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Subcommittee on Terrorism, Unconventional Threats and Capabilities,
House Armed Services Committee, U.S. House of Representatives

Statement by Dr. Tony Tether

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Submitted to the

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Mr. Chairman, Subcommittee Members and staff: I am pleased to appear before you today to discuss the Defense Advanced Research Projects Agency's (DARPA) ongoing activities, and our Fiscal Year (FY) 2009 plans to continue as the engine for radical innovation in the Department of Defense (DoD).

DARPA is 50 years old as of February 7. DARPA's original mission, by the Soviet Union beating the United States into space with Sputnik in October 1958, was to prevent technological surprise. This mission has evolved over time. Today, DARPA's mission is to prevent technological surprise for us *and* to create technological surprise for our adversaries. Stealth is one example of how we created technological surprise.

DARPA conducts its mission by searching worldwide for revolutionary high-payoff ideas and then sponsoring research projects that bridge the gap between fundamental discoveries and their military use.

DARPA is the Department of Defense's only research agency not tied to a specific operational mission: DARPA supplies technological options for the entire Department and is designed to be a specialized "technological engine" for transforming DoD.

This is a unique role within DoD. The Department's operational components naturally tend to focus on the near term because they must meet urgent needs and requirements. Consequently, a large organization like DoD needs a place like DARPA whose only charter is radical innovation.

The DARPA Model

DARPA's mission is fairly easy to understand. In recent years, DARPA's success has inspired efforts to replicate DARPA at other Federal agencies – notably in the Department of Homeland Security, Department of Energy, Department of Health and Human Services, and in the Intelligence Community. So the questions become, "How does DARPA do it? What are the features of DARPA that have made it so successful in its mission?"

A little over a year ago, an article appeared in *The American Interest*[1] that did a good job of capturing what makes DARPA DARPA. Borrowing and adapting from that work, here are some key characteristics to keep in mind when trying to set up something like DARPA elsewhere:

- *Small and flexible*: DARPA has only about 140 technical professionals; some have referred to DARPA as "100 geniuses connected by a travel agent."
- *Flat organization*: DARPA avoids hierarchy, essentially operating at only two management levels to ensure the free and rapid flow of information and ideas, and rapid decision-making.
- *Autonomy and freedom from bureaucratic impediments*: DARPA has an exemption from Title V civilian personnel specifications, which provides for a direct hiring authority to hire talent with the expediency not allowed by the standard civil service process.
- *Eclectic, world-class technical staff and performers*: DARPA seeks great talent and ideas from industry, universities, government laboratories, and individuals, mixing disciplines and theoretical and experimental strengths. DARPA neither owns nor operates any laboratories or facilities, and the overwhelming majority of the research it sponsors is done in industry and universities. Very little of DARPA's research is performed at government labs.
- *Teams and networks*: At its very best, DARPA creates and sustains great teams of researchers from different disciplines that collaborate and share in the teams' advances.
- *Hiring continuity and change*: DARPA's technical staff is hired or assigned for four to six years. Like any strong organization, DARPA mixes experience and change. It retains a base of experienced experts – its Office Directors and support staff – who are knowledgeable about DoD. The staff is rotated to ensure fresh thinking and perspectives, and to have room to bring technical staff from new areas into DARPA. It also allows the program managers to be bold and not fear failure.
- *Project-based assignments organized around a challenge model*: DARPA organizes a significant part of its portfolio around specific technology challenges. It foresees new innovation-based capabilities and then works back to the fundamental breakthroughs required to make them possible. Although individual projects typically last three to five years, major technological challenges may be addressed over longer time periods, ensuring patient investment on a series of focused steps and keeping teams together for ongoing collaboration. Continued funding for DARPA projects is based on passing specific milestones, sometimes called "go/no-go's."
- *Outsourced support personnel*: DARPA extensively leverages technical, contracting, and administrative services from other DoD agencies and branches of the military. This provides DARPA the flexibility to get into and out of an area without the burden of sustaining staff, while building cooperative alliances with its "agents." These outside agents help create a constituency in their respective organizations for adopting the technology.

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[1] "Power Play," W. B. Bonvillian, *The American Interest*, Volume II, p 39 (November-December 2006).

- *Outstanding program managers*: The best DARPA program managers have always been freewheeling zealots in pursuit of their goals. The Director's most important task is to recruit and hire very creative people with big ideas, and empower them.
- *Acceptance of failure*: DARPA pursues breakthrough opportunities and is very tolerant of technical failure if the payoff from success will be great enough.
- *Orientation to revolutionary breakthroughs in a connected approach*: DARPA historically has focused not on incremental but radical innovation. It emphasizes high-risk investment, moves from fundamental technological advances to prototyping, and then hands off the system development and production to the military services or the commercial sector.
- *Mix of connected collaborators*: DARPA typically builds strong teams and networks of collaborators, bringing in a range of technical expertise and applicable disciplines, and involving university researchers and technology firms that are often not significant defense contractors or beltway consultants.

We cannot claim to have been so wise as to have invented this entire model all up-front. In fact, it evolved over time in response to various conditions and constraints DARPA has faced over the years. But it works quite well for us, and is a major contributor to our success.

Because, in many ways, DARPA operates quite differently from the rest of the government, it can be easy to inadvertently damage our approach.

For example, we are sometimes asked why DARPA's annual obligation rates are not higher in the midst of a fiscal year. As you may know, there is a constant push on Federal agencies to obligate their money as quickly as possible during the fiscal year – the fiscal motto being, "Use it or lose it." However, DARPA takes a different approach. Rather than rush to obligate money at the beginning of a fiscal year, DARPA holds funds until performers pass significant, agreed-upon milestones – their "go/no-go's." This keeps people highly motivated, but it can also artificially make our obligation rates look lower than they really are during a fiscal year, which raises eyebrows and makes us a target for budget cuts because of "poor financial execution." But we think our approach results in better technical management because it is focused on performance-based results, rather than financial imperatives.

Also, last year there were some proposals in Congress to augment the post-employment restrictions on Federal employees. While well-intentioned, these kinds of moves could harm an organization like DARPA. Consider this from the point of view of the world-class technical talent that DARPA wants to recruit, many of whom may take a salary cut to join us. They know they will only be with DARPA for four to six years, and they would like their careers to continue to flourish when they leave us. If they believe it will be more difficult to find a job in their field after they leave DARPA, that will tend to discourage them from joining us in the first place.

My point here is simply that DARPA's model – which has been very successful, and which people would like to replicate elsewhere – is different from almost all other government organizations. If DARPA is to remain successful, its unique business processes must be protected.

DARPA's Outreach

Because DARPA works on "blue-sky" projects, it is easy to believe that we are off by ourselves without much contact with other organizations. It's not like that at all.

We put a tremendous amount of energy into outreach to two different groups. One group might be called our "customers." These are people within DoD who have difficult operational challenges that need to be solved, or whom we need to convince to try a new technology. We need to understand their operational challenges and eventually market new technologies to them. Just over this past year alone, we have briefed several DoD leaders on our efforts and obtained their direct feedback. The individuals we have briefed include:

- Deputy Secretary of Defense, Mr. Gordon R. England
- Secretary of the Army, Mr. Pete Geren
- Vice Chairman, Joint Chiefs of Staff, General James E. Cartwright
- Commandant of the Marine Corps, General James T. Conway
- Commander, U.S. Southern Command, Admiral James Stavridis
- Commander, U.S. Special Operations Command, Admiral Eric Olson
- Under Secretary of the Air Force, Dr. Ronald M. Sega
- General Counsel of the Department of Defense, Mr. William J. Haynes II
- Commander, Air Force Space Command, General Kevin P. Chilton
- Commander, Air Combat Command, General John D. W. Corley
- Commander, Air Combat Command, General Ronald Keys
- Commander, U.S. Army Training and Doctrine Command, General William S. Wallace
- Deputy Under Secretary of Defense, Advanced Systems and Concepts, Mr. John Kubricky
- Director, Missile Defense Agency, Lieutenant General Henry A. Obering III
- Director, National Security Agency/Chief, Central Security Service, Lieutenant General Keith B. Alexander
- Commander, Marine Corps Combat Development Command, Lieutenant General James F. Amos
- Surgeon General of the Air Force, Lieutenant General James G. Roudebush
- Commander, U.S. Army Medical Research and Material Command, Major General George Weightman
- Commander, U.S. Submarine Forces, Vice Admiral John J. Donnelly
- Deputy Director, Strategy and Policy, J-5, Rear Admiral Frank Pandolfe

- Deputy Surgeon General of the Navy, Rear Admiral Thomas R. Cullison
- Special Assistant for Undersea Strategy, Rear Admiral Winford Ellis
- Defense Liaison Office N87, Rear Admiral Joseph Enright
- Administrator, National Aeronautics and Space Administration, Dr. Michael Griffin
- Director for Defense Procurement and Acquisition Policy and Strategic Sourcing, Mr. Shay Assad
- Deputy Director, National Security Agency, Mr. Chris Inglis

The other group is what one might call our "suppliers." DARPA does not conduct any research on its own. Instead, we sponsor other people – primarily in industry and academia – to do the research and create new technologies. So we ultimately depend on good ideas well executed by others. We need to reach those people, get their ideas, and carry those ideas forward.

To reach out to our customers within DoD, we have a group of people we call our Operational Liaisons. These are senior military officers from the Army, Navy, Air Force, and Marine Corps who keep us well connected to problems within the Services. They help us understand the operational challenges, and are also instrumental in transitioning our technologies to the Services. Essentially, they bring problems in and take solutions out. We also have individuals assigned to DARPA from other DoD agencies: the National Geospatial-Intelligence Agency, Defense Information Systems Agency, and National Security Agency – and a special assistant who works full-time on developing strategies and plans for technology transitions.

As a particular focus for our outreach, we have an individual assigned full-time to U.S. Special Operations Command (USSOCOM), so that we can use USSOCOM as our real-world laboratory, and they, in turn, use DARPA for experimental technologies.

In addition, we have junior officers who come to DARPA on short-term assignments. These officers help us understand what's going on in the various Services and forge connections at the working level. But more importantly, we are building relationships so that when they become senior officers they will know how to use DARPA to effectively solve future operational challenges.

Our senior management team takes trips to visit our forces in the field to get a better, hands-on "feel" for their operational challenges. For example, in January we took a trip to U.S. Southern Command to get a much better idea of the Joint Task Force's counter-narcotics operations. As a result of the visit, we are recommending DARPA-developed technologies in surveillance and tracking, information displays, and vessel inspection, which could help improve the Task Force effectiveness.

The other part of our outreach effort is to connect with innovative researchers wherever they are. So we are constantly trying to find people with great ideas, and help people with great ideas find us.

Our signature event for this is DARPATech, a technical conference where we lay out our vision of the future for the research community and discuss technical problems and opportunities. The goal is to spur people to develop bold ideas that lead to great proposals, great projects, and ultimately the best technology for our warfighters.

The most recent DARPATech was held last August in Anaheim, California. It was our largest event ever, attracting over 3000 attendees. We held almost 1000 "sidebars" in which individuals could discuss their ideas with DARPA program managers in short, private meetings. As a result of DARPATech, we received many new ideas for programs that could lead to important new capabilities for DoD.

Major Progress Since 2001 – and More to Come!

Since 2001, DARPA has accomplished a great deal for our national security. To describe the enormous progress we have made across a wide swath of technology and our plans to continue that progress, let me just highlight eight broad areas.

The eight areas are:

- Deny hiding in any environment and cultural background;
- Provide persistent situational awareness and rapid strike;
- Beat the OODA (observe-orient-decide-act) loop of modern adversaries;
- Provide cyber operations dominance;
- Remove the value of using biological weapons;
- Increase survival from life-threatening wounds;
- Restore injured warfighters to the way they were; and
- Develop core technologies that maintain U.S. military superiority.

Deny hiding in any environment and cultural background

The U.S. military is incredibly adept at precision strikes against targets on the traditional battlefield. Our adversaries know and understand this, and they are getting smarter about concealing their activities and their movements. DARPA is working to counter these efforts to hide, move, or blend in with the culture and environment by developing technologies to detect enemy activity in all situations and, once adversaries are detected, never to lose track of them.

The first step to finding hidden people and objects is to have good intelligence that cues us about their location. One way to improve our intelligence is to dramatically improve our ability to rapidly translate foreign languages using automated translation technologies. Today, linguists translate important information, but it is a slow and arduous process. We have massive amounts of raw data and not enough linguists to handle the constant streams of information. To manage the enormous quantity of data and intelligence we capture and receive, we must dramatically reduce the growing reliance on linguists at both the strategic and tactical levels by providing revolutionary machine translation capabilities.

The Global Autonomous Language Exploitation (GALE) program is designed to translate and distill foreign language material (e.g., television shows and newspapers) in near real time. The system highlights salient information and stores the results in a searchable database. Through this process, GALE will be able to produce high-quality answers that are normally provided by bilingual intelligence analysts. GALE is working toward fully achieving this ambitious goal by 2010.

Initial capabilities developed in the program were deployed to Iraq in 2006 and 2007. GALE continuously translates Arabic regional news, both speech and text, into English and alerts the warfighter to events of interest and other potentially mission-critical information. GALE is also being used to monitor the reactions of the region's population to current events, promptly capture misinformation/disinformation, and then quickly respond and correct inaccuracies in news reporting. In addition to providing timely translations of Arabic media, GALE systems enable the warfighter to efficiently search and retrieve previously translated information that would otherwise not be readily available.

GALE has continued to dramatically improve the state of the art in machine translation. In the first year, GALE achieved an accuracy rate two times better than was thought possible, and the program is continuing these strong technological advancements. Overall, GALE's translation of structured speech and text (e.g., broadcast news and newswire) has improved to the point that it produces "edit-worthy" text. This saves time, since it is more efficient for a translator to edit the GALE product directly, as opposed to retranslating the original material.

The success of the GALE technology is making it possible to automate the exploitation of hard-copy documents and text images under our new Multilingual Automatic Document Classification Analysis and Translation Exploitation program.

At the tactical level, there are not enough translators for each patrol or vehicle checkpoint. Our warfighters also need automatic, on-the-spot speech translation to work with Iraqi units and so they can quickly use what they might be told by locals about insurgents or suspicious activities.

DARPA's Spoken Language Communication and Translation System for Tactical Use (TRANSTAC) program is working on a two-way speech translation system, a device that converts spoken foreign language input to English output, and vice versa. Such communication systems are indispensable for our troops as they interact with the local population and coalition partners.

Improved intelligence based on faster, more widely available translations can then be coupled with physical sensors to help uncover enemy activities.

For the urban environment, DARPA's Autonomous Real-time Ground Ubiquitous Surveillance – Imaging System (ARGUS-IS) program is developing a new wide field-of-view video sensor to significantly improve the number of targets tracked. The sensor will supply over 65 real-time video windows, each providing high-resolution motion video comparable to that currently provided by Predator. Each window will also be independently steerable, allowing operators to keep critical areas of interest under constant surveillance. ARGUS-IS is designed to operate on the A160, a revolutionary high-altitude, long-endurance, unmanned helicopter.

And for operations in forested areas, last year we successfully demonstrated a foliage penetrating radar that detects vehicles and dismounted adversaries under heavy forest canopy. The radar, called FOPEN Reconnaissance, Surveillance, Tracking and Engagement Radar (FORESTER), was installed on a Black Hawk helicopter and flew at a standoff range. Operators onboard the aircraft could detect people walking under foliage in and around concealed encampments. This year we also plan to install and demonstrate this radar on the A160.

The Synthetic Aperture Ladar for Tactical Imaging (SALTI) program will develop and demonstrate an airborne synthetic advanced laser radar (ladar) imager capable of producing high-resolution, three-dimensional imagery at extended ranges. For deployment within a tactical-sized package, SALTI will combine the long-range day/night access of conventional synthetic aperture radar with the interpretability of high-resolution optical imagery and exploitability of three-dimensional imagery. The program will demonstrate full operation at tactically relevant high altitudes and extended ranges.

DARPA's Integrated Sensor Is Structure (ISIS) program is the most capable U.S. moving target indicator radar for air and ground targets ever conceived and includes foliage-penetration. Using the enormous platform surface area available on a stratospheric airship, ISIS will incorporate an extremely large antenna (approximately 5000 square meters) directly into the structure of the airship. For example, a single ISIS stationed over Baghdad today would provide total airspace knowledge and unprecedented ground vehicle tactical tracking across more than 80 percent of Iraq. Having completed ISIS component development – lightweight/long-life hull material, active electronically scanned aperture X-band/UHF radar, and fully solar-regenerative power system – DARPA is beginning design and manufacture of a scaled demonstration system.

Back on the ground, DARPA's Advanced Soldier Sensor Information System and Technology (ASSIST) program is developing tools to enhance the intelligence-gathering capabilities of our ground troops and help increase the situational awareness for our patrol leaders. The Tactical Ground Reporting (TIGR) system, developed as part of ASSIST, combines sensors, networks, and advanced software so Soldiers can share their observations and experience with ease and accuracy. Details of each patrol and mission are captured in the form of digital photos, videos, GPS tracks, and voice annotations. During mission planning, a patrol leader can quickly tap into TIGR's rich database and analyze recent attacks along all routes, bring up photos and information on the local leaders, census data for the villages, and any other relevant information for the locations that he will be visiting or driving through.

User response has been overwhelmingly positive. TIGR was introduced in Iraq in January 2007, and the users have quickly grown to over 2000 Soldiers across four brigades. An Army lieutenant using TIGR remarked, "A patrol is able to leave the gate knowing all the information needed to accomplish the mission. Seeing what I can know with TIGR, if I had to operate without it, I would feel as if I were in the dark." DARPA is now collaborating with the Army to add key enhancements to TIGR.

Of course, individuals and activities are increasingly being hidden underground. Our Counter-Underground Facility program is developing a variety of sensor technologies and systems – seismic, acoustic, electromagnetic, optical, and chemical – to find, characterize, and conduct post-strike assessments of underground facilities. For example, our Low-Altitude Airborne Sensor System is demonstrating the use of airborne electromagnetic, acoustic, and gravity sensors to rapidly find underground facilities and map out their backbone structure.

In the maritime arena, our Fast Connectivity for Coalitions and Agents (Fast C2AP) program, now complete, developed software agents to allow naval watchstanders to automatically monitor vessels and locate, investigate, and intercept vessels engaged in suspicious activity. Fast C2AP was deployed to both the U.S. Navy's Sixth Fleet and the North Atlantic Treaty Organization's Component Commander-Maritime and was used to identify vessels engaged in illicit behavior. Fast C2AP increases the number of vessels that watchstanders can monitor from tens to thousands per watch, and reduces the time required to obtain detailed information regarding ships from hours to minutes. At the end of 2007, Fast C2AP was transitioned to the Navy.

To support maritime domain awareness, DARPA's Predictive Analysis for Naval Deployment Activities (PANDA) program is developing technology that exploits surface maritime vessel tracks to automatically learn the normal behavior of over 100,000 vessels, and then detect deviations. PANDA will automatically provide alerts on those vessels exhibiting suspicious activity, including activities that have not been previously seen or defined.

Our Collaborative Networked Autonomous Vehicles (CNAV) program is developing improved intelligence, surveillance, and reconnaissance capabilities in littoral waters. CNAV successfully created a self-forming network of unmanned undersea vehicles deployed in a cluttered maritime environment over a two square mile area. These vehicles shared information over a wireless underwater network.

In addition to these systems, DARPA has been working on tagging programs to positively track items of interest. While we cannot discuss most of this work in this forum, I can say a few words about our Dynamic Optical Tags (DOTS) program. DOTS has developed and demonstrated a small, robust, persistent, covert two-way tagging, tracking and locating system that will allow for covert two-way data exchange and tagging operations in friendly and denied areas. DOTS can support data rates greater than 100 kilobits per second up to 10 kilometers, and interrogation angles up to 60 degrees off-axis. In addition, the tags will operate for greater than two months, over a two-year period, in real-world environmental conditions – a capability of great value to our warfighters.

Provide persistent situational awareness and rapid strike

Over the last seven years, DARPA has made great strides toward more responsive and persistent air operations. Our goal is to plan quicker, get there faster, and stay there for a long time.

To plan faster, we are developing cognitive computing technologies that will link key personnel and quickly gather information for them about the target, including the threat, response options, operational forces available, and possible weapons.

Our flagship cognitive computing program is the Personalized Assistant that Learns (PAL), which is developing integrated cognitive systems to act as personalized executive-style assistants to military commanders and decision-makers. PAL is creating a new generation of machine learning technology so information systems can automatically adjust to new environments and new users, help commanders maintain the battle rhythm, and adapt to new situations, priorities and enemy tactics. PAL will also help new personnel come up to speed quickly in command operations, while making more effective use of resources.

PAL technology is being tested at several organizations and activities for possible transition, including U.S. Strategic Command's Strategic Knowledge Integration Web (SKIWeb). Senior military leadership use SKIWeb to share intelligence and to stay abreast of events unfolding throughout the world in real time. SKIWeb uses threaded discussions, or blogging, to share ideas, and encourages collaboration by providing up-to-the-minute situational awareness. PAL learning technology will help SKIWeb recognize and respond to critical event information. Outstanding performance was recently demonstrated in an experiment with real SKIWeb data.

When the U.S. decides to act, we envision using new hypersonic vehicles to quickly reach any point on earth without the need to organize an air refueling tanker fleet to support a long-range mission.

With this vision in mind, DARPA's Falcon program has been working to vastly improve the U.S. capability to promptly reach other points on the globe. A major goal of the program is to flight-test key hypersonic cruise vehicle technologies in a realistic flight environment. Recently we conducted both low- and high-speed wind tunnel tests that validate the stability and control of the hypersonic technology vehicle across the flight regime. The program is also developing a vehicle test bed called Blackswift. By the end of 2012, our goal is for Blackswift to take off under its own turbojet power from a runway, accelerate to Mach 6 under combined turbojet/scramjet propulsion, and land on a runway.

DARPA's Rapid Eye program is working to place a high-altitude, long-endurance platform quickly over any spot on earth. Rapid Eye will create the capability to deliver a persistent intelligence, surveillance, and reconnaissance asset anywhere worldwide within one hour. The program will develop a high-altitude, long-endurance aircraft that can be put on existing space launch systems, withstand atmosphere re-entry, and provide efficient propulsion in a low-oxygen, low-speed environment. Rapid Eye's response time will be hours, not days.

While not hypersonic, DARPA's Oblique Flying Wing program will provide complementary capabilities. Oblique Flying Wing will demonstrate a design concept for a new class of efficient supersonic aircraft capable of flying in a swept configuration with low supersonic wave drag and a non-swept configuration increasing subsonic efficiency. This flexibility will improve range, response time, fuel efficiency, and endurance for supersonic strike, intelligence, surveillance and reconnaissance, and transport missions. The goal of the program is to prove out the stability and control technologies required for an oblique flying wing with an X-plane that will demonstrate an asymmetric, variable sweep, tailless, supersonic flying wing. We have completed the baseline

X-plane design, and we conducted ground-breaking, high-speed wind tunnel testing of a subscale model tailless oblique flying wing last September.

At the tactical level, the Heliplane program will help us quickly reach areas that don't have runways by developing a revolutionary air vehicle that can take-off, land, and hover vertically like a helicopter and cruise with the speed and efficiency of a fixed-wing aircraft. Heliplane offers a two- to three-fold improvement in forward flight characteristics over conventional helicopters. Unlike a helicopter that relies on a rotor for both hover and cruise, the Heliplane adapts lifting mechanisms to achieve high efficiency throughout its flight envelope: a rotor in hover and slow-speed flight and a fixed wing combined with turbofan engines for high-speed flight.

Of course, one key to intelligence, surveillance, and reconnaissance is persistence, which can be enabled by autonomous air refueling or by aircraft that can remain on-station for over five years, for example. Such platforms could be staged in an area of interest and remain there continuously for extended periods of time.

DARPA's Autonomous Airborne Refueling Demonstration (AARD) program developed technologies to perform the complex and dangerous task of midair refueling of unmanned air vehicles (UAVs). Midair refueling would enable new long-range UAV missions with expanded operational envelopes, while reducing the forward basing required for today's generation of unmanned aircraft.

Improved safety and efficiency for manned aircraft is an obvious and important part of AARD. Last year the program successfully demonstrated this technology on a modified F-18, during which the pilot watched the entire operation with his hands and feet off the aircraft's controls. We are currently exploring a range of near-term applications of autonomous refueling to manned fixed-wing aircraft and helicopters, even as we support a broader community that is developing long-range UAVs.

One successful effort to provide airborne persistence has been DARPA's A160 program. The A160 is an unmanned helicopter designed for intelligence, surveillance, and reconnaissance missions with long endurance – up to 18 to 20 hours – and the ability to hover at high altitudes. The A160 concept is being evaluated for surveillance and targeting, communications and data relay, crew recovery, resupply of forces in the field, and special operations missions in support of Army, Navy, Marine Corps, and other needs.

Finally, our Vulture program will develop an aircraft capable of remaining on-station for over five years, pushing technology and design so that the system will not require refueling or maintenance. Our vision reflects a fundamental change in the nature of airborne surveillance – the previously unimagined endurance of a Vulture aircraft will provide a breakthrough in both quality, quantity and timeliness. A single Vulture aircraft could support traditional intelligence, surveillance, and reconnaissance functions over country-sized areas – while at the same time providing an unblinking eye over a critical target, monitoring that target night and day, day in and day out, month after month – providing unprecedented high-value intelligence. Vulture aircraft will also be able to provide communications capabilities available today only from geostationary satellites – offering opportunities for new, more flexible, expandable and relocatable communication architectures at a fraction of the cost of dedicated satellite capabilities. The challenges here include developing solar cell, energy storage, and reliability technologies that will allow the aircraft to operate continuously, unrefueled for over 44,000 hours. The Vulture program will conclude with a year-long flight demonstration with a fully functional payload.

<u>Beat the OODA (observe-orient-decide-act) loop of modern adversaries</u>

Modern warfare means carrying out an "OODA" loop – observe-orient-decide-act – faster than any enemy, which means that we can respond effectively to anything they plan to do, or they cannot respond to anything we want to do. For example, we could disrupt attacks before they can be carried out. One of the promises of network-centric warfare is that it will speed up our OODA loops by making information widely available and fusing the typically separate functions of intelligence and operations. But, of course, network-centric warfare depends on having a *network*. So to really speed up the OODA loop, these networks must not only be effective and robust, but we must be able to set them up quickly – or, better yet, have them be self-forming and self-maintaining.

DARPA has many networking programs to help achieve a vision of linking tactical and strategic users through networks that can automatically and autonomously form, maintain, and protect themselves. We are developing technologies for wireless tactical net-centric warfare that will enable reliable, mobile, secure, self-forming, ad hoc networks among the various echelons that make the most efficient use of available spectrum.

A seminal DARPA tactical networking program, completed a couple years ago, was the Small Unit Operations Situational Awareness System to link together dismounted Soldiers operating in difficult environments such as in cities and forests. This self-forming and self-healing communications network technology transitioned to the Army, where its basic network waveform is being integrated into the Joint Tactical Radio Systems Ground Mobile Radios and the Handheld, Manpack, Small Form Factor Radios.

More recently, to connect different tactical ground, airborne and satellite communications terminals together, our Network Centric Radio System (NCRS) (formerly Future Combat Systems–Communications) program developed a mobile, self-healing ad hoc network gateway approach that provides total radio/network compatibility on-the-move in any terrain – including the urban environment. NCRS has built interoperability into the network itself, rather than having to build it into each radio, so any radio can now be interoperable with any other. Today, using NCRS, previously incompatible tactical radios – military legacy, coalition, and first responder – can talk seamlessly among themselves and to more modern systems, including both military and commercial satellite systems.

This brings me to the frequency spectrum. Most of the spectrum is already allocated to users who may or may not be using it at a given time and place. DARPA's neXt Generation (XG) Communications program has been developing technology to make ten times more spectrum available by taking advantage of spectrum that has been assigned but is not being used at a particular point in time. XG technology senses the spectrum environment in real time and then, in response, dynamically uses spectrum across frequency, space, and time – searching and then using spectrum that is not busy at the moment. XG is designed to resist jamming and not interfere with other users. XG was one of the technologies we displayed in the House Armed Services Committee Hearing Room on January 29.

Building on DARPA's XG and adaptive networking technologies, the Wireless Network after Next (WNaN) program is developing technology and architecture to enable an affordable and rapidly deployable communication system for the tactical edge. The low-cost, highly-capable radio developed by WNaN will provide the military with the capability to communicate with every Soldier and every device at all operational levels. WNaN networking technology will exploit high-volume, commercial components and manufacturing processes so that DoD can affordably and continuously evolve the capability over time. We are working to put this affordable, tactical communications technology into the hands of the warfighter as soon as possible. This was the other technology on display on January 29.

DARPA is also working to bridge strategic and tactical networks with high-speed, high-capacity communications networks. The Department's strategic, high-speed fiber optic network, called the Global Information Grid (GIG), utilizes an integrated network whose data rate is hundreds to thousands of megabits per second. To reach the theater's deployed elements, data on the GIG must be converted into a wireless format for reliable transmission to the various elements and echelons within the theater.

DARPA's Optical and Radio Frequency Combined Link Experiment (ORCLE) program demonstrated a means for relaying GIG information to operational assets at the edge – even if some high data-rate links are degraded by atmospheric or physical obstructions – by teaming high-speed free-space optical communications with high-reliability radio communications. Now, building on this we are planning to design, build, and demonstrate a prototype tactical network connecting ground-based and airborne elements. Our goal is to create a high data rate backbone network via several airborne assets that nominally fly at 25,000 feet and are separated out to ranges of 200 kilometers, which provides GIG services to ground elements up to 50 kilometers away from any one node.

All-optical technology will be essential for ultra-fast strategic networks in the future. A foundation for this will be integrating multiple functions onto a single chip for all-optical routers with highly scalable capacity and throughput. DARPA's Data in the Optical Domain–Network (DOD-N) program has demonstrated a monolithically integrated, compact time buffer with waveguide delays up to 100 nanoseconds. Temporarily storing high-speed data is a critical power-consuming bottleneck for electronic routers, and this first demonstration of an all-optical buffer is a significant step toward overcoming the storage limitations for future data routers.

These networks need to be robust and able to resist disruption. Networks rely on a widely available timing signal, or common clock, to sequence the movement of voice and data traffic. The timing signal is often provided by the Global Positioning System (GPS), and we should expect adversaries to attack our networks by attacking GPS.

To protect these networks, for several years DARPA has been developing a miniature atomic clock – measuring approximately one cubic centimeter – to supply the timing signal should the GPS signal be lost. The Chip-Scale Atomic Clock (CSAC) will allow a network node, such as a Soldier using a Single Channel Ground and Airborne Radio System (SINCGARS), to maintain synchronous operation with the network for several days after loss of the GPS signal. The CSAC microsystem derives its timing stability by coupling a miniature laser, with associated electronic circuits, to an atomic transition in a reference gas. Recently we have demonstrated an innovative application of an alternative laser-atomic state interrogation scheme that allows more than an order-of-magnitude increase in the system's stability. This new scheme should enable an accuracy equivalent to the loss of less than a tenth of a second error in timing over 100 years of operation. We currently have plans to insert a CSAC into a SINCGARS radio to demonstrate that it can provide a time signal if GPS is not available.

Provide cyber operations dominance

It is increasingly clear that cyber warfare will be a major and growing part of future operations. In particular, cyber warfare offers the possibility that an adversary could inflict widespread technological surprise and damage. DARPA's mission is to prevent that sort of technological surprise. While much of our work in this area cannot be discussed in this forum, for several years DARPA has been making considerable progress to ensure that the United States is well prepared for this novel form of conflict.

Everyone understands the need for cyber security – what we at DARPA usually call "information assurance." We have been developing technologies to make DoD computers and networks not only secure, but also disruption-tolerant and, when attacked, self-reconstituting.

As the U.S. military adopts network-centric warfare, terrorists and other nation-states are likely to develop and employ malicious code to impede our ability to fight efficiently and effectively. The ever-growing sophistication of the malicious code threat has surpassed the ability of normal commercial markets to address this problem. For example, computer worms that have never been seen before ("zero-day worms") pose a specific threat to military networks because they have been shown to exploit thousands of computers using previously unknown network vulnerabilities in seconds.

The Dynamic Quarantine of Computer-Based Worm Attacks program has been developing dynamic quarantine defenses for U.S. military networks against large-scale malicious code attacks, such as computer-based worms, by creating an integrated system that automatically detects and responds to worm-based attacks against military networks, provides advanced warning to other DoD enterprise networks, studies and determines the worm's propagation and epidemiology, and immunizes the network automatically from these worms. The final system will quickly quarantine zero-day worms to limit the number of machines affected, as well as restore the infected machines to an uncontaminated state in minutes, rather than hours and days, which is today's state of the art.

Normally, large, homogeneous networks can be quite vulnerable to cyber attack: if all the network computers have identical operating systems and software, then a software vulnerability or fault in any one component or device can make the entire network vulnerable to catastrophic disruption. However, the vision of the Application Communities program is to turn network size and homogeneity into *advantages*. By sharing knowledge about attacks, configuration errors, and bugs – along with possible recovery strategies – a community of safely contained commercial off-the-shelf systems can use automated diagnosis, containment, and repair actions to prevent the spread of problems to other systems and restore normal functionality to those already affected.

In 2007, the Application Communities program demonstrated fully automated detection, diagnosis, and recovery of a 20-node community in response to a self-propagating zero-day exploit of an e-mail application vulnerability and a fully automated repair to an attack on Firefox that took advantage of a JavaScript bug. The attack was recognized and the response was initiated. Different repairs were attempted, and the third repair successfully resolved the problem, and Firefox was able to continue. The exploit was closed after only five attacks, ensuring that most community members could continue without any problems.

DARPA also has a role in the Comprehensive National Cyber Security Initiative, part of our FY 2009 budget request.

Part of our drive to keep the United States cyber-dominant is to ensure that our country has the highest-performance computers in the world. The High Productivity Computing Systems (HPCS) program is the Federal Government's flagship program in supercomputing. HPCS is pursuing the research, development and demonstration of economically viable, high productivity supercomputing systems for national security and industrial users. Phase III of the High Productivity Computing Systems (HPCS) program, encompassing design, development, and prototype demonstration, has been underway for a little more than a year. The program will culminate in a prototype demonstration at the end of 2010.

While the actual hardware will not be available to users until 2010, the vendors are making visible progress on software that contributes to achieving the program's goal of improving productivity. In 2007, several key pieces of software were released to our Mission Partners (i.e., the Department of Energy and the National Security Agency, who are helping to fund HPCS) for their assessment; some were also released to the entire high performance computing community.

<u>Remove the value of using biological weapons</u>

For over a decade, DARPA has pursued a variety of technologies to reduce the threat of biological weapons.

DARPA's vision is to develop technology so we can respond *quickly* and effectively to any biological warfare (BW) attack – whether it uses known or unknown pathogens – thereby blunting the effect of the attack and greatly diminishing its value. With this understanding of the strategic necessity for rapid response in mind, DARPA has pursued programs to rapidly identify pathogens, develop and evaluate therapies for treating the diseases they inflict, and then manufacture therapeutics in large quantities.

Figure 1 shows the various steps required to respond to an unidentified or novel BW attack. DARPA has been working to speed up these steps with the ultimate goal of producing three million doses of definitive therapy in less than 16 weeks after a pathogen has emerged.

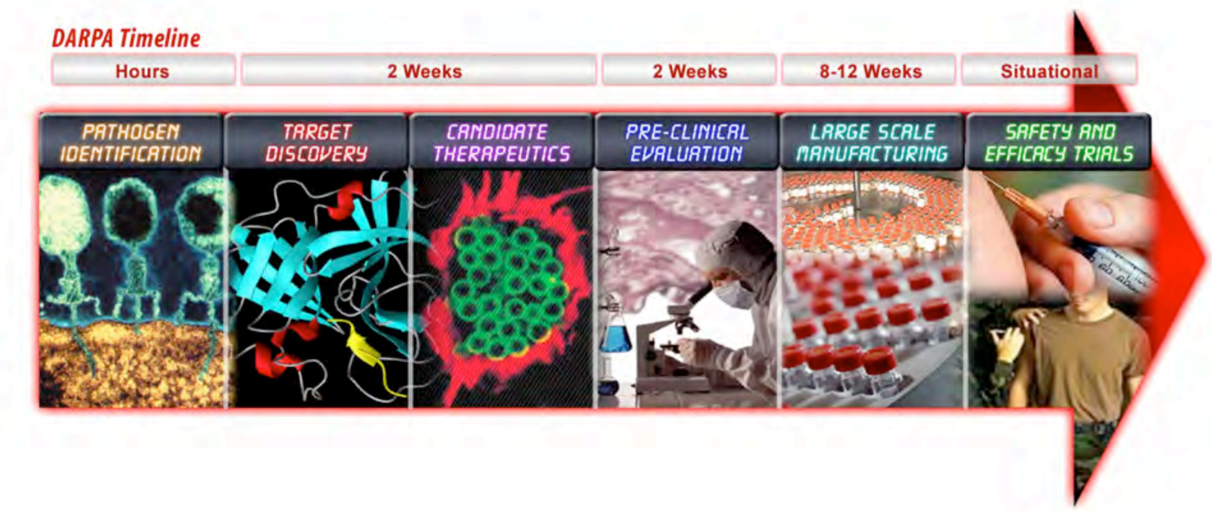

Figure 1: The steps to DARPA's goal of producing three million doses of definitive therapy in less than 16 weeks after a pathogen emerges.

Two major programs for rapidly identifying pathogens were TIGER and HISSS.

DARPA's Triangulation Identification for Genetic Evaluation of Risk (TIGER) program developed a "Gold Standard" universal sensor. TIGER is a strategic national asset that can detect any type of pathogen – even unknown and engineered ones – through an innovative method of measuring and weighing nucleic acid sequences. TIGER has been rigorously validated for biodefense applications, including surveillance for biological weapons agents in environmental samples and analysis of a broad range of biological samples for important human pathogens.

TIGER is completed and has been deployed to a number of places, including the U.S. Army Medical Research Institute of Infectious Diseases at Fort Detrick, Maryland, the National Institute for Allergies and Infectious Disease in Bethesda, MD, and the Centers for Disease Control. In 2006, two companies announced plans to manufacture and distribute a system that uses the DARPA TIGER technology, and the commercial unit is available for purchase.

In the arena of field sensors, DARPA's Handheld Isothermal Silver Standard Sensor (HISSS) program developed component technologies to enable a tactical-level handheld biological warfare agent sensor capable of laboratory-quality detection of the full spectrum of biological threats on the battlefield: bacteria, viruses, and toxins.

Once a pathogen has been detected, we need ways to quickly develop and evaluate a vaccine or other countermeasure. In this area, our Rapid Vaccine Assessment program is developing new methods to test vaccines and provide more precise, fast, and biologically relevant evaluation of human responses than conventional tissue culture systems or animal models. The Modular IMmune In-Vitro Construct (MIMIC) is the first-ever credible method for replacing animal vaccine studies with a safe, accurate approximation of the human immune system that does not require injecting people. MIMIC's potential to improve the safety of clinical trials and reduce the need for animal testing resulted in *R&D Magazine* honoring it with a *2007 R&D 100 Award* as one of 2007's 100 most technologically significant developments in the world.

MIMIC is currently transitioning to the DoD's primary medical countermeasure development office at Defense Threat Reduction Agency (DTRA) and several pharmaceutical companies. MIMIC's evaluation of both successful and failed vaccines will be compared with actual clinical data to demonstrate its ability to predict the immunogenic potential of vaccines prior to expensive and lengthy animal and clinical trials.

Once a vaccine, antibody, or immune enhancer has been identified by MIMIC and undergone pre-clinical evaluation, technology from our Accelerated Manufacturing of Pharmaceuticals (AMP) program could take over. AMP is developing strategies to rapidly and inexpensively manufacture millions of doses of life-saving drugs or vaccines in weeks, instead of the years required by today's manufacturing practices. AMP will do this by combining high-speed natural biological production systems, such as bacteria, fungus and plants, with powerful, flexible bioreactor and automated growth technologies to produce antibodies or vaccines quickly on an unprecedented scale.

AMP early results have already outperformed current vaccine production systems. For example, in November 2007, AMP's plant-based technology demonstrated the capability to produce over 800,000 doses of crude avian influenza vaccine within a month. A second platform demonstrated a high yield of 30,000 doses of raw viral vaccine per liter of culture. It is important to note that conventional influenza vaccine systems would have taken six- to nine-times longer to do the same using egg-based vaccine production. DARPA's next steps are to demonstrate that vaccines produced in these novel platforms are as pure and effective as those produced conventionally. Current plans call for AMP's best performing platforms to be transitioned to the Defense Threat Reduction Agency.

Increase survival from life-threatening wounds

As we send our men and women in uniform into harm's way, two of our solemnest duties are to do what we can to protect them, and to do everything we can to heal the injured.

With this obligation in mind, for the past several years DARPA has made great progress in technologies to protect our troops from harm, keep them at the peak of their performance, and care for them when injured.

As a long-term effort to reduce injuries, our PREventing Violent Explosive Neurological Trauma (PREVENT) program is a basic research program looking for the mechanisms of neurological injury – particularly brain injury – caused by blast.

We do not have a good enough understanding of the mechanisms behind the symptoms we are seeing. It used to be thought that peak overpressure was the primary mechanism for blast injury, but that does not appear to be the case for many of the neurological symptoms in today's wounded. PREVENT is an aggressive program to fully characterize the harmful components of blasts, including the brain effects of repeated small blasts that individually might not seem harmful. Once we better understand the physical mechanisms of neurological injury, we can design specific technologies to protect our warfighters against them.

Testing is underway to further examine the causes of injury. Initial tests with biological models have concluded that overpressure alone does not account for lasting neurological injury. Additionally, experiments have shown that even conventional explosives produce low-level electromagnetic pulses, which may further explain the complex presentation of brain injury resulting from blast.

Several DARPA programs have been aimed at maintaining the warfighter's peak physical and cognitive performance once deployed, despite extreme battlefield stresses such as heat and altitude, prolonged physical exertion, and sleep deprivation.

For example, the Peak Soldier Performance program has developed a completely new approach to maintaining normal body temperature in the face of extreme heat. The Rapid Thermal

Exchange Device is a special cooling glove into which one hand is inserted. A slight vacuum is applied to the palm, which contains special blood vessels that can act like radiators. Cold water circulates through the grip, and, as a result, large amounts of blood can be rapidly cooled, maintaining normal body temperature even in extreme heat or during exertion. A modified version of the cooling device will be undergoing field testing on Light Armored Vehicles this summer. Another version is being adapted to maintain body warmth during prolonged underwater diving operations.

DARPA researchers have identified a very safe, natural antioxidant – called Quercetin – and developed it into a new form that is now available to the military and the general public. Among Quercetin's many potential benefits is illness prevention. In a randomized, placebo-controlled study, Quercetin helped prevent viral illnesses, like colds and flu, after physical exertion. Following a strenuous three day exercise routine, 50 percent of the control group became ill with colds and flu, whereas only five percent of the Quercetin supplemented group did. This important immune protective effect will help keep our warfighters healthy during training and deployment. Quercetin has been commercialized as RealFX Q-Plus soft chews, which are now available through several commercial vendors, as well as to all military personnel at a 50 percent discount.

When our troops are injured or wounded, one of the most important things we can do for them is reduce their pain. Under our Soldier Self Care program, DARPA has been pursing a radically different way of treating acute, severe pain. The current best treatment is morphine, which reduces pain quite well. But because morphine acts on the central nervous system, it also impairs cognition and can dangerously depress body functions. Instead, DARPA is pursuing capabilities to protect cognition by blocking the pain receptors right at the injury site to prevent them from firing and sending a pain signal to the central nervous system. This will help a Soldier remain alert in dangerous situations.

This research is progressing well. We've shown the treatment is safe, and, at this point, even more effective than morphine – but without morphine's side effects. The small company that developed the technology has been purchased by a large pharmaceutical firm, and there is a clinical development plan in place that is aggressively moving forward.

Hemorrhage continues to be the leading cause of death on the battlefield, accounting for about 50 percent of fatalities. To stop bleeding on the battlefield, DARPA's Deep Bleeder Acoustic Coagulation (DBAC) program has been working on a portable device to stop deep internal bleeding, which could be operated on the battlefield by non-medical personnel. The approach will utilize novel, high intensity focused ultrasound (HIFU) to detect, locate, and coagulate deep internal bleeders. The DBAC team includes test and standards development experts for HIFU devices at the FDA's Center for Devices and Radiological Health. Involving the U.S. Food and Drug Administration at the start of the program will help ensure that the transition from DARPA to the battlefield will occur as quickly as possible.

Complementing DBAC, the Surviving Blood Loss (SBL) program has been developing novel strategies to delay the onset of hemorrhagic shock due to blood loss, providing increased time for evacuation, triage, and initiation of supportive therapies. The program aims to extend the "golden hour" after severe trauma to six to ten hours, or more. SBL is working to understand the control mechanisms of energy production, metabolism, and oxygen utilization, and to identify and control the protective mechanisms that preserve cellular function despite critically depressed oxygen delivery. SBL has identified very promising compounds, including hydrogen sulfide and estrogen, that, in large animal tests, extend survival after lethal hemorrhage to more than three hours without requiring resuscitative fluids. Human safety trials for hydrogen sulfide, paid for by the company that created the technology, are proceeding on schedule.

There are no simple, automated respiratory support devices that are suitable for the combat medic. Breathing emergencies on the battlefield either go untreated or require the full attention of combat medics, leaving them unavailable to help other casualties. The SAVe: Portable Ventilator program developed an automated "Ambu bag" usable in theatre by the combat medic that is simple to operate, safe, rugged, and inexpensive. Since last year, the SAVe ventilator has been deployed with combat medics, and is saving lives today. Because of its compact size, ease of use, and cost, a modification of the SAVe is being developed for civilian emergencies, such as pandemics.

The Compact Volume Angio Computed Tomography (COMPACT-VAC) program has been developing a digital imaging system that is both markedly reduced in weight and volume, yet able to provide higher quality CAT scan images than any system currently available. Because of its size, the COMPACT-VAC will be suitable for deployment in vehicles such as the Stryker, enabling early diagnosis of injuries, including sources of bleeding.

Restore injured warfighters to the way they were

Building on our obligation to care for our troops when they are injured entails a longer-term obligation to do the best we can to rehabilitate them. DARPA's goal is to restore them, as best we can, to who they were before they answered the call to defend our Nation.

The goal of the Restorative Injury Repair (RIR) program is to fully restore the function of complex tissue, such as muscle, nerves, and skin, after traumatic injury on the battlefield. These injuries include both kinetic (i.e., penetrating) wounds as well as other destructive injuries such as chemical and thermal burns, musculoskeletal injuries, and blast overpressure. By developing a comprehensive understanding of wounds, RIR aims to replace nature's process of "wound coverage" through fibrosis and scarring, with true "wound healing" by regenerating fully differentiated, functional tissue at the wound site.

Improvements in body armor have increased survival, but also have led to more loss-of-limb injuries. Those losing a limb may be denied the chance to return to active duty if they wish. DARPA's flagship program in this area, Revolutionizing Prosthetics, holds the promise of ensuring they have that opportunity.

Current prosthetic leg technology is good and is improving. However, prosthetic arm technology is much more challenging, since it involves so many more joints and movements as well as the combined abilities to touch, sense, and manipulate fine objects.

Many of you saw this technology demonstrated here in the Rayburn Foyer back in October.

DARPA's goal is to revolutionize upper extremity prosthetics, specifically arms and hands. Today, individuals experience such prosthetics – to the extent they can use them at all – like a *tool*, not like a limb. We are developing a prosthetic arm that can be directly controlled by the brain and be used exactly as a natural limb, providing dexterity and sensation equivalent to a natural hand or arm. In two years, full clinical trials will begin on prosthetics that have functions almost identical to natural limbs in terms of motor control and dexterity, sensory feedback, weight, and environmental resilience. These devices will be directly controlled by neural signals. Our goal is to give our military upper limb amputees the chance to return to normal life and, possibly, active duty as quickly as possible.

We are making rapid progress: the program has already developed several prototype prosthetic arms that have entered clinical trials. These devices are far more advanced than any currently available, enabling many degrees of freedom for complex grasping and individual finger movements, while being rugged and resilient in all environments.

In January of 2007, the first generation prototype arm was fitted and attached to an amputee. Within hours and with minimal training, he was able to control the arm in all seven degrees of freedom, including a powered shoulder. Today, six patients, including two ex-Service members, have accumulated hundreds of hours experience controlling and using these arms. One patient, injured in Iraq, has even demonstrated the ability to manipulate individual fingers on a five fingered hand – something never done before.

In 2008, patients at Walter Reed and Brooke Army Medical Centers will begin training for this next generation DARPA-developed prosthetics. They will use both prototype limb systems and a simulation that will use signals generated by the user's brain or peripheral nerves to move and manipulate computer models of arms when new prototypes are manufactured in the lab. This "virtual integration environment" will allow users to tailor the responsiveness and control of their prosthetic limbs to their needs and daily demands, will allow patients an environment to train and practice with virtual limbs prior to manufacture of their final prosthetic, and will ensure that all patients have access to training with the latest limb systems.

Develop core technologies that maintain U.S. military superiority

I have just described seven broad areas where DARPA, over the last seven years, has made great progress in improving our systems and operational capabilities. The progress underpinning these accomplishments, in many cases, ultimately depends on the progress we continue to make in our core technology work, an area of DARPA's research that we emphasize largely independent of any particular set of circumstances. These core technologies are the investments in fundamentally new technologies, at the component level, that historically have been the technological feedstocks that lead to new systems and significant advances in U.S. military capabilities.

Quantum Science and Technology

Until recently, quantum effects in electronic devices did not have overriding significance. However, as device sizes shrink, quantum effects can influence device performance. DARPA is sponsoring research aimed at technology that exploits quantum effects to achieve revolutionary new capabilities.

DARPA's "Slow Light" program is exploiting the quantum properties of materials to control the speed of light and slow it to a tiny fraction of its normal speed. Such tunable control will allow storing and processing of optical information. This past year, the program demonstrated that slow light materials can slow, stop, and store two-dimensional images. The ability to slow, store and switch entire images before they are projected onto film or electronic detectors could lead to intriguing methods of capturing images, and further opens the door to novel approaches for ultra-high-speed image processing.

One example of a material that exploits quantum effects is superconductors, which conduct electricity with no energy loss due to electrical resistance.

High temperature superconducting materials cannot practically be modeled using quantum mechanics – even with today's fastest supercomputers. For example, a high performance computer running a quantum mechanical Monte Carlo code to calculate a phase diagram for one million atoms would require approximately four trillion years to complete the calculation. This computational intractability means that it is fundamentally infeasible to use computer models to systematically search for and identify new and manufacturable forms of these materials.

So, drawing inspiration from scale models and wind tunnels used to investigate aircraft designs, our Optical Lattice Emulator (OLE) program will construct a scaled artificial material – an emulator – whose mathematical and physical behavior is governed by the same underlying quantum mechanics as the superconductors of interest. This emulator will use approximately 10 billion ultra-cold atoms held in a lattice formed by laser beams. Controlling the states of the atoms in the optical lattice will help us understand properties directly related to the desired behaviors of real materials.

To illustrate the power of this emulation tool, OLE techniques would solve the million-atom phase diagram problem I previously referred to in a little over 10 hours.

The bottom line is that OLE will give us, for the first time, a practical tool to search for and identify the atomic compositions of special materials like room temperature superconductors that could be practically manufactured.

Bio-Info-Micro

For the past several years, DARPA has been exploiting and developing the synergies among biology, information technology, and micro- and nanotechnology. Advances in one area often benefit the other two, and DARPA has been active in information technology and microelectronics for many years. Bringing together the science and technology from these three areas produces new insights and new capabilities.

The Fundamental Laws of Biology (FunBio) program is working to discover the fundamental laws that govern the multiple, interconnected scales of biology – from molecule to cell to organism to population – that can be used to make accurate predictions about biological processes, just as physics-based theories enable predictions about the inanimate world. One part of the program has already delivered results with enormous potential benefits for both military personnel and the general public. Two FunBio team members have developed the first exact solution of a mathematical model that accurately captures the primary mechanisms underlying the rapid rise of resistance to antibiotics. These new mathematical approaches may be used to predict the next flu pandemic, or how a drug will affect a given individual. A new mathematical framework is also needed to discover information embedded in massive biological data sets, as well as to explain the significance of variability in physiological systems, which may provide a basis for personalized medicine.

Materials

DARPA continues to maintain a robust and evolving materials program. DARPA's approach is to push new materials opportunities and discoveries that might change how the military operates. In the past, DARPA's work in materials has led to such technology revolutions as high-temperature structural materials for aircraft and aircraft engines, and the building blocks for the world's microelectronics industry. The materials work DARPA is supporting today continues this heritage.

DARPA's current work in materials includes the following areas:

- *Structural Materials and Components*: low-cost and ultra-lightweight materials designed for structures and to accomplish multiple performance objectives in a single system;
- *Functional Materials*: advanced materials for non-structural applications such as electronics, photonics, magnetics, and sensors; and
- *Smart Materials and Structures*: materials that can sense and respond to their environment.

DARPA's Prognosis program has been developing the science and technology to revolutionize the maintenance of turbine engines. The idea is to do preventative maintenance when physics predicts it is needed, rather than just on a schedule. In 2007, the Air Force and DARPA agreed to transition Prognosis technology into the legacy fleet of F100 and F110 turbine engines that power the Air Force's F-15s and F-16s.

The Oklahoma City Air Logistics Center (OC-ALC) is one of three depot maintenance facilities responsible for repairing and maintaining aircraft and weapon systems. This includes managing and maintaining a $49 billion inventory of more than 30,000 engines. OC-ALC will receive a series of Engine Systems Prognosis tools to manage the life of the F100/F110 engine fleets. The ultimate goal is to maximize engine safety and readiness, while minimizing costs.

DARPA has successfully produced amorphous metal non-skid, highly wear-resistant surface coatings for potential use in the Waterborne Mission Zone (WMZ) of the Navy's Littoral Combat Ship (LCS). The WMZ is a large compartment located in the stern of LCS that is intermittently exposed to seawater and wear and tear from loading and unloading small craft. The LCS WMZ is a challenging environment, and is an ideal testbed for demonstrating the wear/corrosion resistance and damage tolerance of DARPA's coatings.

Researchers in our Naval Advanced Amorphous Coatings (NAAC) program have devised a thermal spray technique that produces textured coatings with a high coefficient of friction and wear, impact, and corrosion resistance that is superior to any other corrosion-resistant, non-skid material. Today's corrosion protection and non-skid coatings are usually replaced every 12-24 months, interfering with ship readiness and significantly increasing maintenance expenses. If successful, NAAC's goal is to require coating replacement only during pre-scheduled, major refits of the ship.

The DARPA Titanium Initiative to produce aerospace-grade titanium at $3.50 per pound is continuing with scale-up efforts to increase capability to 500 pounds per day. This program developed a continuous chemical reduction process that extracts both pure titanium metal and titanium alloy powders from inexpensive feedstock, and a meltless production process for fabricating parts inexpensively. These were selected by *R&D Magazine* to receive a *2007 R&D 100 Award*.

Protecting our warfighters from asymmetric attacks is an ever-present challenge. Improvised explosive devices (IEDs) remain a significant threat to our forces in Iraq and Afghanistan. Our Hardwire program has developed a novel armor concept primarily to protect vehicles. Hardwire's unique composition and topology has demonstrated outstanding protection against armor piercing rounds, fragments, and IED fragmentation. Hardwire's armor weight is much lower than steel armor, meaning that we can achieve protection equivalent to conventional armor at much lower weight, or greater protection at the same weight. More recently, we have been looking at Hardwire's effectiveness in protecting against Explosively Formed Projectiles (EFPs).

Power and Energy

To Napoleon's dictum that an Army moves on its stomach, today's warfighting forces could add, "…and on energy."

Developing portable, efficient, and compact power supplies has important ramifications for increasing our military's reach, while at the same time decreasing material logistic requirements.

One of our flagship programs here is the Very High Efficiency Solar Cell program, aimed at developing photovoltaic modules with efficiencies exceeding 50 percent. The program has a novel design architecture that integrates previously incompatible materials technologies to maximize performance across the solar spectrum. The optical system and key device elements have already achieved record efficiencies – a huge step towards our goal. Early evaluation of the integration of this technology with military battery packs has been very positive. The ultimate objective of an affordable, mass-produced, 50 percent efficient solar module appears well within reach. This will dramatically reduce the battery load on soldiers and on the logistics pipeline. In addition, within a few years of the commercialization of these technologies, the design and manufacturing technology breakthroughs coming from this program will be driving high efficiency module costs to $1 per watt and below.

To help reduce the military's reliance on petroleum-based fuels to power their aircraft, ground vehicles, and ships, DARPA's BioFuels program is working to develop an affordable surrogate for military jet fuel (JP8) derived from oil-rich crops such as rapeseed, other plants, algae, fungi, and bacteria. Initial efforts in the BioFuels program have already delivered BioFuel samples that have passed the key JP8 initial qualification tests – these are BioFuels whose performance is indistinguishable from petroleum-based JP8. The BioFuels program is expanding the development of processes for cellulosic and algal feedstocks with the ultimate objective of providing for an affordable, significant, and diverse supply of military jet fuel.

Power sources limit the size and weight of many electronics and sensing technologies used by our military today. DARPA's Micro Power Sources (MPS) program is working to develop extremely small batteries to remove the "volume bottleneck" in the design of these systems. To-date, DARPA-funded researchers have used a laser micromachining process and enhanced electrochemistry to produce a microbattery that has the energy density of a standard lithium-ion battery, with the goal of achieving 1/100th of its size. The ultimate goal of the MPS program is to produce a battery with a volume less than one cubic millimeter. This is 1/1000th the size of batteries in, for example, today's cell phones – and with comparable energy density (350 watt-hour/liter). Battery size reductions of this magnitude will enable an entirely new generation of ultra-small sensors and actuators for a wide range of military applications, including ultra-small autonomous vehicles.

DARPA's Robust Portable Power program is continuing to develop advanced, ruggedized fuel cells for several military applications. Soldier power applications in the 20-50 watt range include laser designators, mine sweepers, chemical detectors, heavy thermal weapons sights, radios, and toughbooks. Fuel cell applications in the 150 watt range include providing power for robots and unmanned air vehicles.

Microsystems

DARPA is shrinking ever-more-complex systems into chip-scale packages, integrating microelectronics, photonics, and microelectromechanical systems (MEMS) into "systems-on-a-chip" that have new capabilities. It is at the intersection of these three core hardware technologies of the information age that some of the greatest challenges and opportunities for the

DoD arise. The model for this integration is the spectacular reduction in transistor circuit size under Moore's Law. Electronics that once occupied entire racks now fit onto a single chip containing millions of transistors. Being smaller helps these devices to operate at radio frequencies.

Recently, the 3-Dimensional-Integrated Circuits (3D IC) program has demonstrated a 3-dimensional via[2] technology, enabling a significant performance boost for silicon radio frequency (RF) devices. The initial application of this technology is for silicon-germanium bipolar complementary metal oxide semiconductor wireless communication chips for power amplifiers used in wireless systems. Future enhancements to this process will provide powerful 3-D integration technology for enhancing state of the art silicon RF technology.

In addition, programs exploiting the very high-speed properties of compound semiconductors demonstrated power efficient and highly linear low-noise RF amplifiers, which are crucial components for next generation radar, communications, and electronic warfare systems. The Feedback Linearized Amplifier for Radio Frequency Electronics program recently demonstrated the world's first microwave operational amplifier with the highest linearity figure of merit ever reported for any low noise amplifier. At two gigahertz, a record linearity figure of merit was achieved – roughly four times higher than that of any low-noise RF amplifier in use today.

Another important application of compound semiconductor materials is imaging and communication in the terahertz region. The Sub-millimeter Wave Imaging Focal-plane Technology program is pushing the high-frequency performance limits of radio frequency microelectronics. Over the past year, the program fabricated the first transistor that can supply greater than unity power gain at a frequency of at least 1.0 terahertz.

The Scalable Millimeter Wave Architectures for Reconfigurable Transceivers program has demonstrated the most complex millimeter-wave radio frequency integrated circuit ever developed: a highly integrated, Q-band (35-55 GHz) 16-channel receive-side beamformer-on-a-chip. This chip, which contains about 1200 radio frequency transistors, integrates all the required beamforming elements for an electronically steered phased array antenna onto a single

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[2] A via is a small opening in an insulating oxide layer that provide electrical interconnections between layers of integrated circuits

silicon die with a 3.2 x 2.6 square millimeter area. This compact beamforming chip will enable a breakthrough in size, weight, performance and cost in next-generation phased arrays for millimeter-wave military sensor and communication systems.

The 3-Dimensional Micro Electromagnetic Radio Frequency Systems (3-D MERFS) program seeks to revolutionize the performance, cost, and form factor of military communication and radar systems by, for the first time, creating a low-cost high-performance printed-circuit board technology for RF and millimeter wave systems. To replace current micro-strip or stripline waveguide technologies, the 3-D MERFS program has developed the first new waveguide structure in more than a generation – a three-dimensional, lithographically printed rectangular coaxial waveguide. This waveguide out-performs even expensive structures like microstrip on gallium arsenide, with seven times less loss, and 10,000 times better isolation. More importantly, the technology allows fabrication of complex systems with minimal touch labor, decreasing cost and increasing system reliability.

Information Technology

Information technology, which supports a broad set of opportunities to improve our military capabilities, is a core technology that DARPA has supported for decades.

A key area in information technology is embedded systems: computing systems that are built into a platform or system, that help direct or manage it and make it more intelligent and capable in performing such operations as flight control, targeting, sensor performance, onboard data analysis and management, and electronic countermeasures. Embedded computing is critical across a broad range of military applications, such as handheld devices used in the field, intelligent weapon systems, autonomous platforms, and airborne information and command centers.

Current DoD embedded computing systems are typically point-solutions, tailored to a specific, static, and inflexible set of mission requirements. This approach leads to one-of-a-kind systems that are inflexible in purpose, costly to develop, and unable or extremely expensive to adapt to changing requirements.

DARPA has recently been pursuing technologies to overcome these limitations in the Polymorphous Computing Architectures (PCA) program. PCA has created a class of innovative, flexible, high performance single-chip processing architectures that can be optimized to efficiently implement a broad set of DoD applications and adapt to changing missions, sensor configurations, and operational constraints during a mission or over the life of a platform. The architectures are based on replacing many processing types/configurations with a single reconfigurable processing architecture. Rather than requirements having to adapt to existing processors, PCA architectures can be optimized to the application.

PCA is only one part of DARPA's pursuit of advanced and enabling processing architectures. Earlier I discussed our HPCS program, which we hope will come to fruition in the next few years. But DARPA is already looking beyond HPCS, and is laying the foundation for the next set of investments to dramatically improve processing capabilities.

Our ExaScale program is pursuing concepts that include self-aware processing to enable systems that know their state and react to self-optimize their performance; integrated processing core developments to provide optimized performance and advance processing capabilities at multiple levels – embedded, departmental, and high performance computing centers; architectural concepts to revolutionize how we think of memory versus logic; rapid turn-around, high-performance customizable processing approaches; compiler environments to enable the effective and efficient use of complex processing systems for DoD applications; and techniques to recover, maintain, and redeploy the considerable investment in critical existing application codes.

As I mentioned last year, DARPA also has some programs to generate exciting new ideas in computer science and attract students to the subject.

Our Computer Science Study Group (CSSG) program educates a select group of extremely talented early-career academic computer scientists on DoD's needs, and then asks them to use the knowledge they've gained to propose ideas for basic research relevant to DoD. The program plans a multi-phase cycle for each class of about 12 participants. In the first phase, the participants obtain a Secret clearance and are familiarized with DoD and its challenges through group visits to DoD's labs, bases, defense contractors, and operational settings. The visits occur during four week-long trips during the first year. In the second phase, the participants' ideas are competed, and the best proposals may be awarded up to $500,000 to conduct basic research of interest to DoD. In the third phase, the participants may be awarded an additional $250,000 for their research, provided they find matching funds from another source.

We have now selected three classes for CSSG, with the first two classes delving further into their research projects. As an example, one of the research projects will look at novel ways to network wireless imaging systems and other wireless sensors, emphasizing change detection. This has obvious counterterrorism applications. Another example is a novel way of using algorithms and sampling to detect similarities in data and exploit those similarities to minimize existing bottlenecks and inefficiencies in network data transfer. A third project initiated development of a secure, coherent software methodology for information-sharing for both cross-domain and intra-domain communication applications.

Our Computer Science Futures program is aimed at attracting and cultivating talent for computer science, in this case linking up world-class computer science researchers with interested high school students. Here we ask a panel of young computer science professors to propose "Grand Challenges" for computer science – problems that are important, hard, and exciting to tackle. The professors then brief their ideas to high school students, and the students are asked which of the challenges are exciting enough to draw them to study computer science.

In the first year, the students ranked three challenges as most interesting, led by the Programmable Matter Challenge, which seeks to use programming to direct mobile units to form dynamic three-dimensional objects. The students were also interested in merging computer science with other fields and using computer science to enhance safety. The second year yielded six challenges that were again presented to high school students. One of the ideas that the students liked this time around was the Computational Biology Challenge. The goal, which is of significant relevance to DoD, is to develop computational models of embryological development that can be used to understand why life adapts well to certain environmental changes. The models are relevant to understanding why some types of computer networks are vulnerable to attacks and failures, while others are resistant.

Mathematics

Our current mathematical themes include topological and geometric methods, inverse methods, multiresolution analysis, representations, and computation that are applied to design and control complex systems, extract knowledge from data, forecast and assess risk, develop algorithms, and perform efficient computations. These techniques underlie key Defense applications such as signal and image processing, and aid in understanding biology, materials, sensing, and design of complex systems.

For example, DARPA's Topological Data Analysis (TDA) program uses novel mathematical concepts and techniques to develop algorithms that identify and extract hidden geometric properties of massive data sets. These algorithms will result in new, ultrafast, user-friendly software tools.

Recent program results include key insights in such diverse fields as images, material science, cancer biology, virus evolution and medical diagnostics. Distinguishing high-dimensional patterns in the statistics of natural images is leading to the development of a novel, non-linear, compression scheme that will revolutionize the way that images are analyzed. Similarly, TDA methods will transform the way that doctors triage patients, through construction of non-linear, non-invasive medical statistics to assess patients in intensive and critical care situations.

Another DARPA mathematics program, Sensor Topology for Minimal Planning (SToMP), leverages high-dimensional mathematical insights from topology and geometry to create new DoD capabilities in network and sensing problems. The program creates mathematical innovations to extract an overall picture from local information in distributed and coordinated sensing platforms. Recent SToMP results on sensor coverage and tracking issues are revolutionizing how networked sensors and autonomous sensor agents are analyzed, distributed, and controlled.

Manufacturing Science and Technology

The DoD requires a continuous supply of critical, defense-specific materiel and systems. To ensure reliable, robust, and cost-effective access to these items, manufacturing technologies that can meet DoD's needs must be available within our industrial base.

DARPA's Disruptive Manufacturing Technologies (DMT) program is developing manufacturing technologies and processes to provide significant and pervasive cost savings for multiple platforms or systems, and/or decreases in manufacturing cycle time for components for existing and future military procurements.

In this program, we are piloting new manufacturing process initiatives in microwave electronics, adaptive software development, and advanced materials. We are focusing on producing microwave amplifiers for electronic and information warfare, radar, and communication systems; designing and producing adaptive software-intensive systems; and revolutionary new, faster, and lower-cost methods for producing polymer matrix composites for aerospace components, superalloy high-strength blades that power aircraft turbine engines, and boron carbide inserts for body armor.

For example, DMT will leverage 3-D MERFS technology (described earlier in the *Microsystems* section) to increase power handling capability and ease the integration of 3-D MERFS structures with other components. The goal is to replace traveling wave tube amplifier (TWTA) systems used by aircraft towed-array-decoy systems with solid-state devices that cost ten times less. If successful, the program will result in more than $150M savings for planned TWTA procurements alone.

More importantly, however, the intimate integration enabled by the DMT program promises to break through the cost barrier that has kept many radar and communication systems so expensive. Many such systems are limited by the cost of monolithic microwave integrated circuit (MMIC) components. These components are fabricated on novel and expensive substrates, typically at very low yield. The DMT program will enable the majority of components to be removed from the MMICs and placed in higher performing 3-D MERFS substrates. This will decrease the amount of expensive substrates required by several orders of magnitude, as well as dramatically increase yields, resulting in higher performance systems at significantly lower cost.

Lasers

Lasers have multiple military uses, from sensing to communication to electronic warfare to target designation. Since the technology was first demonstrated, the DoD has maintained a steady interest in High-Energy Laser Systems (HELS) for a wide range of speed-of-light weapon applications. Starting in the early 1960s, DARPA has been involved in lasers and laser technology development for the DoD, and continues its work today in this crucial area.

The High Energy Liquid Laser Area Defense System (HELLADS) program offers dramatically reduced size and weight so that the system can be mounted on a variety of platforms for self-protection. HELLADS is developing a high-energy laser weapon system (approximately 150 kilowatts) with an order-of-magnitude reduction in weight compared to existing laser systems. With a weight goal of less than five kilograms per kilowatt, HELLADS allows for new and innovative capabilities, such as use on tactical aircraft systems for effective self-defense against even the most advanced surface-to-air missiles.

Last year, the program demonstrated 15 kilowatts of multimode laser output power. The current focus is on completing the development of a unit cell laser module that will scale directly to 150 kilowatts and on the weaponization of a solid-state laser. HELLADS has already developed a laser that overcomes the fundamental limitations of solid-state lasers. The program now offers the opportunity to greatly accelerate the fielding of a small-size, low-weight tactical laser weapon that will transform operations and provide a tremendous advantage to U.S. forces.

DARPA has also been working to improve the performance of components used in high-energy laser systems. Over the past year, the Super High Efficiency Diode Sources (SHEDS) program has succeeded in improving the efficiency of diode lasers intended for use in HELS pumping sources by nearly a factor of 1.5, from 50 percent to 72 percent, with a corresponding 50 percent decrease in the waste heat. In addition, the efficiency of the vertical cavity surface emitting diode laser array has increased from 18 percent to the current record of 51 percent, and the power intensity is double that of standard edge-emitters. These advances should enable dramatic reductions in the size and weight of HELS and the development of portable HELS platforms.

Military applications of high-power lasers also require precise steering of tightly focused optical beams. The Adaptive Photonic Phased Locked Elements (APPLE) program is developing a revolutionary optical phased array technology that coherently combines an array of fiber lasers with all-electronic beam steering. For aircraft-mounted HELS, this approach should simultaneously reduce atmospheric effects and scale to weapons-grade power levels. For high-power applications, 100 sub-apertures, each driven with kilowatt-class fiber lasers, can all be directed to the same small spot on a distant target.

In closing, DARPA's progress over the past seven years in the eight areas has been impressive, and would not have been possible without the tremendous support we've received from Congress. As DARPA celebrates its 50th anniversary this year, I can report that, with Congress' continued support, DARPA is positioned to provide even more important capabilities that will benefit our Nation and Armed Forces.

DARPA was created out of the shock of Sputnik, and it is clear that the overall strategic situation of the United States is quite different than it was 50 years ago. Nevertheless, the need for DARPA's mission – to prevent the technological surprise of the United States and create it for our adversaries by keeping our military on the technological cutting edge – remains.