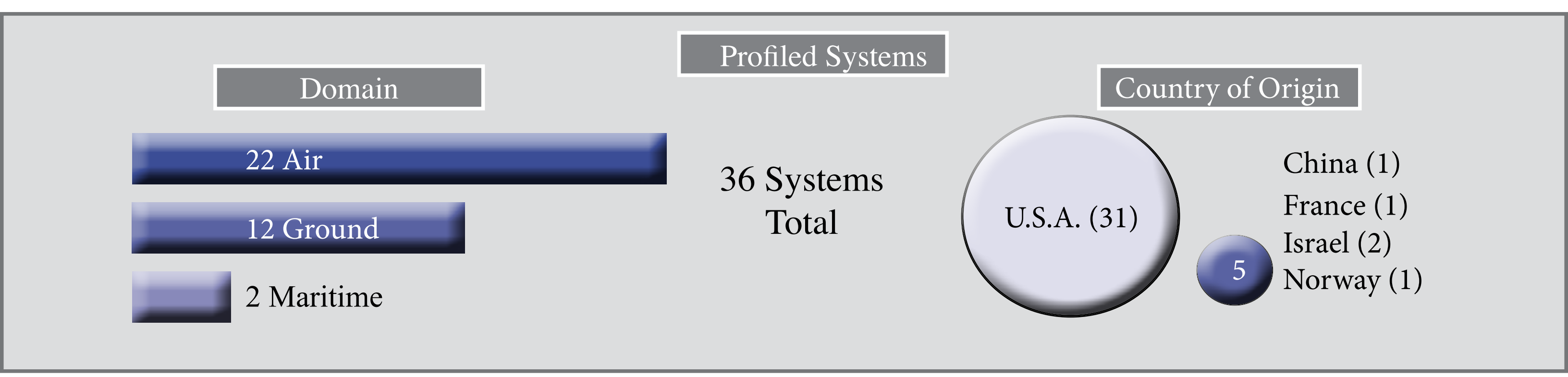
Photo credit: Lance Cpl. Julien Rodarte/USMC

In 2009, not many people were talking seriously about robots in war. Even though every U.S. armed service operated drones either in the air, on the ground, or undersea, and though numerous initiatives to develop the next generation of advanced systems were already publicly underway, there was very little broad public dialogue on the topic. By 2012, the year that we founded the Center for the Study of the Drone, news stories about unmanned systems technology and its implications were appearing regularly, and a vibrant public debate around the use of these systems was increasingly filling the airwaves.

What put drones into the the public spotlight? One factor was undoubtedly the inauguration of President Obama, whose administration quickly expanded the military's use of drones. Another significant factor was the book *Wired for War: The Robotics Revolution and Conflict in the 21st Century* by Peter W. Singer. Published in 2009, *Wired for War* offered a comprehensive portrait of the influx of drones into the U.S. military at a critical time in the history of the technology, and the many ways in which they would transform the battlefield. By presenting the rapidly expanding menagerie of drones in both the sky and on the ground, Singer demonstrated that the field of military robotics had matured to a point where it was disrupting the status quo. He described proliferating technologies that were already presenting significant challenges and opportunities—one example being the psychological impact of remote warfare on drone pilots and sensor operators—as well as programs and fields of research that were likely to yield new transformative capabilities in the near future. One such track was the development of autonomous weapons systems that can identify and engage targets without human intervention.

The book served as a core text in our class "The Drone Revolutions," an undergraduate seminar held at Bard College in the spring 2016 academic semester. The class sought to lay out a broad overview of unmanned systems technology in both military and civilian spheres, and equip students with the analytical tools to conduct original research on unmanned systems. As a final assignment for the seminar, we asked each student to research two platforms or technologies described in *Wired for War* in order to determine whether the program still exists, how the system has developed, and how the technology is currently being used (and by whom).

"The Drone Revolution Revisited" offers a guide to the evolving ecosystem of unmanned systems technologies as it stands in 2016, and reflects the ways in which the technology has evolved and matured over the past seven years since the publication of *Wired for War*. The research produced by our students served as the basis for Chapter I, which consists of portraits of 30 systems that Singer presented as the harbingers of the drone revolution. Some of the systems—for example, the U.S. Navy's MQ-8 Fire Scout—have grown into large multi-billion dollar military acquisition programs, while other systems that seemed promising, such as the Boston Dynamics BigDog or the Foster Miller SWORDS, have fizzled. Of these 30 systems, 13 are active or deployed, three remain in development, and 14 have been cancelled or are inactive. By revisiting these systems, we have sought to update, expand upon, and interrogate Singer's 2009 portrait of the drone revolution.



For each system, we explain what it does, which military service or agency developed it, its specifications, its history, and (if the information is available) its cost. We also describe whether the system remains in development, has been deployed, or was cancelled. For deployed programs, we describe the extent to which they have been used, and by whom. For cancelled programs, we identify the reasons for their cancellation. It should be noted that the benchmarks "developmental," "deployed," and "cancelled" that we present on page 5 refer to the formal military programs under which a particular system was managed, rather than the actual system. If a particular program is cancelled by the military, that does not necessarily spell the end for the particular drone or robot. For example, prototypes of a cancelled system may remain in contractors' inventories; though the Pentagon cancelled the Global Observer program in 2012 the manufacturer, AeroVironment, is actively seeking alternate customers for the drone. Or new programs may emerge that build on technologies that were matured through earlier cancelled program. Though the Air Force is phasing out its MQ-1 Predator, the MQ-9 Reaper—essentially a larger, faster variant of the Predator—is slated to remain in use far into the foreseeable future.

The systems and programs in this report represent only a sample of the many drones that exist today. Some of the most significant trends that we are currently witnessing are not fully reflected by the systems that existed or were already under development in 2009. The maritime domain has become more important in recent years; unmanned undersea and surface vehicles are slated to play a prominent role in naval operations in the near future, and numerous high-profile maritime drone development programs are currently underway. Likewise, certain ground and airborne unmanned systems programs that already existed in 2009 have evolved in dramatic ways, or given rise to entirely new programs. For example, the Northrop Grumman X-47A, an in-house prototype combat drone, has since given rise to the X-47B, an impressive demonstrator combat drone developed for Navy's Unmanned Carrier Launched Airborne Surveillance and Strike program, which was recently reconceived as the MQ-25A Stingray, an aerial refuelling drone with strike capabilities. Finally, and crucially, non-U.S. drone programs have expanded significantly; China and Europe, for example, are seeking to develop advanced aerial drones that can match the capabilities of U.S. systems. In order to reflect these trends, we present portraits of six platforms not mentioned in *Wired for War* that are representative of important shifts in the recent history of drone technology development. These platforms are highlighted in light blue.

In Chapter II, Peter Singer revisits the book and reflects on the trajectory of the drone evolution in the time since it was published. Singer points to trends that have emerged since 2009, such as the growth in the use of drones in the U.S. targeted killing program and the emergence of swarming technology programs, and predicts the ways in which the field is likely to evolve in the near future.

This report points to numerous possible avenues for future research. Why do some technologies fail while others thrive? How have the priorities for certain drones changed over the years and how are these priorities reflected in the defense budget? By reviewing programs side by side, our hope is to foster dialogue about the broader patterns that can indicate whether or not a system is likely to be successful or not, as well as lessons regarding the types of point failures that can cause a program to be cancelled. In doing so, we are looking to spark a conversation about where the most significant technological advances are likely to happen and to inform predictions on the next seven years of drone technology development.

Photo credit: Petty Officer 2nd Class Antonio Turetto Ramos/U.S. Navy

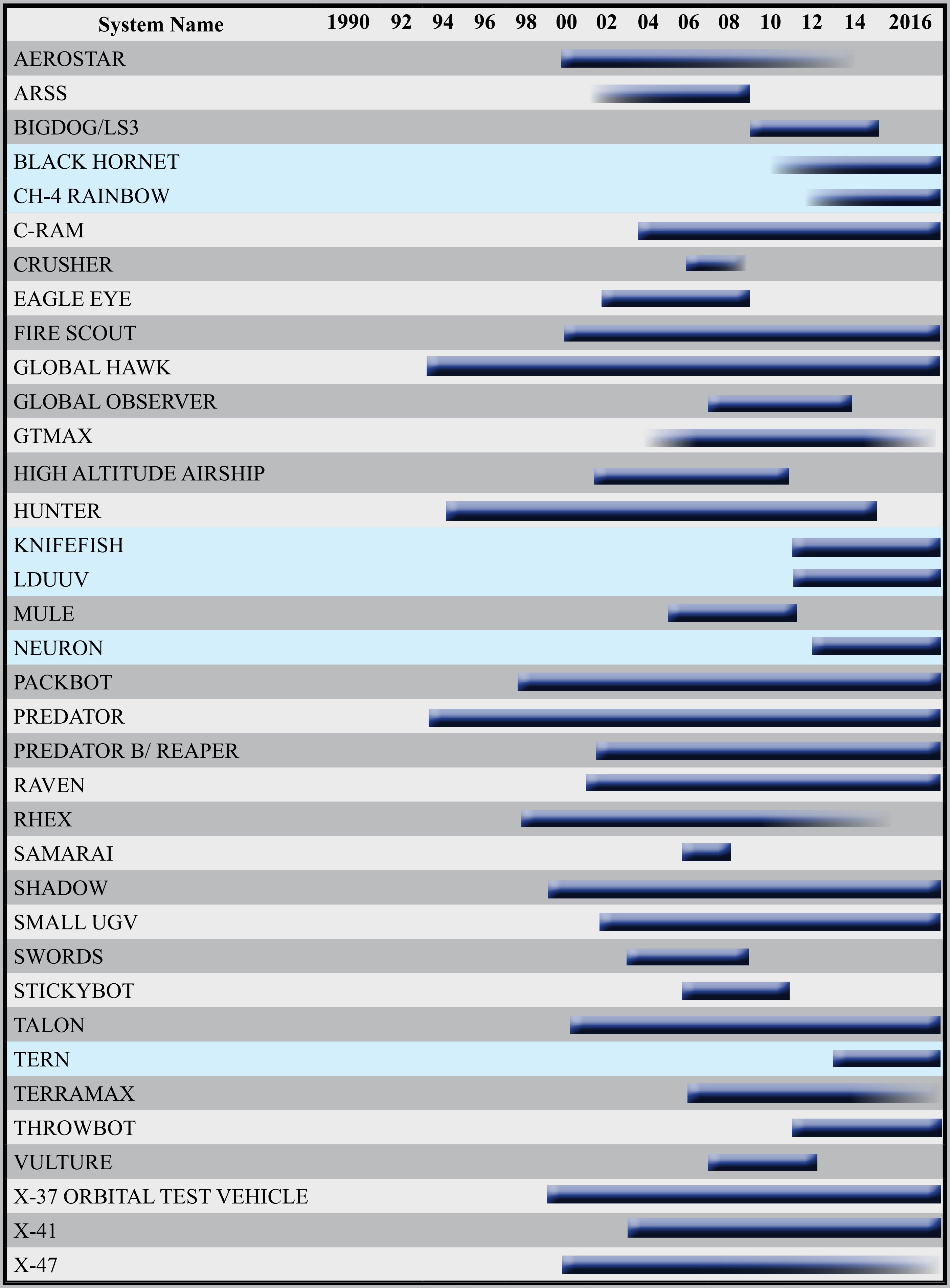
Systems

Photo credit: Staff Sgt. Paul Labbe/USAF

Systems Status in 2009 and 2016

System Name	In 2009	In 2016
AEROSTAR	Deployed	Inactive
ARSS	Developmental	Cancelled
BIGDOG/LS3	Developmental	Cancelled
BLACK HORNET	Developmental	Deployed
CH-4 RAINBOW	N/A	Deployed
C-RAM	Deployed	Deployed
CRUSHER	Terminated (as planned)	Inactive
EAGLE EYE	Suspended	Cancelled
FIRE SCOUT	Deployed	Deployed
GLOBAL HAWK	Developmental	Deployed
GLOBAL OBSERVER	Developmental	Cancelled
GTMAX	Developmental	Active
HIGH ALTITUDE AIRSHIP	Developmental	Cancelled
HUNTER	Deployed	Retired
KNIFEFISH	N/A	Developmental
LDUUV	N/A	Developmental
MULE	Development	Cancelled
NEURON	N/A	Developmental
PACKBOT	Deployed	Deployed
PREDATOR	Deployed	Deployed
PREDATOR B/ REAPER	Deployed	Deployed
RAVEN	Deployed	Deployed
RHEX	Developmental	Inactive
SAMARAI	Developmental	Cancelled
SHADOW	Deployed	Deployed
SMALL UGV	Developmental	Deployed
SWORDS	Developmental/Deployed	Replaced
STICKYBOT	Developmental	Inactive
TALON	Deployed	Deployed
TERN	N/A	Developmental
TERRAMAX	Developmental	Developmental
THROWBOT	Developmental	Deployed
VULTURE	Developmental	Cancelled
X-37 ORBITAL TEST VEHICLE	Developmental	Deployed
X-41	Developmental	Developmental
X-47	Developmental	Replaced

Program Timeline by Year



Aerostar

The Aeronautics Defense Systems Aerostar is an Israeli-made tactical surveillance and reconnaissance drone. It has a wingspan of 7.6 meters, a flight ceiling of 3,000 meters, and a 7- to 9-hour flight endurance. The Israel Defense Forces acquired its first Aerostars in 2000. In 2006, the Israel Highway Police reportedly conducted an experiment using the Aerostar to detect traffic offenders. Several countries, including the Netherlands and Nigeria, have either rented or purchased Aerostars. In 2012, a $35 million deal with Poland for two Aerostar systems fell through after the aircraft failed to meet capability requirements. Aeronautics Defense Systems produces several other drones including the Orbiter and Dominator.

Research by Maggie Barnett. Photo credit: Wikimedia

ARSS

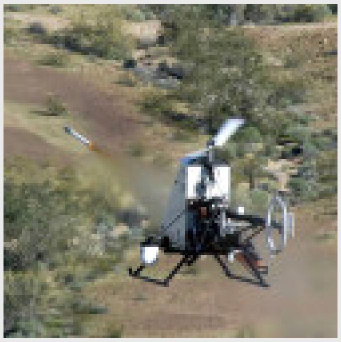


Photo courtesy of Advanced Technologies Incorporated

The Autonomous Rotorcraft Sniper System (ARSS) was an experimental unmanned helicopter equipped with a sniper rifle. The vehicle was based on the Vigilante 502, an unmanned helicopter developed in the early 2000s by Science Applications International Corporation. The ARSS was armed with an RND Manufacturing Edge 2000 .338 caliber rifle that was placed on a lightweight, stabilized turret called the Precision Weapons Platform, developed by Utah State University's Space Dynamics Laboratory. The sniper turret could be controlled using an Xbox gaming controller. The ARSS project began in 2005 as part of the U.S. Army's Aerial Delivery of Effects from Lightweight Aircraft (ADELA) program. The ARSS was designed to act as a cost-effective replacement for helicopter-borne human snipers, a dangerous and difficult role. The ARSS program ended in 2009, though Space Dynamics Laboratory's Precision Weapons Platform program remains active.

BigDog

Legged Squad Support System

Research by Maggie Barnett. Photo credit: Sgt. William Holdaway/USMC

The Boston Dynamics BigDog is a four-legged unmanned ground vehicle. It was designed to serve as an autonomous load-carrying infantry vehicle capable of handling terrain that would be impassable with traditional wheeled and tracked vehicles. The technology underpinning the BigDog has its roots in the 1980s, when researchers at the Massachusetts Institute of Technology developed a series of legged robots that could move dynamically and balance themselves. In 2004, DARPA awarded Boston Dynamics, a venture that grew out of the MIT lab projects, an initial grant to develop BigDog. BigDog features 50 sensors, enabling it to autonomously follow a soldier like a pack animal. In 2009, DARPA awarded the company a new contract to develop a heftier variant of the BigDog called the Legged Squad Support System (LS3). The program was transitioned from DARPA to the U.S. Marine Corps in 2013, and the LS3 took part in the 2014 RIMPAC exercises. All told, the LS3 program reportedly cost $42 million. The Marines eventually cancelled the BigDog/LS3 in December 2015 after finding that it was too loud for operational use.

Black Hornet

One of the major trendlines in the evolution of unmanned systems is the push to develop smaller, more agile drones that can be easily carried by individual soldiers. The PD-100 Black Hornet is a nano drone developed by Prox Dynamics, a Norwegian company. This pocket-sized drone weighs 18 grams, has a rotor span of 120 millimeters, and a maximum flight endurance of 25 minutes. They are designed to provide infantry units and law enforcement officers with a discreet and portable reconnaissance capability. Prox Dynamics was founded in December 2007 by Petter Muren, a former DARPA employee who worked extensively on micro air vehicles. A prototype Black Hornet made its first flight in July 2008. In February 2013, the U.K. Ministry of Defence announced that it would outfit 160 infantry units with the Black Hornet under a $26.2 million contract with Prox Dynamics. Following deployments with British troops to Afghanistan, the Ministry of Defence decided in September 2015 to extend the contract for Black Hornets. In April 2016, the U.S. Army announced that it was considering the Black Hornet as a possible option for its plan to outfit infantry units with micro drones by 2018.

Photo credit: Lance Cpl. Julien Rodarte/USMC

CH-4 Rainbow

In recent years, other countries besides the United States have made an effort to develop and deploy sophisticated military drones of their own. China has recently invested heavily in the field, and is emerging as a leading exporter of unmanned systems, many of which represent efforts to match the capabilities of U.S. systems. The CH-4 "Rainbow" is a medium-altitude, long-endurance surveillance and strike drone that resembles the U.S. MQ-9 Reaper. It is manufactured by the China Academy of Aerospace Aerodynamics, a department within the China Aerospace Science and Technology Corporation (CASC). The CH-4 was publicly unveiled at the Zhuhai Air Show in November 2012 in a bid to offer potential buyers a cheaper alternative to U.S. or Israeli unmanned aircraft. The aircraft can be equipped with the Blue Arrow 7/9, a precision-guided anti-tank missile. Earlier this year, a CH-4 performed a live fire test via a satellite link, a first for a Chinese unmanned aircraft. China has marketed the CH-4 and the smaller CH-3 as a cheaper alternative to a number of foreign buyers, including Saudi Arabia, Nigeria, Myanmar, Kazakhstan, the United Arab Emirates, and Egypt. Shortly after the Iraqi Air Force acquired an armed CH-4 in October 2015, it used the aircraft to carry out strikes against the Islamic State. Other Chinese drones such as the BZK-005 and the SOAR Dragon reflect China's growing and long-term investment in highly capable unmanned systems.

Photo credit: CASC

C-RAM
Counter Rocket, Artillery and Mortar System

The U.S. Army's Counter Rocket, Artillery, and Mortar (C-RAM) program covers the development of a set of automated land-based, short-range air defense weapon systems. Each of these systems is designed to defend populated areas and military installations from incoming indirect fire, such as rockets or mortars. One of the systems currently in use, the C-RAM Centurion, was adapted from the U.S. Navy's Close-In Weapon System. The C-RAM Centurion incorporates several different types of radar to detect and track incoming indirect fire, a warning system, and a Land-Based Phalanx Weapon System (LPWS) to engage the targets. The C-RAM Centurion reacts to fire without requiring direct intervention of a human operator, by automatically sensing and intercepting incoming ordnance. Development of C-RAM systems began in 2004 in response to the growing use of mortars against U.S. troops in Iraq. The C-RAM Centurion entered low-rate initial production in 2012 and has since been deployed to multiple conflict zones, including to Afghanistan and Iraq. As of early 2016, the C-RAM system has completed more than 300 successful intercepts of rocket or mortar fire and 5,600 timely warnings of indirect fire. The C-RAM is an ongoing program; in the Fiscal Year 2017 budget, the Army has proposed $20 million in research and development funds for upgrading and enhancing C-RAM systems. Other militaries besides the United States have deployed versions of the C-RAM; Israel's Iron Dome, for example, is considered to be a missile-based variant of the C-RAM that has been deployed since 2011.

Research by Sofia Ortiz. Photo credit: Sgt. Jarred Woods/U.S. Army

Crusher

Crusher is a large wheeled unmanned ground combat vehicle test prototype created by the Carnegie Mellon University National Robotics Engineering Center (NREC). Unveiled in 2006, the Crusher vehicle (the official name of the program was Unmanned Ground Combat Vehicle and Perceptor Integration System) was the result of a $35 million project funded by DARPA and the U.S. Army under the Future Combat Systems program. It is a stronger, more agile, and more reliable variant of the earlier Spinner system. Crusher is roughly 5 meters long and 1.5 meters tall, and can carry up to 4 tons of payload and armor. It is powered by in-hub electric motors, high power density lithium-ion batteries, and a 60-horsepower turbodiesel engine (from a Volkswagen Jetta). It can be outfitted with a .50 caliber Rafael Mini-Typhoon gun. Crusher has not been deployed; rather, between 2006 and 2008, it served as a test-bed platform to explore algorithms for machine learning and autonomous behavior. The program ended in 2008 as planned; some of the technologies developed on the system have been adopted for newer programs.

Research by Samuel Williams. Photo courtesy of Carnegie Mellon

Eagle Eye

The Bell Eagle Eye is a tiltrotor vertical take-off and landing (VTOL) drone designed to provide aerial intelligence gathering capabilities in land and sea environments. Modelled on the V-22 Osprey manned VTOL aircraft, it is a hybrid of a helicopter and a fixed-wing plane (it takes off vertically and then transitions into fixed-wing horizontal flight). Initial flight tests were conducted in 1992 and 1993. In 1998, after a period of dormancy, Bell successfully demonstrated the aircraft's dual-mode flight capability. In 2002, the U.S. Coast Guard selected the Eagle Eye for ship-borne reconnaissance and surveillance operations, and announced plans to acquire 69 aircraft at a cost of nearly $1 billion. In 2006, however, an Eagle Eye crashed after losing power during a test flight and, in 2008, the Coast Guard suspended the program out of concern that the technology was not sufficiently mature. Interest in tiltrotor drones persists, however; in early 2016, FlightGlobal reported that the U.S. Army may resurrect the Eagle Eye.

Photo credit: Wikimedia

Fire Scout

The Northrop Grumman MQ-8 Fire Scout is a large single-rotor unmanned aerial vehicle created to provide intelligence gathering and targeting capabilities to the U.S. Navy. In 1999, the U.S. Navy created the Vertical Takeoff and Landing Tactical Unmanned Aerial Vehicle (VTUAV) competition to find a replacement for the AAI RQ-2 Pioneer drone. On February 9, 2000, the Navy awarded Northrop Grumman a $93.7 million contract for the VTUAV program. Although it was cancelled following budget cuts in 2001, Congress restarted development of the Fire Scout in 2003 in order to field a reconnaissance aircraft that could deploy with the Littoral Combat Ship. The first two variants of the platform, the MQ-8A and MQ-8B, were based on the Schweizer 300SP series manned helicopter. The B-model Fire Scout was first deployed on board the USS *McInerney* (FFG-8) in October 2009. The newest variant of the Fire Scout, the MQ-8C, which is larger than its predecessors, is based on the manned Bell 407 helicopter. The MQ-8C has an endurance of 12 hours and a maximum range of 2,300 kilometers. The C-model Fire Scout flew for the first time in 2013 and the Navy received the first MQ-8C aircraft for testing in 2014. After requirement changes resulted in a surge in costs in 2014, the Navy reduced the total number of Fire Scouts it intended to buy from 177 to 61. An estimate in December 2014 put the total cost of the program at $2.85 billion. The U.S. Army is reportedly interested in acquiring the Fire Scout or a similar VTOL drone system.

Photo credit: Petty Officer 2nd Class Michaela Garrison/ U.S. Navy

Global Hawk

Research by Kalen Goodluck. Photo credit: Staff Sgt. Eric Harris

The Northrop Grumman RQ-4 Global Hawk is a high-altitude long-endurance surveillance drone. The Global Hawk has a wingspan of 40 meters, flies at 18,300 meters and has an endurance in excess of 34 hours. Initially conceived as a replacement for the U.S. Air Force's high-altitude U-2, a manned aircraft, the Global Hawk program began as a DARPA Advanced Concept and Technology Demonstrator (ACTD)—a low-cost experimental concept program—in 1995. The aircraft first flew on February 28, 1998 and achieved Initial Operating Capability in 2011. The Air Force has purchased 55 RQ-4 aircraft, with a current active inventory of 33 airframes. In September 2015, the Air Force awarded Northrop Grumman a $3.2 billion contract to provide development, modernization and maintenance of the Global Hawk until September 2025. The RQ-4B Block 40, the newest variant of the Global Hawk, integrates the Multi-Platform Radar Technology Insertion Program, a next-generation long-range radar sensor. The Global Hawk has been deployed to several locations around the world, including to Andersen Air Force Base in Guam. After a lengthy debate between lawmakers and the Air Force, the Global Hawk is slated to entirely replace the U-2 fleet by 2019. In addition to the U.S. Air Force, NATO is expected to begin flying a variant of the RQ-4 Global Hawk, the Alliance Ground Surveillance UAV, in 2017. As of May 2016, total procurement for the RQ-4 is estimated to have cost approximately $4.4 billion. The U.S. Navy is currently developing a maritime variant of the Global Hawk called the MQ-4C Triton.

Global Observer

Research by Acacia Handel.
Photo courtesy of AeroVironment, Inc.

The AeroVironment Global Observer is a liquid hydrogen-powered high-altitude long-endurance unmanned aerial vehicle designed for intelligence and surveillance operations and communications relay missions. The Global Observer was initially developed as a Joint Capability Technology Demonstration (JCTD) managed by the United States Special Operations Command. In 2007, AeroVironment was awarded a $57 million contract for the development of up to three Global Observer aircraft over a three year period. On April 1, 2011, just a few months after its maiden flight, the first Global Observer prototype crashed 18 hours into a test flight at Edwards Air Force Base in California. In December 2012, the Pentagon cancelled its development contract for the Global Observer. In 2014, AeroVironment announced a partnership with Lockheed Martin to market the system to customers beyond the Department of Defense. Though the Global Observer has yet to find a buyer, the high-altitude long-endurance drone field continues to expand; the U.K. Ministry of Defence is working to acquire the Airbus Defense and Space Zephyr, a solar-powered high-altitude drone. Both Facebook and Google are developing similar systems—also known as sub-orbital satellites—to beam Internet to remote areas.

GTMax

Research by Acacia Handel. Image courtesy of the Georgia Institute of Technology

The GTMax is an open-source unmanned helicopter testbed developed by the Georgia Institute of Technology and various partner institutions and organizations. The GTMax program was funded by DARPA and the U.S. Air Force Research Laboratory, and is used to test autonomy and flight control systems. The GTMax utilizes the frame from a Yamaha RMAX, a remotely piloted helicopter developed in Japan in the 1980s for agricultural use. Georgia Tech worked with Boeing to develop the Open Control Platform, which provides a software architecture that allows the GTMax to choose between several different guidance systems and low-level flight control systems in mid-flight. This software platform enables the GTMax to perform autonomous takeoff and landing, waypoint navigation, and allows it to adapt to primary flight control system failures. Such features have become common even on inexpensive commercial drones, but represented a significant technological achievement at the time of the GTMax's development in the 2000s.

High Altitude Airship

Research by Emily Stern. Photo credit: Wikimedia

The Lockheed Martin High Altitude Airship (HAA) is a long-endurance lighter-than-air unmanned blimp that can be used for surveillance, communications relaying, or weather observation. According to its original planned design, the HAA would operate at an altitude of 19,800 meters carrying a sensor and communications payload of 900 kilograms. The program began in 2002 as an Advanced Concept Technology Demonstrator for the U.S. Missile Defense Agency. It was transferred to the U.S. Army Space and Missile Defense Command in 2008. The following year, the Army awarded Lockheed Martin a $400 million contract to develop a High Altitude Long Endurance Demonstrator (HALE-D) prototype featuring a powerful radar system. The program conducted a test flight of the HALE-D on July 28, 2011, reaching an altitude of 9,753 meters; however, the aircraft suffered a technical anomaly and crashed in a forest in Pennsylvania. The program was cancelled shortly thereafter.

Hunter

The Northrop Grumman RQ-5/MQ-5 Hunter is a medium-altitude tactical intelligence, surveillance and reconnaissance drone used by the U.S. Army from 1999 to 2015. The Hunter has a 10-meter wingspan and an endurance of 21 hours. The system was based on a 1989 design by Israel Aerospace Industries. The Hunter was originally manufactured by TRW Inc., which was acquired by Northrop Grumman in 2002. The U.S. Army Hunter acquisition program began in 1994. The aircraft was fielded for the first time in 1995 in support of training operations in the United States and, in 1999, it was deployed to assist with U.S. operations in Kosovo. In 2003, the Hunter was deployed to Iraq and was outfitted with Viper Strike bombs. The Army planned to retire the Hunter in 2012 and replace the system with the larger MQ-1C Gray Eagle, but in 2013 it reversed the decision, awarding Northrop Grumman a $37.3 million contract to sustain Hunter operations. In December 2015, the Army officially retired the Hunter after nearly 20 years of service and nearly 100,000 lifetime flight hours and is actively seeking a replacement system.

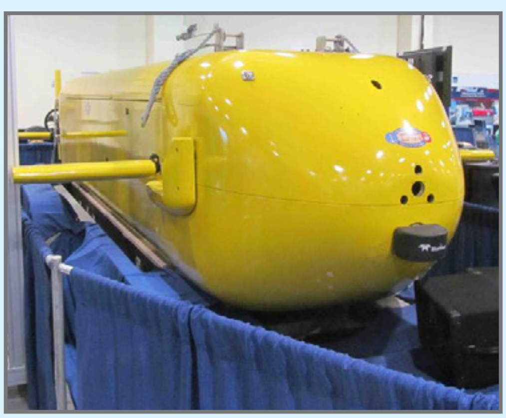
Research by Kirsten Harvey. Photo credit: Lt. Kristine Volk/U.S. Navy

Knifefish

Though they have received much less attention than aerial drones and unmanned ground vehicles, maritime drones have existed for decades, and are expected to play an increasingly significant role in naval operations in the near future. One such system is the Knifefish, a large unmanned undersea vehicle (UUV) built by General Dynamics Mission Systems and Bluefin Robotics. This 5.8-meter-long 770-kilogram underwater drone is based on the Bluefin-21 underwater robot and was developed for the U.S. Navy to detect and locate sea mines. In the 2004 "Unmanned Undersea Vehicles Master Plan," the Navy listed mine countermeasures as the second of nine priorities for future UUV capabilities, the first being intelligence, surveillance and reconnaissance. In November 2011, Bluefin Robotics was awarded a subcontract through General Dynamics to manufacture the Knifefish. In 2014, a Bluefin-21, the older variant of the Knifefish, was deployed to the Indian Ocean to help search for the remains of Malaysian Airlines flight 370. The Navy announced in April 2016 that the Knifefish would be one of several UUVs to replace the Remote Minehunting System unmanned undersea vehicle program, which was cancelled in 2015. In Fiscal Year 2017, the Navy will transition the Knifefish from a research and development project to a procurement program, and has allocated $11 million in procurement funds to the program.

Photo of a Bluefin-21 by Petty Officer 1st Class Peter D. Blair/U.S. Navy

LDUUV



The Large Displacement Unmanned Undersea Vehicle (LDUUV) is a research and development program at the U.S. Navy's Office of Naval Research (ONR) that seeks to create a UUV capable of carrying out multiple missions, including persistent intelligence collection and payload delivery. It will have a longer endurance than other UUVs, a high level of autonomy, and will operate independently of other vessels. ONR launched the LDUUV program in 2011, following a joint initiative with OPNAV N2/N6 (the Navy's office for information warfare) to develop requirements for a fourth class of UUVs. ONR will launch sea trials of a demonstrator vehicle in 2016. In March 2016, the Navy decided to end industry involvement with the project and instead keep LDUUV development as an in-house initiative. The Navy hopes that it will be able to deploy a squadron of LDUUVs by 2020.

Photo of a LDUUV Prototype by ONR

MULE

Research by Kirsten Harvey. Photo credit: Wikimedia

The Lockheed Martin Multifunctional Utility/Logistics and Equipment vehicle (MULE) was an unmanned ground vehicle developed for the U.S. Army's Future Combat Systems (FCS) program. Three variants of the 2.5-ton MULE were designed for different roles, including transport, countermine operations, surveillance and reconnaissance, and attack operations (one variant could be armed). In 2005, the FCS program awarded Lockheed Martin a $61 million contract to develop several prototype vehicles. In 2007, a MULE prototype climbed a 30-inch step and cleared a 70-inch gap without human intervention, a significant achievement at the time. The FCS program, which included thirteen unmanned vehicle projects, was cancelled in 2009. The MULE program survived the cancellation of FCS, but was ultimately terminated in 2011. The vehicle has evolved into the Squad Mission Support System, which has been tested in the field by the U.S. Army.

nEUROn

Photo via Wikimedia

The Dassault nEUROn is a French demonstrator unmanned combat air vehicle (UCAV), similar to the U.S. Navy's X-47B and the U.K.'s Taranis. It is intended to incorporate stealth-like capabilities and advanced algorithms into an unmanned platform. The nEUROn was developed under the Logiduc plan, a program formulated by the French military in the late 1990s to develop and acquire combat drones and tactical reconnaissance drones. Prior to the nEUROn, the Logiduc program produced two earlier UCAV demonstrators, the Dassault Petit Duc and Moyen Duc. The nEUROn initiative was announced at the 2003 Paris Air Show with a joint contract awarded to Dassault, Thales and EADS France. The first flight of the demonstrator aircraft took place on December 1, 2012 in Istres, France and, as of December 2015, nEUROn had conducted 123 test flights. France continues to lead the project, but has since been joined by Italy, Sweden, Spain, Switzerland, and Greece. On March 3, 2016, Britain and France announced that they will jointly invest $2.1 billion in a program to develop the next generation of combat drones, a project that will build on the designs of the nEUROn and the U.K.'s Taranis stealth combat drone demonstrator.

PackBot

The iRobot PackBot is a 60-centimeter-long unmanned ground robot used for reconnaissance and explosive ordnance disposal. It is one of the most widely used ground robots in existence. This small tracked robot can climb stairs, operate under one meter of water and navigate through rubble. The PackBot program began in 1998 when iRobot won a DARPA competition to develop a tactical unmanned ground vehicle. Following the September 11 attacks, the Center for Robot-Assisted Search and Rescue and a team from iRobot deployed the PackBot to Ground Zero to aid in the search and rescue response. The PackBot was deployed with U.S. Army soldiers to Afghanistan, where it helped clear caves in the search for Osama bin Laden. On March 17, 2011, iRobot provided authorities in Japan with two 510 PackBots, the newest variant of the system, as well as two 710 Warrior systems, to measure radiation at the Fukushima nuclear plant. The United Kingdom, France, Germany, Sweden, Norway, Italy, Brazil, Pakistan, Israel, Australia, South Korea, Singapore, Bosnia, Lithuania, Qatar, Taiwan, South Africa, and Canada also operate the PackBot. In a push to focus on civilian robots, iRobot sold its military robotics vertical to Arlington Capital Partners in February 2016, which renamed the company Endeavor Robotics.

Research by Jessica Chappe. Photo credit: Senior Airman Janelle Patino/USAF

Future Combat Systems
A Major Drone Program Object Lesson

Future Combat Systems (FCS) was a large U.S. Army acquisition program that sought to equip conventional ground units with a range of advanced unmanned systems and other technologies. Slated to cost up to $200 billion, it was set to be the Army's largest and most ambitious acquisition program, as well as the single largest acquisition program involving unmanned systems undertaken by any service. The program was conceived in the 1990s to thoroughly modernize the Army's infantry force by leveraging ongoing and predicted advances in networked and unmanned systems. The program proposed an operational model that emphasized the seamless interaction of manned and unmanned systems connected by an advanced network.

The FCS program consisted of 18 technologies, including four classes of unmanned aerial vehicles and three types of unmanned ground vehicles. Some of the unmanned systems developed under FCS were extremely ambitious, even by today's standards. The Multi-function Utility/Logistics and Equipment system (MULE) was a large unmanned ground vehicle chassis that was intended to support various types of configurations for a range of operational roles. To this day, large unmanned ground vehicles of this scale (depending on the configuration, it weighed up to 3 tonnes) have yet to be deployed widely in the field. Meanwhile, the Class IV unmanned aerial vehicle proposed under FCS would be capable of flying for up to 24 hours while maintaining constant and direct communication with manned aircraft during coordinated operations. The Navy's current Fire Scout drone, which is similar to the proposed FCS Class IV system, has a maximum endurance of just 12 hours.

If there is one clear example of the promises and perils of unmanned technology development, it would be FCS. The program was cancelled in 2009 following lengthy delays and cost overruns. The total cost of the program up to its cancellation was approximately $14 billion. Only a small number of sub-systems developed under FCS survived beyond the program's cancellation (one system that survived was the iRobot SUGV, which is described on page 18). According to several official reviews of the program, as well as a detailed post-mortem conducted by the RAND Corporation, one of the major pitfalls of FCS was that the development of the technologies proposed by the program lagged far behind the progression of the program itself. For example, in 2003 the Army announced that the program had cleared a major milestone even though numerous technologies required for some of the FCS platforms had not yet matured, and were even thought by some to need another decade of development before they could be properly integrated. FCS is an important example of the longstanding enthusiasm for adopting unmanned systems as a means to modernize military forces, as wel l as some of the challenges of maturing and integrating sophisticated unmanned systems technologies.

Predator

The General Atomics Aeronautical Systems MQ-1 Predator is a medium-altitude, long-endurance surveillance, reconnaissance, and strike aircraft. It has a wingspan of 16.8 meters and a length of 8.22 meters. It can carry two laser-guided AGM-114 Hellfire missiles. Development of the Predator began in 1994 as an Advanced Concept Technology Demonstrator (ACTD) under a joint Department of Defense program. Upon completion of the ACTD phase in 1997, the Predator program was transferred from the Army to the U.S. Air Force. The Predator was first deployed to support U.S. military operations in Bosnia in 1996. It successfully launched a Hellfire missile for the first time in winter 2001. The armed Predator of present-day fame was deployed to Afghanistan in September 2001 as part of the response to the attacks on the World Trade Center. In June 2006, MQ-1B Predators were used to conduct 600 hours of persistent surveillance of Abu Musab al-Zarqawi, the leader of al-Qaeda in Iraq, providing intelligence that eventually led to the strike that killed him. The system remains in use, with the U.S. operating a total fleet of 139 aircraft. Although the Air Force plans to phase out its MQ-1B fleet by 2018, the Predator's cousins—the Gray Eagle and the Predator B (Reaper)—will remain in use by the Army, Air Force, and Special Operations Command. The Predator series drones have served as a central asset in the U.S. government's campaign to target members of al-Qaeda and affiliated groups in Pakistan, Yemen, and Somalia. In addition to the U.S., both Italy and the United Arab Emirates operate variants of the Predator.

Photo credit: Spc. Leah R. Burto/U.S. Army

Preator B/Reaper

The General Atomics Aeronautical Systems MQ-9 Predator B/ Reaper is a medium-altitude, long-endurance surveillance and strike drone. The U.S. Air Force Air Combat Command initiated the MQ-9 Reaper program (then known as the MQ-9 Predator B) on May 2, 2002. Although a handful of aircraft were purchased in subsequent years for testing and development, it wasn't until 2006 that the Pentagon began ramping up production. The first Reaper unit, the 42nd Attack Squadron, was activated on November 6, 2006 and became operational in 2007. Since then, the MQ-9 Reaper has become one of the U.S. military's largest unmanned systems procurement programs. As of the end of Fiscal Year 2015, the Air Force has purchased approximately 290 aircraft systems out of a planned total of 347; the lifetime cost of the program is estimated to be over $12 billion. The Reaper is flown by the U.S. Air Force and U.S. Special Operations Command. It has been deployed to several combat theaters, including the campaign against ISIS in Iraq and Syria. The U.K., Italy, France, the Netherlands, and Spain have also purchased MQ-9 Reapers.

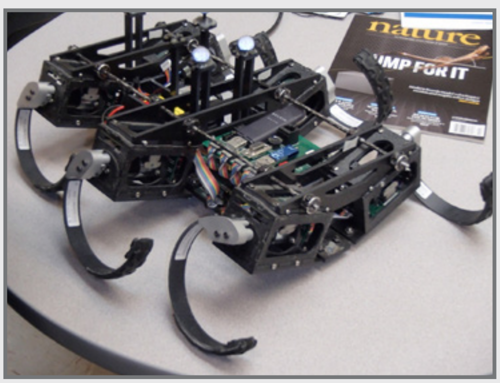
Photo credit: Senior Airman Christian Clausen/USAF

Raven

Photo credit: Pfc. Michael Bradley/U.S. Army

The AeroVironment RQ-11 Raven is a hand-launched tactical surveillance and reconnaissance drone. It has a wingspan of 1.4 meters, weighs 1.9 kilograms, and can be flown during day or night at a range of over 10 kilometers. The Raven was created after the U.S. Army asked AeroVironment to develop a smaller variant of its FQM-151 Pointer. The system conducted its maiden flight in October 2001. By 2007, the Army's Ravens had logged more than 30,000 flight hours. The U.S. Air Force began using the Raven in 2004, and the Marine Corps acquired the system in 2007. Ground units use the Raven, which can transmit live video, to improve situational awareness. The Raven remains one of the most popular military unmanned aircraft ever produced. The system has been acquired by Spain, Bulgaria, Denmark, Estonia, Hungary, Kenya, Lebanon, Macedonia, Romania, Uganda, Uzbekistan, Yemen, Spain, Ukraine, and the Czech Republic, among others. AeroVironment's Wasp and Puma surveillance drones, which are similar to the Raven, are also popular among the U.S armed services and foreign militaries.

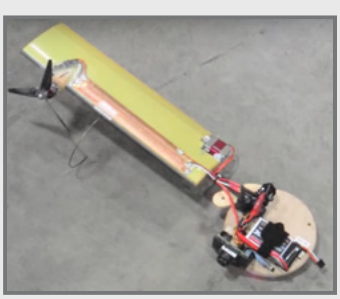
RHex



The Boston Dynamics RHex is a ground robot with six independently controlled legs that can travel across rough terrain with minimal operator input. The first prototype was built in 1999 under a research consortium of university laboratories led by Kod*lab. The program received $5 million in funding over five years from DARPA, as well as additional funding of $3 million from other organizations, including the National Science Foundation. RHex can operate over complex terrain such as rocks, swamps and railroad tracks. RHex can be remotely operated at distances of up to 700 meters. Developmental RHex variants featured biologically inspired locomotion systems, gait control, sensor-based navigation, energetic running gaits, higher autonomy, visual navigation, and obstacle avoidance. Current research platforms include the X-RHex and the X-RHex XRL. Boston Dynamics demonstrated RHex at the U.S. Army's Robotics Rodeo in 2012.

Research by Eleanor Buse. Photo credit: Edward Rooks

Samarai



The Lockheed Martin Samarai was a hand-held micro drone modeled on the shape of a maple seed. The 7-centimeter-long aircraft had just two moving parts, weighed less than 10 grams, and was equipped with navigation equipment and imaging sensors. It could be controlled by a remote control or an app on a tablet computer. It was primarily intended for military and law enforcement agencies. Troops could throw the Samarai like a boomerang around a corner to see what might be out of sight or drop them from planes to collect ground-level imagery. In 2006, DARPA awarded the Lockheed Martin Intelligent Robotics Laboratory a $1.7 million contract to develop the Samarai under the DARPA Nano Air Vehicle initiative. In 2008, DARPA decided against continuing funding for the Samarai, awarding AeroVironment a contract for a micro air vehicle instead. However, in 2011, Lockheed Martin conducted a flight demonstration of the 3-D-printed Samarai at the Association for Unmanned Vehicle Systems International convention, suggesting that the program has not been entirely shelved. The University of Maryland has a similar program to develop a maple seed-inspired drone called the Samarai.

Research by Jonah Dratfield. Image via FlightGloal/YouTube

Shadow

Photo credit: Sgt. Justin Moeller/U.S. Army

The Textron RQ-7 Shadow is a tactical surveillance and reconnaissance unmanned aerial vehicle. It is designed for intelligence, surveillance, and reconnaissance missions, and can also be used as a communications relay. The Shadow is manufactured by AAI Corp., a division of Textron, and is a newer variant of the AAI RQ-2 Pioneer. The V2 variant of the aircraft has an endurance of up to 9 hours, a maximum takeoff weight of 212 kilograms, and a wingspan of 6 meters. It can carry 43 kilograms of payload. It is equipped with an EO/IR camera and a laser designator. Following the cancellation of the Alliant RQ-6 Outrider UAV in 1999, the U.S. Army selected the Shadow 200 as its primary tactical unmanned aircraft system. The RQ-7A was first fielded by the U.S. Army in 2001 and by the Marines in 2007. The system remains in use today, recently surpassing one million lifetime flight hours. The Shadow is frequently used in support of infantry forces, performing overwatch for ground patrols. The system is also used for seeking out enemy forces. Although the Army continues to dedicate funds to modifying and replacing its current Shadows, the procurement of RQ-7 drones was phased out in Fiscal Year 2009. Italy, Sweden, and Australia also operate the RQ-7. In 2012, Textron began flight testing of the newest Shadow variant, the M2. With a 16-hour endurance, the M2 rivals the capabilities of larger drones like the MQ-1 Predator.

SUGV

In 2003, the iRobot Corporation was awarded a contract to develop the Small Unmanned Ground Vehicle (SUGV) as a part of the U.S. Army's Future Combat Systems (FCS) program. The SUGV is a tracked system featuring four cameras and an arm that can manipulate and lift objects. The system began development in 2007; iRobot collaborated with Boeing to develop the SUGV based on iRobot's popular PackBot design. The SUGV was one of the few platforms that survived the cancellation of the FCS program. The SUGV is available in two variants: the 310 for dismounted mobile operations, and the 320, which is designed for infantry. The SUGV has been used in combat missions in Afghanistan. On August 3, 2015, the U.S. Marine Corps ordered 75 iRobot SUGV units for a total cost of $9.8 million.

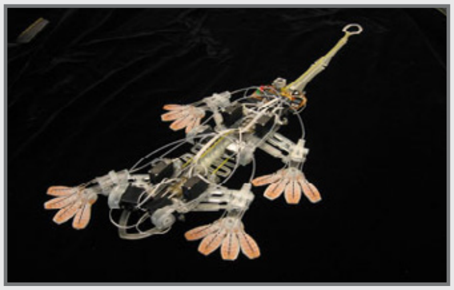
Research by Nathaniel Carlson. Photo credit: Specialist 2nd Class Sean Furey/U.S. Navy

SWORDS

The Special Weapon Observation Reconnaissance Direct-Action System (SWORDS) is a remote-controlled weapons attachment system that was integrated onto the Foster-Miller TALON unmanned ground vehicle. The SWORDS system was developed by the U.S. Army Armament Research, Development, and Engineering Center following a request from an explosive ordinance disposal team that wanted a weaponized platform to clear enemy positions. The first SWORDS system prototype (a TALON 6 armed with a light machine gun such as the M249) was successfully field tested in late 2003 in Kuwait. The cost of a single SWORDS system was $240,000. Three SWORDS systems were deployed with the U.S Army to Iraq between 2007 and 2009, though they were only used in fixed positions for base protection. According to a U.S. Army colonel involved in the program, the SWORDS experienced reliability issues and "nobody had the remotest idea of how to employ a ground robot." The SWORDS program was supplanted by the Modular Advanced Armed Robotic System (MAARS), developed by Foster Miller's parent company QinetiQ. The MAARS, a larger variant of the SWORDS, which can carry both lethal and non-lethal payloads, has not been deployed. In 2008, Iran unveiled its own armed unmanned ground vehicle, and Russia is reportedly testing an unmanned miniaturized tank called the Uran-9.

Research by Ian Sicurella. Photo of a MAARS system by Lance Cpl. Julien Rodarte/USMC

Stickybot



The Stickybot is a small unmanned ground vehicle developed by the Biomimetics and Dexterous Manipulation Laboratory at Stanford University. The system is designed primarily to test adhesive climbing technologies that would enable robots to scale walls. There have been three versions of the Stickybot. The initiative began in 2006 out of a collaboration between roboticists Mark Cutkosky and Robert Full. This project appears to have concluded in 2011. NASA's Jet Propulsion Laboratory runs a project called Gecko Gripper, which adheres to walls using the Stanford lab's microspines, which are similarly employed by DARPA's Z-Man project.

Photo credit: Mark R. Cutkosky/National Science Foundation

TALON

The QinetiQ TALON series are a variety of tracked unmanned ground vehicles for military, law enforcement, and first responder applications. The TALON V variant of the system is 86 centimeters long and, depending on its payload configuration, can weigh up to 50 kilograms. The TALON platform can be equipped with multiple cameras capable of high-definition video capture, an extendable arm for gripping objects, and a two-way communications system. It is capable of travelling at speeds up to 11 kilometers per hour. The first TALON vehicles were deployed with explosive ordinance disposal teams in Bosnia in 2000. Since 2001, several versions of the TALON have been deployed by the U.S. Navy, Marine

Corps, and Army. TALON systems have also been acquired by the militaries of Iraq, Pakistan, the Czech Republic and Poland, among others. Israel and China are also working to develop armed UGVs.

Photo credit: Cpl. April Price/USMC

TERN

Illustration credit: DARPA

Several U.S. military programs are working to develop large fixed-wing drones that do not require a runway to takeoff and land, a capability that enables operations on ships or in mountainous terrain. The Tactically Exploited Reconnaissance Node (TERN) is the latest push to develop a capable vertical takeoff and landing (VTOL) drone. The TERN will be a medium-altitude, long-endurance drone capable of flying from Navy warships such as the Littoral Combat Ship. The TERN will match the capabilities of a large drone like the Air Force's Predator, but will not require a runway or an aircraft carrier. The program began in March 2013 under the Defense Advanced Research Projects Agency, which was later joined by the U.S. Navy's Office of Naval Research as a program partner. TERN features a fixed-wing "tailsitter" design; it will takeoff and land vertically like a helicopter but fly horizontally like an airplane. On December 24, 2015, Northrop Grumman was awarded a $93 million contract to build a full-scale demonstrator aircraft. In June 2016, DARPA allocated $17.8 million for a second test vehicle, a move that suggests that the program will be larger than initially predicted. DARPA expects an initial test flight to take place in 2018.

TerraMax

Research by Conrad Brittenham. Photo via Wikimedia

The Oshkosh Corporation TerraMax is a set of technologies that enables users to convert manned vehicles into unmanned ground vehicles. The TerraMax kit can be integrated into any type of tactical vehicle. The technology is implanted into the steering, engine, brakes, and transmission; TerraMax vehicles can be operated remotely, autonomously, or semi-autonomously. The vehicle can identify obstacles, and either await human input or make a decision as to how to proceed on its own. The system was unveiled in 2004 as part of the DARPA Grand Challenge, a competition to develop driverless vehicle technologies. In the 2005 Grand Challenge race, the TerraMax completed the 212-kilometer course in 12 hours and 51 minutes. In 2006, DARPA awarded Oshkosh a $1 million contract to continue development of the system. In 2010, the U.S. Marine Corps Warfighting Laboratory initiated the Cargo UGV project and awarded Oshkosh a $5 million contract to explore how the TerraMax system could be integrated into tactical wheeled vehicles for logistics convoys. In 2014, the Office of Naval Research awarded Oshkosh a contract to continue the work initiated by the Marine Corps in 2010. As of May 2016, Oshkosh is pursuing internal research and development of TerraMax technology. The company is marketing the kit as a potential solution to remove human operators from vehicles that might be susceptible to IED attacks or ambushes.

ThrowBot

The ReconRobotics ThrowBot XT is a small unmanned ground system that can be literally thrown into a potentially dangerous or inaccessible space in order to collect video data. It is designed to be used by infantry, engineering, and explosive ordnance disposal units, as well as by law enforcement officers. The ThrowBot weighs 500 grams and can withstand a 9-meter fall. The ThrowBot's origins trace to 1999 with DARPA's Tactical Mobile Robotics program, which sought to develop low-cost, semi-autonomous robots that could easily be deployed by infantry. Under this program, the University of Minnesota's Center for Distributed Robotics developed a series of miniature, highly mobile robots. ReconRobotics was founded in 2006 with the intention of commercializing this research, resulting in the ThrowBot product line. In 2011, the Pentagon's Joint IED Defeat Organization included the ReconRobotics ThrowBot in a delivery of small ground robots to troops in Afghanistan to fulfill an urgent operational requirement. In 2012, the U.S. Army awarded ReconRobotics a $13.9 million contract for 1,100 ThrowBot XT systems. Nearly 4,500 Recon Scout and ThrowBot systems have been deployed by the U.S. military; more than 900 are in use by law enforcement agencies worldwide. ReconRobotics products are marketed through a distribution network in 35 countries.

Research by Eleanor Buse. Photo credit: Sgt. 1st Class Lisa Litchfield

VULTURE

The Very-high altitude, Ultra-endurance, Loitering Theater Unmanned Reconnaissance Element (VULTURE) was a DARPA program that sought to develop a high-altitude, long-endurance unmanned aircraft. The VULTURE had a 133-meter wingspan and was designed to carry a 454-kilogram payload. The proposed system could fly at an altitude in excess of 25,000 meters and perform similar missions to those of a reconnaissance satellite, as well as serve as a communications relay. In 2007, DARPA awarded Boeing a $3.8 million Phase I contract for the VULTURE. In 2010, Boeing and QinetiQ received an $89.3 million contract to build the SolarEagle prototype vehicle as part of the VULTURE II program. NASA provided technical support for the project and the U.S. Navy expressed interest in VULTURE's capacity to provide communications in the event of disrupted satellite communications. The Boeing SolarEagle was intended to make its first demonstration flight in 2014, but the project was cancelled in 2012. A concurrent in-house Boeing effort to develop a hydrogen-powered high-altitude drone called Phantom Eye failed to find a buyer.

Research by Jonah Dratfield. NASA photo of the Helios, a variant of the VULTURE.

X-37 Orbital Test Vehicle

The Boeing X-37 Orbital Test Vehicle (OTV) is a reusable unmanned spacecraft operated by the U.S. Air Force. It was designed as a research platform to conduct experiments and demonstrate new technologies—part of a broader effort to develop more efficient and cost-effective space travel systems. The program began in 1999 as a joint Air Force and NASA enterprise, with Boeing serving as the principal contractor. In September 2004, NASA transferred the program to the Defense Advanced Research Projects Agency (DARPA). The Air Force currently operates two X-37Bs, a modified version of the original X-37A vehicle. The X-37B has served in three classified missions (OTV 1 to OTV 3) since 2010, totaling 1,367 days in orbit. As of July 2016, an X-37B remains in orbit on the program's fourth mission (OTV 4). In addition to its classified roles, the vehicle is serving as a platform for NASA's Materials Exposure and Technology Innovation in Space (METIS) test program, which seeks to study the effects of long-term space exposure on 100 different materials. It is also equipped with an experimental Hall thruster, an electric propulsion system made by Aerojet Rocketdyne that combines electricity with xenon to create small amounts of power for maneuvering in space. In November 2013, DARPA announced that it was initiating a separate reusable unmanned space plane program, the Experimental Spaceplane (XS-1).

Research by Samuel Williams. Photo credit: Wikimedia

X-41 CAV

The X-41 Common Aero Vehicle is an experimental test vehicle designed for suborbital hypersonic flight. The X-41, also known as Falcon, is part of the the Hypersonic Test Vehicle Program, an initiative by DARPA and the Air Force to develop hypersonic unmanned aerial vehicles that can be used to deliver weapons to targets thousands of miles from the continental U.S. This program is part of a broader Pentagon effort called Prompt Global Strike, which seeks to create a weapon delivery system capable of hitting any target on Earth within an hour. The X-41 Falcon system is intended to reach a cruising speed of Mach 20, allowing it to strike targets at a distance of over 6,500 kilometers. DARPA began soliciting bids for an experimental prototype aircraft in 2003 and the first tests of the system were conducted in 2010. In 2011, a prototype Hypersonic Technology Vehicle (HTV-2) was successfully launched to cruising altitude, but the vehicle crashed after nine minutes of flight due to stress caused by high temperatures. The DARPA Hypersonic Test Vehicle Program is ongoing, and the Air Force continues to issue contracts for test vehicles and enabling technologies. Beyond the U.S., China and Russia are both developing hypersonic vehicle systems technology.

Photo credit: Wikimedia

X-47

The X-47A and X-47B are prototype unmanned combat aerial vehicles developed by Northrop Grumman. Initiated in 2000, the X-47A was designed and funded in-house by Northrop Grumman to demonstrate capabilities and technologies that might be employed for the ongoing Unmanned Combat Air Vehicle (UCAV) program, a joint Air Force and DARPA project. The goal of the joint UCAV project was to build a drone that could operate in heavily contested airspace and carry out a variety of missions such as suppressing enemy air defenses. The X-47A prototype was unveiled on July 30, 2001 at an Association for Unmanned Vehicle Systems International convention. The X-47A was never deployed; the vehicle had only one documented test flight, as well as a few taxi tests. The X-47A served as the basis for Northrop Grumman's X-47B, developed under the Navy's iteration of the UCAV program—known as Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS). The X-47B went on to make aviation history as the first fixed-wing unmanned aircraft to autonomously conduct an arrested landing on an aircraft carrier. On February 1, 2016, the UCLASS program was redefined and converted into a new program intended to create an aerial refueling drone with strike capabilities called the MQ-25A Stingray.

Research by Nathaniel Carlsen. Photo of an X-47B courtesy of the U.S. Navy

Discussion

with Peter W. Singer

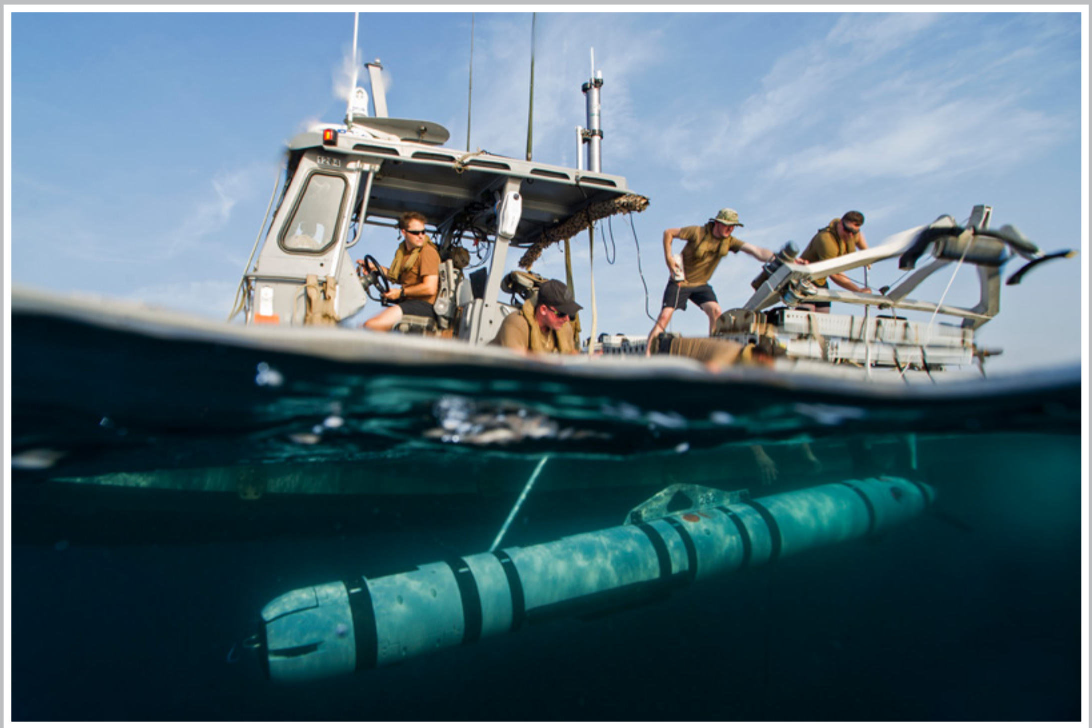


Photo credit: Petty Officer 1st Class Blake Midnight/USN

Peter Warren Singer is a Strategist at New America and an editor at Popular Science magazine. He is the author of Corporate Warriors: The Rise of the Privatized Military Industry*,* Children at War*,* Wired for War: The Robotics Revolution and Conflict in the 21st Century*,* Cybersecurity and Cyberwar: What Everyone Needs to Know*, and* Ghost Fleet: A Novel of the Next World War.

What was the hypothesis that you put forward in *Wired for War*?

It's interesting to go back to the timing of that question. The book came out in January of 2009, but the journey of writing it began several years earlier. Things that seem so evident today were considered controversial, new, and in some ways almost heretical back then. The underlying argument of the book was that this thing that we had thought of as purely science fiction—the robot—was not just becoming real, but was beginning to be used in war in a way that would shake up not only what was possible but also introduce new questions of what was proper, raising new issues of right and wrong. I proposed that we would be living through the equivalent of the introduction of something like the steam engine or the tank or even the atomic bomb. That robotics was a technology that was truly going to shake things up and introduce all of these new tough questions. And the idea was to establish the history of the field, and then take a tour around the world looking at robotics in war from multiple different perspectives. Everything from where the designers get their ideas from, to the influence of science fiction, to what it's like to visit a robot factory that is building military robots, to what it means for the experience of the warrior– the person piloting the drone– someone who was fighting but not physically in the war zone, who was engaged in combat but never leaves Nevada. I wanted to also consider the inverse: what it means for the soldiers on the ground to have a robotic teammate.

The bigger idea here was to tell a story not just of how robotics matter for war, but also, by taking this tour, to gain an insight into war in the 21st century overall. The subtitle of the book is "The Robotics Revolution and War in the 21st Century." Both matter. For example, there's a section on how we're seeing the locales of war changing; we are increasingly fighting in cities. Again, things that now seem evident. But back then militaries were planning for fighting in open deserts or small villages in Afghanistan even though urbanization trends pointed to something different. And we've seen, in battles that range from Sadr City to Mosul, that trend is playing out. It was using the tour to explore what was changing about war, not just in terms of the technology of robotics, but writ large.

In other words, that the technology is going to change significantly, and that change is going to have consequences.

Robotics in war will have social, political, legal, ethical consequences. The world will be different because of this shift. I go back to the idea to this two-fold issue of gaining possibilities that you hadn't imagined before, but also facing new questions of right and wrong. Those questions of right and wrong might be an ethical question, a legal question, or it might be an organizational question. For instance, how should I organize my Air Force now that I have these planes that I don't have people inside of? Even the fundamental question of what to call them is a question: drones, robots, RPAs, UAVs, UAS….You're seeing these kinds of disputes on everything from the large-level issues—'Does this mean there is more or less war?'—to micro-level questions such as 'What do I call them?', 'What do I call the people that fly them?', 'Should the people that fly them be eligible for a medal?' When you've got that kind of debate at all those different levels, that means this is something different. It means this is something more significant than just a better rifle or a slightly better tank or plane.

In the last seven years, what has surprised you most?

The biggest surprise has been the scale of the use of drones in what I jokingly call 'Not So Covert Operations.' The book was mostly about their use in overt wars, wars that we openly admitted we were fighting in places like Iraq or Afghanistan. There had been a few of the "drone strikes" into places like Yemen or Pakistan by the CIA, but they were not of the scale and centrality to the story at that time. I did talk about these operations, and some of the dynamics and questions that they raised—questions of whether it's lawful, whether you should look at it as war or not, to how the local population is reacting. So the book touched on those operations, but the numbers back then were relatively small, as the book was written before the Obama administration, and was released just a couple of days after the President's inauguration. If you asked me back then, 'Do you think we will carry out more than 500 of these strikes in Pakistan alone?' I would have been surprised by that number and would have maybe pushed back with, 'Well, are we engaged in a military operation? This scale seems well beyond what the CIA might do.' It had been sub-50 at that point. You're talking about an order of magnitude bigger. And that's just Pakistan. I can guarantee you, because I was coordinating the defense policy team for the Obama, nobody on the inside was anticipating that it would ramp up to this level.

"Robotics in war will have social, political, legal, ethical consequences. The world will be different because of this shift."

Let me be clear here: If you go back and look at things that Obama was saying—he was saying that we need to focus more on Afghanistan, we need to shift away from Iraq—there's certainly no opposition to drone strikes. But it's also certainly not talked about in the manner that it becomes a signature part of his foreign policy. When you're writing the history of the Obama administration's security and foreign policy, you will talk about drones. I don't think that was what anyone in the campaign would have projected back in 2007 or 2008. That kind of discussion wasn't on the inside.

Where do you see some of the most significant developments and growth on the science and technology side?

At the end the day, the system is made up of three things: sensors, processors, and effectors. The sensors have gotten better, but not in ways that have caught people off guard. We've gone from the single soda straw Predator feed to the Gorgon Stare able to do wide-area. You could see that playing out in that period. The effectors—everything from the propulsion to the weapons that drones might be carrying—have also gotten better, but not crazily so. The Reaper flies faster and further than the Predator, and now we're testing out the UCLASS/UCAS/CBARS, which is jet-powered. We're going from a little over 100 mph to 200 mph to 400, 500, 600 mph. That's amazing, but it was anticipated.

I think it's the autonomy that has been the most striking, and that has the greatest importance. The more intelligent an unmanned system becomes, the more the technology is able to do on its own. This is the case whether you're talking about a tracked ground robot, a carrier-launched drone the size of a jet fighter, or a hand launched one that we can put in our pocket. The more autonomous it is, the more roles it is able to take on, and also the more people are able to use it, because it means you don't have to have advanced training to use the technology to achieve your own goal. For example, when I first wanted to use a computer, I had to be trained to use it. I had to learn a programming language. My son is three and this morning he picked out a video to watch on his iPad by himself. He can't yet write, he can't type, but he's able to do that because the system has figured out how to make itself accessible to him. We're seeing the same parallel with drones, where the more autonomous it becomes, the simpler it becomes for the human to operate it, whether it's the soldier, the pilot, the farmer, the journalist, or the policeman.

This expanding use side then takes off. Back then, the two primary areas that we were seeing actual prototyping and deployment was in ground robots that were used primarily in a bomb-hunting role and unmanned aerial systems primarily used in a surveillance role with the occasional strike. Now we're seeing how, in addition to the expansion of applications in these two domains, the technology has been taking off in other domains. Take the sea. There was a lot of chatter and experiment-type projects in the at sea roles back then; now we're seeing the deployment of these systems and a much wider array of R&D and prototyping initiatives, whether it's in undersea warfare or onboard ships. This is both because the tech is better and the context is changing, something I explored in a more recent book, Ghost Fleet. Why is it now taking off in the sea space? Because the Navy is looking around and worrying about a war with China, about being outnumbered by China, worrying about their technology, and so turning to unmanned systems.

You've noted that of the top 10 programs in DoD, not a single one is unmanned. How is this the case given the interest in the technology?

Though there are no unmanned systems among the top ten programs of record, you cannot help but notice the sheer numbers of unmanned systems in existence: there are a little over 10,000 in the air and 12,000 on the ground. That's at least a doubling in the aerial domain and more so on the ground in the past decade.

But you're also seeing the technology proliferate in other more subtle ways. Although none of the top ten programs of record are unmanned, you are seeing many of the manned programs adopting unmanned technologies. Whether you're talking about anti-submarine warfare, anti-mine warfare, logistics–there's some level of unmanning that's going on. This is something I didn't explore much in the book, that I would do differently now if I had to go back and write it again: how our manned systems are also becoming more and more robotic. The cover of *Ghost Fleet* is the USS *Zumwalt*, which is the next-gen stealthy warship that will be commissioned this year. That ship is a manned ship: it's a Navy destroyer. A ship of its size and role a couple of generations ago would have had a crew of 1,293. The Zumwalt will have a crew size of 141. And the reason is robotics, AI. The engine room only needs a couple of people to run it. It only needs a couple of people to serve on the bridge. It's not what we could call a "robotic ship," but it has one tenth the size of the crew because of robotics. We see that on the civilian side, too. Much of the attention has gone to robotic cars that are testing—the Google Car, the Tesla, and now two self-driving cars that are driving 2,000 miles across Chinese highways. But maybe the more subtle shift is that cars can parallel park themselves. Mercedes is unveiling a system this year called AutoBahn Pilot. It allows you to drive down the highway and never touch the steering wheel, the brakes, or the accelerator. It's cruise control, but it's AI cruise control. Tesla has already released a similar system. To me, that's one of the more remarkable changes.

"Our manned systems are also becoming more robotic."

And, when there is a human role, robotics changes the human role and the skills that you want for it. The Navy secretary, who is kindly a fan of both *Wired for War* and *Ghost Fleet*, described the F-35 as what should be the last manned jet fighter. There's a battle within the military that is pitting manned fighter jets against unmanned systems. They're always put in comparison, but what's interesting is that in the F-35, the pilot's role is not Maverick from "Top Gun," where we're going to judge you solely by how quickly your hand can pull that joystick or how many Gs you can take. When they talk about the role, the human pilot is not piloting the plane in our traditional definition; they're more like a manager, managing all the things that it's doing. And that means that you judge who's a good "pilot" differently. You see that in other areas, such as the way robotics has changed surgery. It used to be that the best surgeon was the one who could hold their hand the stillest and tie the tiniest knot. Now no human surgeon can match a DaVinci robotic system at that.

The category of manned vs. unmanned is becoming blurred.

It is becoming redefined. It's very rarely a one-for-one replacement. The U.S. military's present vision is to use teaming. Instead of 'How do we replace this human with this machine?' it's 'What's the combination of humans and machines that allow us to do our job differently and more effectively?' That's one vision of this world that still has the human playing a core role.

There's also a lot of exciting things happening with robotic swarming, which is a different pathway. The idea is to have lots of really dumb systems that become an intelligent system when they cooperate. Teaming is a bit like having a police officer with a police dog teammate. Swarming is more along the lines of a group of ants: each little ant is dumb, but they can do incredibly sophisticated things when many of them all work together.

"When you start to ask what matters more, quality or quantity, that means you're at one of these turning points in war."

This takes you down very different paths for war and how we might use robots in it in the future. Back in WWI, they would send masses of humans out with the goal of forcing the other side to shoot at their masses of humans. They would literally expend humans. You could imagine using robotic systems not just to surveil or detect the enemy, but to force the enemy to reveal itself, force the enemy to use up its ammunition shooting your drones down. This isn't me spinning this. That was actually the Israelis' original vision with drones. It wasn't going to be used for surveillance. It forced the Syrians to shoot off their valuable missiles. But we haven't thought that way in war in 100 years.

There's been a lot of research energy into swarms. It has not yet been deployed because it's an utterly different approach, not only at a tactical level, but also in how our defense economy is structured. The major defense contractors don't design, make, and sell in volume anymore. The way it was expressed to me is that they used to make Jeeps in large volumes, and now they make Ferraris in small volumes. Recently I had an exchange with some senior military officers where I pointed out that we may want to go back to thinking about deliberately disposable robotics, but the question is whether our imagination and contracting system will let us.

Photo credit: Master Sgt. Mark C. Olsen/ANG

When you start to ask what matters more, quality or quantity, that means you're at one of these turning points in war. That's the story of Napoleonic change in war, or the gunpowder revolution, or the English longbowmen versus the French knights. Do you need just a small, highly professional force, or do you need masses? That's the kind of discussion we're having again with robotics. Do I want an $80 million drone that can take-off and land from an aircraft carrier and is highly intelligent and autonomous, or do I want to do the exact same mission with 1,000 3D-printed, cheap, disposable drones? If I need to find an enemy missile battery somewhere in China, we need to figure out if we want a super stealthy expensive drone or lots of cheap disposable ones. This is a debate that's happening in the military right now.

What are some of the significant developments that have happened in the international sphere?

At New America we have been able to document at least 80 different countries using unmanned systems in their militaries. We've been able to document not just use unarmed drone use, but also armed use. Carrying out drone strikes used to be a small club. It used to be just the U.S. and Israel. Since then, the U.K., Pakistan, Nigeria, and Iraq have all joined that set. Russia and China have been in the armed camp for a while, but they haven't carried out a strike. Turkey may well join. Who knows who's next. The question is not whether you have the technology, it's whether you're at war or not. There is also the growing non-state actor use. If in Iraq War 2.0 we saw the introduction of unmanned ground vehicles and true drone use, in Iraq War 3.0 every single side in the war—whether it's the U.S., ISIS, Iraq, Hezbollah—is using unmanned systems. That's the definition of the end of proliferation. That discussion is over; the technology has proliferated.

One of the major changes in the last seven years is China's entry. They have everything from their Predator knock-off to three different long-range strike drone programs. But they have also become a major seller of unmanned systems, and that will continue. The Iraqi military carried out its first drone strike using a Chinese drone. Depending on how you interpret the photos, it may have even had Chinese technician aid. The story is the same in Nigeria. It's not just who they're selling to—which often includes nations that the U.S. wouldn't sell to—it's also their willingness to use drones in certain ways or sell systems that we might not. Every country looks at weapons and robotics in different ways, and have different codes that they follow. For example, the U.S has not sold any armed ground robots to foreign buyers. Meanwhile, at a recent military trade show in Malaysia, Chinese firms showed off an armed ground robotic system.

Photo credit: Tech. Sgt. Frank Miller/USAF

Russia has definitely been very public and boastful about its adoption of armed ground robots; maybe even too boastful, as there's debate whether they actually did deploy it in Syria. You don't see the U.S. military in its online recruiting ads showing off imagery of the SWORDS system, whereas you see that on the Russian side. This proliferation is important not just in terms of who has them and how they might use them, but also which boundaries we'll push or not.

What are your predictions for the next seven years?

I would frame it like this: More, more, more.

First, more diversity. We're moving away from the technology looking like the manned systems that it was replacing. The Predator looks like a plane without a human in the cockpit. We're moving toward design inspiration that comes from outside of existing manned technologies, most notably from nature. We're also seeing more diversity in terms of the size. We're pushing the size spectrum from teeny, tiny drones that fit on the tip of your finger to large scale drones with wings the length of football fields that are designed to stay in the air not for hours, days, or weeks, but months and years. This diversity in size, shape, and form is aligned with more intelligence and autonomy. As the systems become more capable and autonomous, it enables the technology to be more useful to more people in more roles, particularly as a wider set of people are able to use the technology without having to go through deep training.

This, in turn, means you have more users globally. The technology will become proliferated in both military use and in civilian world use. As a role is proven in one world, it will take off in the other. So, for example, airborne surveillance was pioneered on the military side, and now we see everyone from paparazzi to police using surveillance drones. There will be applications that move in the other direction, too. We're seeing this with delivery, which will take off on the civilian side and move over to the military side.

> *"As the systems become more capable and autonomous, it enables the technology to be more useful to more people in more roles."*

We are simply going to see more, more, more. And then you will have synergies between the mores, which will drive the story of robotics in the years ahead, such as teaming between ground robotics and swarms of drones or drones in the air passing information to robotic subs. *Wired for War* may be a few years old now, but the robotics revolution has only just begun.

May 18, 2016

New America, Washington, D.C.

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Photo credit: Sgt. Sarah Anderson/USMC

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