Statement by

Frank Fernandez

Director
Defense Advanced Research Projects Agency

Before the

Subcommittee on Emerging Threats and Capabilities
Committee on Armed Services
United States Senate

March 21, 2000

TABLE OF CONTENTS

Mr. Chairman, Subcommittee Members and staff: I am very pleased to appear before you today to discuss my management priorities and investment strategy, and to highlight a selection of DARPA's FY 2001 programs.

DARPA GOALS

In today's world, change has become the norm, not the exception. The threats facing the U.S. are much different than those of the Cold War. We are faced, not with a peer competitor who is well known and well understood, but, instead, with adversaries whose location and capabilities are highly variable. As a result, our forces are being called to fight in places where the terrain and the pre-existing infrastructure vary greatly. Our forces must interoperate and coordinate with an ever-changing mix of allied and coalition forces. And they must be prepared to perform a wide spectrum of missions – from peacekeeping and humanitarian activities to full-scale, traditional warfare, with the resulting rapidly shifting rules of engagement.

Coupled with the changes facing the U.S. military are the added challenges of today's multinational and globally intertwined economies. "U.S." companies may now be wholly or partly owned by foreign investors, and they may have significant foreign operations, even when totally U.S.-owned. In addition, many technologies simply are widely known and are widely used, no matter who developed or owned them. Therefore, the technologies critical to the U.S. for new weapons systems have become increasingly available in the global marketplace and thus are accessible to our potential adversaries as well.

Lastly, all of this is taking place at a time when the resources available to the Defense Department must cover both current and future needs and balance the Department's central priorities – people, readiness, and modernization. The affordability of our weapons systems and enabling technologies is therefore a key issue. Warfighters no longer desire increased performance if it comes at a considerably increased cost. Technology developers must, instead, offer technologies that can actually lower costs while increasing performance, or, at a minimum, offer increased capabilities at a cost that is competitive with current systems.

Given this changing environment, DoD needs the talents of a "change leader," i.e., an organization that can be the agent of change by moving quickly and flexibly to adapt to a changing world. I view this as a natural role for DARPA.

My vision is to make DARPA the technical enabler for innovation for the DoD.

DARPA STRATEGIC PLAN

To achieve this goal, I have started a process to develop and periodically evaluate or modify a strategic plan for DARPA. The strategic plan must maintain the flexible, adaptable, opportunity-driven, bottoms-up approach to creating programs that distinguishes DARPA from other DoD research and development activities, and at the same time provide for the eventual transition of DARPA-developed technologies to the warfighter.

In developing this plan, I consult with my senior management and my Office Directors, and evaluate recommendations from outside experts such as the Defense Science Board, the Unified Commanders and security agencies, the National Academy of Sciences, and the Office of Science and Technology Policy.

As a result of this process, I have determined that DARPA's strategy must consist of two different, but related parts: a strategy for allocating investments and a strategy for ensuring that these investments are properly managed.

DARPA's Investment Strategy proceeds along three parallel tracks. Although the technologies used in these tracks are often related, the focus for each track is quite different:

- First, we will help the DoD find technical solutions to national-level problems. My current priority is on problems that may impact our national survival.

- Second, we will be the technical enabler for the revolutionary innovation required for our warfighters to achieve dominance across the range of military operations – Operational Dominance.
- Third, we will continue to develop and exploit high-risk, high-payoff technologies that are critical to our Nation's defense.

I will shortly discuss the particular focus areas that populate these three tracks. First, however, I will discuss a second aspect of my strategic plan, the establishment of my *Management Priorities*.

As I mentioned last year, my management priorities are: to attract top-quality people; to foster an atmosphere of healthy competition for top performers; to reach outside the normal DoD industrial base for ideas; and to work with the Services and the Unified Commands to use experimentation as a vehicle to provide the iteration between operational concept and technology development that I feel is necessary to achieve revolutionary innovation in warfighting.

My top priority is to attract excellent people to DARPA. As you may know, our sources for staff includes industry, the military, academic institutions and non-profit organizations such as Federally Funded Research and Development Centers, and Federal government organizations. Recruiting from the government sector is straightforward, and recruiting from academia and non-profit organizations works quite well through the Intergovernmental Personnel Act.

However, attracting top-notch military officers remains a problem because DARPA assignments do not represent Joint billets. The Defense Science Board Task Force Report on the Investment Strategy for the Defense Advanced Research Projects Agency noted, "DARPA should be assigned a number of joint billets to attract the very best military officers as Program Managers." I am happy to report that my staff is working closely with the Joint Staff to determine how we might implement this recommendation.

In recruiting from industry, we have had significant success using the Section 1101, Experimental Personnel Management Authority you provided DARPA in 1998. I have been able to hire 10 new managers. All have advanced degrees and previously held senior positions in private sector companies of various sizes, in defense and non-defense industries. For example, three were Vice Presidents or Chief Scientists and one was President and Chief Executive Officer. Two were from commercial companies, six from small to mid-sized defense contractors, and two from major defense contractors. In addition, the Experimental Personnel Management Program has allowed us to drastically reduce our time to hire new employees. It is taking us between 21 and 47 days between offer acceptance and reporting date for these new employees. Prior to the experimental program, it took us between four and 10 months to hire employees without prior government service. If we continue to use this authority to hire employees for four-year terms, we will have hired the law's quota of 20 employees by the end of this year.

All in all, together with the Intergovernmental Personnel Act, this experimental program has significantly improved my ability to hire talented managers at DARPA.

I spoke to you last year about my efforts to reach out to the commercial sector, to ensure that DoD is aware of external trends and how they may impact national security. We have identified some of the key industry sectors of interest. These are industries where DoD is not a majority customer and therefore has limited insight into the industries' future trends. DARPA now hosts periodic meetings at which senior DARPA and DoD officials can informally discuss these issues with key industry leaders. Other reach-out efforts include our annual DARPATech conference, during which we brief industry about new DARPA programs, and a robust web site that discusses ongoing programs.

My efforts to increase DARPA's involvement in DoD's experimentation activities have also born fruit.

DARPA and the Air Force have agreed to continue the productive collaboration between operators and technical personnel that developed during the course of Operation Allied Force. We are partnering for on-going, iterative, focused experimentation at Nellis Air Force Base, NV. The experimentation efforts will focus on mobile targets and seek innovative ways to locate and destroy mobile targets in the open, moving mobile targets and emitters, and mobile targets that are concealed in terrain. DARPA will provide technologists and new technologies while the Air Force provides platforms and tacticians to test new tactics, techniques, procedures and concepts of operations. The Air Force is building a new Dynamic Battle Control Center at Nellis Air Force Base that will be an integral part of the experimentation effort.

This year, the DARPA/Air Force experimentation activity includes a JSTARS/Predator cross-cueing initiative to quickly locate and designate multiple mobile targets, and an assessment of current battle management processes and technologies for rapid reaction targeting. Beginning next year and through FY 2002, the experimentation effort will focus on precision, all-weather target engagement by networking existing Air Force platforms. DARPA programs involved include Affordable Moving Surface Target Engagement, Advanced Tactical Targeting Technology, and Foliage Penetration Radar. As part of the experimentation partnership, DARPA and Air Force leadership will work together to find transition paths for the operational concepts and technologies that prove to be the most valuable.

DARPA technologies are also assisting the experimentation activities of the United States Joint Forces Command (JFCOM), which has been designated the executive agent for Joint Warfighting Experimentation. DARPA, JFCOM and the Institute for Defense Analyses Joint Advanced Warfighting Program conducted an exemplar experiment in FY 1999 that used DARPA's Synthetic Theater of War (STOW) Advanced Concept Technology Demonstration simulation prototype to examine joint attack operations in 2015. JFCOM's FY 2000 experiment will look at the capability of a critical mobile target cell to conduct attack operations in 2007, and the STOW simulation will once again be used. In addition to these JFCOM experiments, the DARPA-developed STOW prototype simulation is the lead simulation for the Navy's Fleet Battle Experiments, and the Army has recently expressed interest in using it for their joint experiment in September 2000.

I am contemplating additional joint experimentation interactions, perhaps, for example in the area of a scalability analysis and information security risk assessment of technologies developed under our Advanced Logistics Project.

Moving now to my *Investment Strategy*, we invest in three parallel tracks as I told you earlier. These tracks include the following major program focus areas:

- <u>Solving National-Level Problems</u>. This area includes programs to provide Biological Warfare Defense and Information Assurance and Survivability.
- <u>Enabling Operational Dominance</u>. This area includes technologies and systems to enable affordable, precision, moving target kill for both offensive and defensive missions. We are also developing technologies and systems to provide dynamic command and control capabilities to our commanders, such as the mobile, wireless, ad hoc networks necessary for information superiority and tools to plan and replan in near-real-time. Lastly, we are investing in technologies and systems that will enable future warfare concepts for air, space, land and sea. This includes the ability to correctly characterize hard and deeply buried targets and warfare using the combined capabilities of manned and unmanned systems.
- <u>High-Risk, High-Payoff Technology Development and Exploitation</u>. This area includes investments in information technology, microsystems technologies, advanced materials, advanced lithography, and MEMS. It is the results of these investments that allow us to build the systems and capabilities for operational dominance in the future.

The majority of our investment resources are devoted to the last two areas, Enabling Operational Dominance and High-Risk, High-Payoff Technology Development and Exploitation. DARPA's smaller investment in Biological Warfare Defense and Information Assurance and Survivability is intended to provide the DoD an ability to leverage other investments being made in the commercial marketplace and by other Government agencies in these nationally critical areas.

Let me first address High-Risk, High-Payoff Technology Development and Exploitation in greater detail. It is often very easy to see the necessity for science and technology investments for biological warfare defense, information assurance and survivability, and future warfare capabilities. The need for fundamental technology explorations is sometimes less clear.

The traditional example used is that of packet-switching technologies. DARPA started investing in packet-switched networks in the late 1970s, because experts believed that computer networking using this technology would be useful to the military. It wasn't until at least 15 to 20 years later that the benefits of this investment became clear.

A more recent example of this type of revolutionary technology investment is micro-electromechanical systems, or MEMS. In the 1990s, DARPA continued its tradition of providing seminal funding for potentially revolutionary technologies with our investment in MEMS technologies. MEMS are micron-scale electrical and mechanical devices that integrate sensing and actuation functions with traditional microelectronics-based processing and control systems.

In 1992, there was little industry involvement and virtually no MEMS fabrication infrastructure anywhere in the world. DARPA's MEMS investments have generated that infrastructure. Today, scientists in the U.S. military have access to MEMS fabrication processes, and the fabrication capability of U.S. companies is robust and growing.

We are already starting to see the revolutionary capabilities offered by MEMS as they replace larger, more costly subsystems in Defense systems. One important example is MEMS-based phase shifters that will radically reduce the cost of air-defense seekers and fire-control radars. MEMS phase shifters also use less power and have lower loss than any other technology available. They enable electronically scanned array (ESA) antennas for radar and missile seekers at a cost that is five to 10 times less than current ESAs. These low-cost ESAs allow the elimination of the seeker gimbal in missiles, and the use of electronic agility in large arrays will finally become affordable. Another interesting application are pico-satellites, which are using MEMS radio-frequency switches to demonstrate the feasibility of low-cost, launch-on-demand, space-qualified, cooperative constellations for space-based communications, remote sensing, and satellite inspection. Other examples of the pervasive impact we are starting to see with MEMS technology include:

- Imaging sensors with associated processing for unmanned aerial vehicles;
- Instrumentation on Patriot missile containers to verify the health of the weapon, including a cellular telephone link that is activated when a fault is detected;
- Pressure/temperature sensors in tires for aircraft and tank carriers; and
- Devices for securely safing and arming torpedoes, projectiles, grenades, and missiles.

DARPA believes that more capabilities are to come, as we not only integrate sensing, computing, actuating, controlling, and communicating, but add power-generation and energy-conversion to make possible sensors of unprecedented mission-duration without the weight and volume penalties imposed by batteries. Once we demonstrate the integration of these MEMS components into microsystems, DARPA's investments will decrease as industry and the U.S. military begin to pick up the technology and fund its continued development for their purposes. In the coming decade, we can expect to see more and more use of MEMS by defense contractors as they propose new capabilities to the military acquisition community.

MEMS technologies are also moving into the world of fluid transport and manipulation at the micro-level. Using MEMS-based microfluidic technologies, we can develop programmable, chip-scale devices that perform hundreds of fluid-based processing sequences for chemical and biological analysis and synthesis. The electronics analogy is microprocessors for large-scale calculations. Microfluidics technologies enables future military systems such as:

- Portable systems for warfighters that can automate the detection of multiple chemical and biological hazards while reducing the time to detect hazards and the chances of false alarms;
- Micro-chemical-reactors that can safely produce hazardous chemicals in small quantities in locations where the chemicals can be delivered immediately without added transportation hazards; and
- Precision metering, analysis and dispensing of biomedical and biological fluids to allow the reconstitution and administration of drugs in the field.

Two other examples of fundamental technology exploration that also offer the potential for revolutionary Defense capabilities are maskless lithography and Beyond Silicon. Maskless lithography, an area of continuing DARPA investment, will revolutionize the way silicon-based integrated circuits are manufactured. And Beyond Silicon is even further-term. This program will investigate approaches to electronic device design that extend beyond today’s scaling of traditional complementary metal-oxide semiconductor (CMOS) devices. This includes the use of organic and amorphous materials and components and systems that leverage quantum effects. This is the first year of DARPA investment in Beyond Silicon. And, while we cannot predict when we might see tangible returns, we believe its long-range potential to be extremely high for developing low-cost-to-manufacture, reliable, fast, and secure information systems critical to meet future military needs.

In the area of Enabling Operational Dominance, DARPA technologies tend to reach the warfighter more quickly. And, during a time of extreme operational need, DARPA is capable of very quick reaction programs.

The High Altitude Endurance Unmanned Aerial Vehicle Advanced Concept Technology Demonstration (ACTD) is an example of a DARPA program that has transitioned to a military Service. This ACTD was a joint, DARPA-led effort to develop and demonstrate an advanced reconnaissance system comprised of two complementary air platforms, Global Hawk and DarkStar, and a common mission ground control station. Global Hawk was optimized for payload, range and endurance; DarkStar incorporated low observable technologies and was intended to be a special purpose aircraft for use in a high-threat environment. The ACTD began in 1994, and, under DARPA’s leadership, progressed through initial flight-testing. In September 1998, the program transitioned to the Air Force, which chose the Global Hawk as the single high altitude endurance platform for operational demonstration, user evaluation and a determination regarding possible procurement. Global Hawk is now undergoing its military utility assessment.

Another example of a DARPA technology now in the hands of the warfighter is our HUMRAAM program. The HUMRAAM program integrated five Advanced Medium Range Air-to-Air Missiles (AMRAAMs) with launchers onto a High Mobility Multipurpose Wheeled Vehicle. Taking only 14 months from idea to field-test, a DARPA-developed prototype HUMRAAM system demonstrated over-the-horizon engagement of multiple, in-bound cruise missiles. Last year, following these demonstrations, DARPA delivered two prototype HUMRAAM systems to the Marine Corps Systems Command. The Marine Corps is now including HUMRAAM in the Marine Corps Complementary Low Altitude Weapon System, which is entering Engineering and Manufacturing Development at the end of this year.

As I mentioned, DARPA also is capable of using science and technology investments to provide very quick-reaction support to the warfighter. During Kosovo operations (Operation Allied Force), DARPA developed and delivered technologies in only five weeks that allowed the Air Force to use the Predator unmanned aerial vehicle as a targeting system. The DARPA project, Targeting by Image Georegistration (TIGER), was initiated in response to an urgent request from the Air Force in April 1999. Based on research being conducted under the auspices of DARPA's Warfighter Visualization project, TIGER became operational on an accelerated timescale and provided a semi-automated tool that displayed geocoordinates of aimpoints that had been observed in Predator video imagery. The TIGER system proved particularly valuable against semi-mobile targets that were difficult to locate and designate.

I have appended additional examples of how science and technology investments of recent years are now providing or will soon provide needed new capabilities for our warfighters (see Appendix A).

I would now like to describe some of the programs that comprise my three thrust areas. To refresh your memory, these three areas are:

- Finding technical solutions to national-level problems;
- Enabling operational dominance; and
- Developing and exploiting high-risk, high-payoff technologies.

TECHNICAL SOLUTIONS TO NATIONAL-LEVEL PROBLEMS

Let me begin by highlighting technical solutions to national-level problems.

PROTECTION FROM BIOLOGICAL WARFARE ATTACK

A clear and growing national security need is protection from biological warfare attack. In addition to being prepared for the potential use of biological agents in warfare, the U.S. must also be concerned about bio-terrorism against U.S. assets both at home and abroad. DARPA has constructed its Biological Warfare Defense program with the goal of developing and demonstrating technologies to thwart the use of biological warfare agents by both military and terrorist opponents. Our efforts, undertaken in close coordination with numerous organizations both within and outside the Department of Defense, are focused primarily on developing innovative, broad-spectrum approaches that can be used to defend against current known threats and potential future threats. Our approach is particularly challenging in that we require our researchers to conduct testing using live pathogenic agents before we declare success.

DARPA's Biological Warfare Defense program has six main thrusts: therapeutic countermeasures, advanced sensors, advanced diagnostics, consequence management tools, air and water purification devices and genetic sequencing of potential biological threat agents.

The **Unconventional Pathogen Countermeasures** program is investigating a wide range of therapeutic countermeasures. These include the development of multi-agent immunizations to be used prior to exposure, ways to develop new immunizations more rapidly, and medical therapeutics against toxins, bacteria and viruses to be used after exposure. In addition, DARPA is exploring ways to disarm pathogens by modulating the body's response to a pathogen so that the pathogen becomes less virulent. The program has had some promising results to-date.

Last year, in the area of decontamination, I mentioned that we had tested a lipid emulsion with good results against a variety of bacteria, including anthrax spores. Unlike bleach (the current decontamination method of choice), the emulsion is non-corrosive and non-toxic. This emulsion was recently tested in a field trial at Dugway Proving Ground, where it was the top performer in a competitive evaluation. It effectively decontaminated a variety of "real" surfaces – paint, cement, carpet, etc. – that had been seeded with spores of Bacillus globigii, an anthrax simulant.

Another DARPA researcher has developed a peptide – a small fragment of a protein – that can protect against Staph enterotoxins and a number of other related bacterial toxins. This peptide both protected mice against a lethal challenge with Staph enterotoxin B (SEB) and reversed the course of the disease. Prior to these tests, there was no known pre- or post-exposure treatment for lethal doses of SEB or other toxic shock-inducing toxins. The researcher will now test this peptide in other animal trials that closely mimic human disease. Other researchers are creating a powerful new class of antibiotics that prevent bacteria from expressing genes necessary for the bacteria to start the infection process.

We are continuing to support these innovative approaches and, in many cases, initiating tests against live agents as planned. We are expanding our efforts in current technical areas as well as soliciting additional unique ideas and approaches. We continue to attempt to interest scientists, researchers and companies that do not normally work for the military, but who may have unique ideas that can help the U.S. respond to the threat of bio-terrorism.

In order to detect the presence of a threat agent, DARPA is investing in the development of advanced **Bio Sensors** that are robust, can operate autonomously, in real-time, and with extreme sensitivity to multiple agents – while being small, low-cost, and generating very few false positive and false negative alarms. One project is looking to improve antibody-based sensors, which are common but suffer from high false-alarm rates. That is because antibodies that target anthrax spores also react to vegetative cells and/or other bacillus spores commonly found in the environment, causing the false alarms. The Bio Sensors program has developed several new antibodies that are highly specific to anthrax spores with an extremely low likelihood of reacting to vegetative cells or other spores. This greatly increased specificity will result in bio sensors with far fewer false alarms. In another effort, we are now conducting tests of the miniaturized mass spectrometer against biological agent simulants at Dugway

Proving Ground. Ongoing work to develop a biochip to identify a variety of bacterial agents using ribosomal RNA has shown great promise, and continues to progress rapidly both for the DoD and for commercial applications.

A portion of our sensor program is aimed at using cells or pieces of tissue to identify a chemical or biological threat agent and to determine the threat's viability and how it causes harm. This will provide key information on the human health risks associated with exposure. Researchers have already made some key advances. This year, they have demonstrated dramatic improvements in the stability of cells used in these sensors by genetically engineering cells to increase their resistance to drying for storage. The program is continuing to design and test cell and tissue systems that reliably report on viral and bacterial exposures and to investigate key sensor features that provide minimal false positives while maximizing signal strength.

In the event of a biological attack, we will need to identify those who have been exposed and to distinguish them from the "worried well," as well as from those with natural diseases that might require different treatment. Therefore, identifying disease markers that could serve as rapid indicators of exposure is one of the focus areas of the DARPA **Advanced Medical Diagnostics** program. One group at Stanford University is testing human cell cultures exposed to a variety of infectious disease agents, as well as to other stimuli for comparison, and have identified a number of human genes that are selectively turned on or off in response to infection. Armed with this information, they will next test for these markers in clinical settings, such as hospital patients. Another group is identifying (in model systems) the critical genes found after exposure to such agents as anthrax, Staph enterotoxin, plague and others. They have already identified some genes that are expressed in all the infections they have investigated and others that are selectively expressed in only certain infections. We still have much to learn, of course, but this is encouraging progress, and we look forward to a greatly increased understanding of the key host responses.

DARPA's **Consequence Management** program has developed, demonstrated and transitioned spreadsheet-like computerized tools for consequence management that can be constructed and tailored by the local responders. DARPA's Enhanced Consequence Management Planning and Support System (ENCOMPASS) was used successfully during the highly successful Joint Expeditionary Forces Exercise to demonstrate detection of five biowar agents via surveillance of medical record data. In collaboration with the Centers for Disease Control, ENCOMPASS was used during the recent World Trade Organization meeting in Seattle Washington. In just under two weeks, tools used by the Air Force were modified and deployed to provide surveillance at eight Seattle hospitals. Over 10,000 hospital emergency department records were collected and a case of infectious meningitis was identified by the system and confirmed by local physicians. The Air Force is using ENCOMPASS as the central element in their Global Expeditionary Medical System, which has been deployed to support operations in Cameroon, Germany and El Salvador. It will be deployed to replace an aging system that provides surveillance for all Air Force personnel deployed to South West Asia. Langley Air Force Base is testing ENCOMPASS to support on-base biological warfare defense and large-scale disaster-incident management. The Air Force plans full operational deployment. DARPA is also working with the Joint Forces Command and Joint Task Force–Civil Support to provide ENCOMPASS components to support domestic response missions.

Clean air and water are crucial to the ability of our military Services to continue operating in the event of a biological and chemical warfare attack. To-date, our program in **Air and Water Purification** has demonstrated a number of excellent results. For example, the pen-sized individual water purification system that I showed you last year, which creates mixed oxidants to kill waterborne pathogens, is now being field-tested by the Marine Corps. The program has also developed a prototype man-portable water system that can both purify and desalinate brackish water and seawater.

We are also starting to develop pioneering approaches for advanced gas mask filters. Mask filter canisters have essentially remained the same since World War II, despite some serious limitations. For instance, today's masks have higher-than-desirable breathing resistance and their capacity (the period of time they effectively filter) is limited. One approach being investigated is the use of surface-treated activated carbon particles, which are expected to increase the filtering capacity. We are also investigating a thermo-catalytic gas mask cartridge that can rapidly heat up the incoming air to destroy chemical and biological agents and then immediately cool the air so it is comfortable to breathe. Because this is not a traditional filtering approach, it promises both to increase capacity and to lower breathing resistance. In addition, because the thermo-catalytic process destroys the agents, the mask filters themselves are no longer contaminated.

Finally, DARPA is working with a number of governmental organizations to exploit recent advances in high-throughput **Genetic Sequencers** to obtain complete genetic information on a number of important pathogens and their non-pathogenic nearest neighbors. This will allow us to develop an inventory of genes and proteins that distinguish pathogens from non-pathogens and to identify pathogenic markers in any guise. This information will be used to provide superior molecular targets and enable new generations of detectors, diagnostics, and therapeutics.

PROTECTION FROM INFORMATION ATTACK

Our Nation, from the President down to individual computer system administrators, possesses very limited capabilities to protect against, detect, and counter sophisticated cyber attacks. Defending against distributed, coordinated attacks requires technology and infrastructure that commercial industry is not developing. The Defense Department, which relies increasingly on advanced information systems, must prepare to defend these systems in cyberspace. The DoD has a vested interest in cyberscience research and the application of other disciplines to cyber defense. To support cyber defense research and technology development, DARPA has initiated the **Information Assurance and Survivability** (IA&S) programs. The goals of these programs are to raise strong barriers to cyber attack; to provide commanders with mechanisms to see, counter, tolerate, and survive sophisticated cyber attacks; and to create cyber defense "playbooks" – compilations of course-of-action alternatives that will enable commanders to employ appropriate cyber defense tactics and to develop the capability to command computing infrastructure as a fighting force.

Last year, the programs developed principles for layered and dynamic defense. Additionally, the programs refined experimentation processes using an integrated Red Team assurance approach. The integrated Red Team approach applies Red Team attack and subversion methodologies throughout experiment and system design processes to significantly improve resulting system assurance levels. In FY 2000, the IA&S programs are conducting experiments using a rudimentary cyber command system to detect and defend against intrusions by sophisticated adversaries. Further, we will conduct scientific research in information assurance metrics, mathematics, design principles, intrusion correlation, automatic intrusion response techniques, intrusion and fault tolerant mechanisms, dynamic policy systems, and situation analysis techniques. In FY 2001, the IA&S programs will integrate evolving security technologies to achieve automatic defense, correlated attack assessment and preliminary situation understanding, improved intrusion tolerance, damage assessment and containment, and policy negotiation with coalition partners. Advanced defensive technologies are being transitioned to warfighters through experimentation and technology transition partnerships with operational commanders.

ENABLING OPERATIONAL DOMINANCE

In DARPA's second track, Enabling Operational Dominance, I mentioned earlier that DARPA emphasizes technologies and systems to enable affordable, precision, moving target kill for both offensive and defensive missions. We are also developing technologies and systems to provide dynamic command and control capabilities to our commanders, including the mobile, wireless, ad hoc networks necessary for information superiority and ability to plan and replan in near-real-time. Lastly, we are investing in technologies and systems that will enable future warfare concepts for air, space, land and sea. This includes the ability to correctly characterize hard and deeply buried targets and warfare using the combined capabilities of manned and unmanned systems.

AFFORDABLE, PRECISION, MOVING TARGET KILL

Current approaches to engaging time-critical surface moving targets include area-of-effect munitions and man-in-the-loop targeting. These approaches traditionally involve large, very expensive weapons, the potential for large collateral damage, and, often, the requirement to put the warfighter in harm's way. DARPA is responding by developing low-cost, highly capable weapons that are netted to a variety of airborne sensors for both offensive and defensive missions, advanced radars capable of detecting targets hidden in foliage and camouflage and broadband antennae that can be electronically reconfigured.

The **Affordable Rapid Response Missile Demonstrator** (ARRMD) program is building and demonstrating an affordable hypersonic (Mach six to eight) missile to execute rapid-response, long-range missions against time-critical targets or hard or deeply buried targets. The program has as a goal a $200,000 average unit flyaway cost. With the capability envisioned by ARRMD, an aircraft would be able to stand off up to 600 miles and launch a hypersonic missile that would hit its target just as quickly as a missile launched from 150 miles away. For the Navy, an ARRMD-type of capability could be launched far from shore, out of range of shore-based anti-ship missiles; and launching an ARRMD-type of missile from carrier-based aircraft would give the aircraft carrier a 900-mile footprint. ARRMD is designed to be compatible with Air Force and Navy tactical fighters, Air Force strategic bombers, and Navy vertical canister launch systems. The program has chosen a single concept known as the Wave Rider. The contractor has demonstrated manufacturing methods for key components, and has conducted the initial series of aerodynamics tests. The program is planning additional testing in support of the preliminary design review scheduled for later this year. In FY 2001, we will evaluate a number of off-the-shelf rocket boosters through wind tunnel tests to select the one that the demonstrator will use to get to the required initial velocity. The program will also finalize the detailed design of the demonstrator.

The **Advanced Tactical Targeting Technology** (AT3) program will develop and demonstrate technologies that will radically improve today's capability to target surface-to-air missile (SAM) threats through the use of networked, next-generation electronic support measures systems. AT3 enables the rapid and accurate targeting of precision-guided weapons to counter the modern, more capable enemy SAM systems being used with increasingly sophisticated tactics such as early target-emitter shutdown. Last year, the program awarded phase one contracts to Lockheed Martin Federal Systems (Owego, NY) and Raytheon Defense Systems Company (Tucson, AZ), and completed the AT3 preliminary designs. In FY 2000, the program is completing system simulation and flight test collection and analysis of radar emitter data, and will conduct critical design reviews and critical component demonstrations. In FY 2001, the program will complete the phase two fabrication of flight-test hardware as well as software development, and perform hardware-in-the-loop testing of the AT3 packages.

The **Affordable Moving Surface Target Engagement** (AMSTE) program is developing technologies to make it feasible and practical for the warfighter to engage individual moving surface vehicles directly, by providing precision targeting in a rapid, affordable manner. The program will demonstrate that, without expensive modifications to existing and planned systems, networked sensors and weapons can provide a robust solution against moving surface targets.

Last year, a predecessor program, the Moving Target Exploitation program, conducted weapon system trade studies to analyze critical system feasibility questions. This produced a pair of air-strike and surface-strike system designs to lay the groundwork for AMSTE, and also furthered the development of precision fire control tracking algorithms. This year, the program is conducting real-time laboratory experiments to assess the accuracy and robustness of the fire control algorithms using radar data collected from multiple airborne sensors, enhancing these algorithms to extend the targets' windows of vulnerability, and completing a detailed system design of an experimental AMSTE system. This experimental system, consisting of representative radar sensors, data links, and weapons, will then be assembled and fielded in FY 2001. The system will demonstrate the capability to engage moving targets precisely through a series of inert bomb drops against real moving targets.

DARPA is concerned that adversaries desiring to challenge the high-technology arsenal of the United States may choose to deploy large numbers of unsophisticated air vehicles to penetrate our air defenses and exhaust limited, high-value weapon inventories. The **Low Cost Cruise Missile Defense** program will employ the latest sensor technologies to develop a low-cost interceptor to counter this potential threat. Last year, the program conducted analyses and laboratory testing to demonstrate the performance potential of six competing low-cost interceptor seeker concepts and selected two of these for continuing development. This year, we will choose a single seeker concept based on field test results of our remaining radar and laser prototype seeker systems. In FY 2001, the program will begin fabrication of a flight-worthy seeker system for live-fire testing.

The goal of the **Counter Camouflage, Concealment, and Deception** program is to mature and demonstrate the technologies required to provide the warfighter with the ability to detect targets hiding in foliage and camouflage. To do this, the program is developing a foliage penetration (FOPEN) synthetic aperture radar (SAR) that can provide all-weather, day/night detection of concealed stationary targets. The program will also explore detection and tracking of moving vehicles obscured by foliage by combining the FOPEN radar technology with electronic support measures for targeting.

In FY 1999, the program completed the final design of the FOPEN SAR, developed real-time software, and developed and tested the wide-band, low-profile, ultrahigh frequency antenna. This year, the program is installing the FOPEN SAR in an RC-12 aircraft and conducting preliminary flight tests to validate real-time image-formation software and verify that the system can provide the required SAR image resolution and sensitivity. In FY 2001, the FOPEN SAR will fly a series of developmental flights to collect data to train and test algorithms, and will undergo performance validation flight tests to verify its target detection performance.

The **Reconfigurable Antenna** program (RECAP) satisfies future military and commercial needs for high-capacity communication and sensors by applying developments in microelectromechanical (MEM) devices and structures to build a new generation of broadband antennas that can be electronically reconfigured. Techniques being developed include artificial magnetic conductors, radio frequency MEM switches, photonic band-gap ground planes, high-density, multi-layer interconnects, and fragmented antennas.

Last year, the program awarded contracts to 12 contractor teams to develop core technologies for the RECAP concepts, leading to very broad bandwidth apertures and flat-plate hemispherical electronic scanning communication antennas. This year, the program is analyzing, modeling and measuring key technologies such as MEM switches, multi-layer substrates, and configurable radiators to optimize integration with system concept demonstrations. In FY 2001, the program will demonstrate critical components, leading to the beginning of system application demonstrations for wide-band military communications using commercial satellites, battlefield communications, electronics intelligence and signals intelligence systems, and radar systems.

DYNAMIC COMMAND AND CONTROL

One key aspect to operational dominance is the ability of the commander to have access to critically needed information and to control that information dynamically. Information technologies can provide this abilities, by allowing disparate information systems and databases to interoperate quickly and efficiently. Other technologies allow commanders to develop operational plans quickly, and revise their plans in near real-time to capture new information or counter an adversary's activities. Mobile networking technologies are also important, as future warfare concepts envision small units armed with comprehensive knowledge of the battlespace and able to communicate while maneuvering. The military has a unique need for communications networks that can be formed and reformed rapidly, without a fixed infrastructure, and DARPA has a number of investments in this area. Other programs are focused on the application of information technology to the critical military challenge of controlling and automating the logistics pipeline and planning process.

A crucial need for the modern military is the ability to rapidly assemble a set of disparate information systems into a coherently interoperating whole. This must be done without system redesign and may include interoperation with non-DoD governmental systems, with systems separately designed by coalition partners, or with commercial-off-the-shelf and open-source systems that are not built to a pre-existing government standard. The **Control of Agent Based Systems** (CoABS) program is exploring the technical underpinnings of such run-time interoperability of heterogeneous systems, and is developing new tools for facilitating rapid system integration.

Last year, the CoABS program developed a framework to facilitate the integration, interoperability, and collaboration of heterogeneous systems. In FY 2000, CoABS is developing and demonstrating a flexible information infrastructure and an interoperability tool called the Agent Grid, which will support the dynamic deployment of complex applications for military command and control. In FY 2001, CoABS will use agent technologies and tools in military scenarios to demonstrate the run-time integration and interoperability of heterogeneous systems in applications that address present and future command and control problems.

Active Templates are default plans that are integrated with dynamic information sources and intelligent problem-solving methods. Applied to special operations, Active Templates allow the commanders to rapidly assemble plans, promulgate information, and execute highly synchronized combined-arms operations with short notice, even when the enemy reacts or the environment changes in unexpected ways. In FY 1999, we developed and deployed graphical plan authoring tools that sped plan development, captured planning decisions as they were made and helped the commander's staff brief the plan, analyze it for errors, track it during execution, and respond to unforeseen events. In FY 2000, the program is integrating new information sources and developing a flexible set of problem-solving methods that will track or analyze the plan to give the commander better control, a better plan, and a higher chance of success. In FY 2001, the program will develop technology to generalize plans automatically and will create a library of generalized plans that may be tailored quickly for the current situation, allowing the computer to handle boilerplate details and freeing brainpower for solving hard problems.

The commander's job is to make decisions and monitor their execution in the midst of great uncertainty. To do this effectively, the commander must be freed from the tyranny of the doctrine and technologies that define the current military command post. The goal of **Command Post of the Future** (CPOF) program is to shorten the commander's decision-cycle to stay ahead of the adversary's ability to react. The visualization and interaction technologies developed under CPOF will enable radically faster situation assessment and response, resulting in a more efficient use of manpower and military assets.

In FY 1999, CPOF designed and executed its first series of visualization and interaction experiments to discover techniques that allow military commanders to interact with their information systems more naturally and effectively. CPOF also developed a new methodology that integrates experimentation, technology development, and new concepts of operations in future military environments. In FY 2000, CPOF is continuing to experiment to discover underlying principles of visualization to enable better situation understanding for experienced commanders, and will begin to explore new concepts of operations and their visualization requirements. In FY 2001, CPOF will develop automated context tracking mechanisms for more efficient use of information resources and more rapid display of relevant information.

The goal of the **DARPA Agent Markup Language** (DAML) program is to create technologies that enable software agents to identify, communicate with, and understand other software agents dynamically (i.e., on the fly, while the computer application is running, not built in at development time). DAML will develop a software language that ties the information on a page to machine-readable semantics including ontologies for intelligence briefings. This effort will provide new technologies for operational users by integrating information across a wide variety of heterogeneous military sources and systems. This year, the first year of the program, we are developing the first working draft of the software language and coordinating it with the World Wide Web Consortium. By FY 2001, we will release working versions of Briefing Tool, Search Tool, and Ontology Creation Tool and define and test a toolset for command and control link application of DAML technologies.

Mobile Networking Technologies

The **Airborne Communications Node** (ACN) program will provide assured communications for joint and multinational forces on maneuver by enabling high-bandwidth, beyond-line-of-sight connectivity utilizing existing manned and unmanned airborne platforms. A critical technical challenge for the ACN is the electromagnetic interference cancellation required to package many channels into a small form-factor with a minimum number of antennas. Additional critical technical challenges involve developing radio-frequency components that operate over broad bandwidths, ensuring compatibility with legacy as well as innovative emerging waveforms, and providing autonomous network management to accommodate the changing needs of the forces during deployment. Last year, three competing contractor teams worked to develop the architecture and proof-of-concept for ACN. In FY 2000, the program will choose two of the competing teams to develop the necessary components and to further mature the architecture. In FY 2001, the program will finalize the preliminary design of the architecture and will verify network performance, latencies, and robustness through detailed testing and simulation.

The **Small Unit Operations Situation Awareness System** (SUO SAS) is designed to develop and integrate key communications, navigation, and situational awareness technologies for use by light, early-entry forces in restrictive terrain where they cannot currently communicate. Technologies are being developed that will allow warfighters to communicate clandestinely in buildings, tunnels, jungles and mountainous terrain using self-forming, computer-controlled networks that continuously monitor the environment, mission needs and the tactical situation, and optimize themselves to ensure that communications are always maintained. These capabilities will greatly increase the effectiveness and survivability of small, dismounted forces.

Last year, this program tested and validated the potential performance of its clandestine communications waveforms, and demonstrated a preliminary non-GPS geolocation technique that uses the communications system's own signals to derive precise position location. This will provide location information even in urban terrain where GPS signals cannot be acquired. This year, SUO SAS technology inventions are being finalized, and the program plans to conduct field and laboratory tests of the communications waveforms and other SUO SAS technologies. The tests will evaluate the technologies' ability to provide accurate, non-GPS geolocation, enable adaptive self-forming communications networks, and perform warrior situational awareness functions. In FY 2001, the program will complete the detailed hardware and software designs, fabricate the major system components, and measure system level performance.

The **Totally Agile Sensor Systems** (TASS) program focuses on high-temperature superconducting (HTS) filters, which, when inserted into conventional receiver systems, provide the highest sensitivity possible for communications intelligence and signals intelligence missions currently being pursued by the U.S. military and intelligence communities. TASS is starting this year, and will build on past accomplishments in the cryogenics program, which demonstrated the superior performance enabled by communications systems using HTS components such as filters. The TASS program will extend the capability of HTS filters by allowing them to be tuned by frequency across the spectrum. As TASS begins, it will develop methods of tuning HTS filters while maintaining the superior filtering capabilities that makes possible their outstanding performance. In FY 2001, the tunability technology will be inserted into airborne and shipborne receivers and sensors using HTS components, in demonstrations of enhanced sensitivity and frequency agility.

Near-Real-Time Planning and Replannning

Many recent studies agree that future adversaries of the U.S. are unlikely to challenge the U.S. directly. Rather, it is more likely that adversaries will present an asymmetrical threat, for example, a small, non-military force may use an unconventional but highly lethal weapon to attack a civilian target. DARPA is undertaking high-risk research to help our military and intelligence agencies identify threats before attacks happen. The DARPA **Asymmetric Threat** initiative will develop a suite of new technological capabilities to better detect, correlate, and understand these asymmetric threats.

In FY 2001, the Human Identification at a Distance project will develop automated multi-modal surveillance technology for identifying humans at a distance using different biometrics techniques such as face and body parts identification, thermography, voice identification, kinematics and remote iris scan. The Rapid Knowledge Formulation project continues its groundbreaking work providing research to rapidly search databases, construct knowledge bases, and draw inferences for key information. The Evidence Extraction and Link Discovery project will piece together these inferences, knowledge bases, and terrorist behavior models into probable events, terrorist networks and predictions that have gone unnoticed in the past. The Wargaming the Asymmetric Environment project will begin to simulate technology for real-time wargaming of asymmetric activities. This will allow us to train our military together with police, the Red Cross and other non-governmental organizations and others to coordinate in responding to asymmetric threats. Project Genoa, ramping down towards its conclusion, provides the structured argumentation, decision-making and corporate memory to rapidly deal with and adjust to dynamic crisis management.

Advanced Information Technologies for Logistics

The objective of the **Advanced Logistics Project** is to demonstrate the feasibility of using advanced agent-based technology to make a quantum improvement in how the DoD provides logistics support to the warfighter. The project will develop and demonstrate a prototype advanced information systems architecture to gain control of the logistics pipeline; enable the warfighter to project and sustain overwhelming combat power sooner; permit forces and materiel to be deployed, tracked, sustained, and redeployed more effectively and efficiently with reduced reliance on large DoD inventories; provide users at any level the ability to effectively interact during planning and execution; permit dynamic replanning; and link operations with logistics staff elements at all echelons, across selected functional areas, and at selected commands. When implemented, the Advanced Logistics Project will revolutionize dynamic planning, execution, and overall information management of the DoD logistics enterprise.

The Advanced Logistics Project is a joint DARPA/Defense Logistics Agency project, in partnership with the U.S. Transportation Command and the Joint Staff Director for Logistics.

Last year, the project demonstrated the first distributed, large-scale, agent-based systems architecture, automatically generated a detailed logistics plan in under an hour (a task that previously took weeks or months), and dynamically replanned specific elements of the plan as necessary to respond to changes. In FY 2000, the project is enhancing the architecture to provide the capability to develop and manage multiple concurrent logistics plans and to conduct "what-if" explorations. It will also begin working with Defense Agencies and Military Services to identify high-payoff pilot projects and start the planning to transition the technology for use in existing and emerging systems and processes. In FY 2001, the project will conclude by demonstrating that the prototype systems architecture has the capability to: generate a level-5 logistics plan in under an hour from a set of operational requirements and the underlying unit information; totally control the transportation pipeline, through information, for all modes to minimize staging, optimize our lift resource utilization and achieve item-level planning; continuously generate time-phased support and sustainment demands appropriate to the changing situation to avoid unnecessary inventories and staging of supplies; monitor the level-5 detail against information from the real world and identify plan deviations in minutes, isolate areas of the plan affected and dynamically repair the plan to get back into execution quickly.

The primary theme of the **Joint Theater Logistics Advanced Concept Technology Demonstration** (ACTD) is logistics command and control. The ACTD will leverage current and emerging technology to produce and rapidly transition advanced collaborative logistics and operational planning and execution capabilities for the Global Combat Support System. It will build a series of web-based Joint Theater Logistics Decision Support Tools that will encourage operations and logistics collaboration during planning and requirements determination, execution tracking, and while realigning resources to meet changing operational situations. The Joint Theater Logistics ACTD will correct existing logistics deficiencies and provide the capabilities necessary to ensure the future success of logistics operations. Last year, the Joint Theater Logistics ACTD produced the implementation directive and management plan that established and coordinated program requirements, goals, direction, and funding. This ACTD builds upon the success of the Joint Decision Support Tools developed under the earlier Joint Logistics ACTD. The Joint Theater Logistics ACTD also incorporates technologies from DARPA's Advanced Logistics Project, other ACTDs and development programs to produce an integrated near-real-time operations and logistics situation assessment capability for improved operational planning and execution capabilities for a Joint Task Force. In FY 2000, the Joint Theater Logistics ACTD is beginning development of the Joint Theater Logistics Decision Support Tools and will demonstrate an initial web-based graphic and textual collaboration capability that integrates operations and logistic information. This ACTD will complement ongoing ACTDs focused on operations. In FY 2001, the Joint Theater Logistics ACTD will demonstrate the ability to collaboratively develop operational courses of action and the corresponding logistic supportability assessments for fuel and ammunition in a Joint Task Force environment.

FUTURE WARFARE CONCEPTS

DARPA is investing in a number of technologies and prototype demonstrations that will enable future operational concepts for many different military missions. We have programs to develop alternatives to antipersonnel landmines, revolutionary space operations technologies, and strategies to control large-scale flow using micro-actuators, plus advanced fire support and maritime technology efforts and a program to characterize the hard and deeply buried targets. We also have significant investments in technologies and systems to enable combined manned and unmanned warfare. The robotics technologies being developed today will allow future warfighters to accomplish their missions more effectively with less risk of casualties, thus preserving the U.S. military's most important resource, its people.

The **Antipersonnel Landmine Alternatives** (APLA) program is focused on long-term alternatives to antipersonnel landmines that would prevent adversaries from maneuvering at will and provide the warfighter with enhanced capabilities. One approach, the Self-Healing Minefield, is developing an antitank minefield that does not require antipersonnel landmines. The military uses antipersonnel landmines within an antitank minefield to prevent dismounted soldiers from finding and disabling the antitank mines. In the Self-Healing Minefield, no antipersonnel landmines are used. Instead, antitank mines detect a breach attempt via mine-to-mine communication and respond by repositioning a fraction of the mines remaining in the minefield to fill in the breach.

During FY 2000, the program is investigating several concepts for the antitank mine mobility system, communication systems, and behavioral responses to breaching. The year will culminate with the laboratory testing of viable candidate technologies that will then be integrated into several test-platforms for initial, integrated system tests. During FY 2001, the program will use information gathered during initial testing of the enabling technologies as well as the initial mine-level test platforms to build and test a small set of inert antitank mines.

In a second approach, the APLA program is investigating the tagging of dismounted enemy soldiers with small, burr-like radio frequency transmitters. These transmitters will detect enemy soldier movement, and provide precise location information to allow the soldiers to be targeted with short-range indirect fire. In FY 2000, the program is investigating feasibility of developing and deploying radio frequency transmitters. In FY 2001, the program will assess viable candidate radio frequency tagging technologies to further determine the capabilities of this concept.

The **Orbital Express** program is designed to create a revolution in space operations. It will demonstrate the feasibility of unmanned refueling, upgrading, and extending the life of spacecraft while they are on orbit. This capability will lower the cost of doing business in space, and provide radical new capabilities for military space such as highly maneuverable satellites, autonomous orbital operations, and satellites that can be reconfigured as missions change or as technology advances. By maneuvering on orbit, military satellites would have dramatic advantages. They would be able to accomplish the same mission with fewer satellites; deny adversaries the ability to avoid detection through activity scheduling; or arrive overhead an area of interest at an optimum time, such as during clear weather. This program is beginning in

FY 2001 with studies determine the optimum architecture for an on-orbit servicing infrastructure. In FY 2001, the program will select multiple teams to build components necessary for the on-orbit demonstration of this capability, and continue development of key technologies.

The **Discoverer II** joint program is a joint U.S. Air Force, DARPA and National Reconnaissance Office (NRO) advanced research and development program. Discoverer II will establish the technical feasibility and affordability of a space-based surveillance system offering high-range-resolution ground moving target indication (HRR-GMTI), synthetic aperture radar (SAR) imaging, and high-resolution, digital, three-dimensional terrain mapping data. Additionally, the program will develop and explore direct tasking by theater or joint task force commanders and surveillance data products directly downlinked to theater tactical ground stations. Such a global surveillance capability is required to ensure that U.S. forces attain the dominant battlefield awareness envisioned in Joint Vision 2010. In fact, it is DARPA’s view that the only way to accomplish battlefield surveillance is to build on a sensor architecture that exploits motion on the battlefield through the use of HRR-GMTI sensors and smart, georeferenced databases. This moving target indication-based approach is contrasted with how we accomplish intelligence collection today, which often overloads the available exploitation personnel. The program affordability goal is to demonstrate a design that would allow for a satellite cost of less than $100 million in a follow-on engineering and manufacturing development program. This represents a significant reduction in cost – a factor of 10 less than that possible through today’s technology, and a factor of three less than that possible from technologies and approaches expected in the near future.

The Discoverer II program will design, fabricate and launch two research and development, prototype HRR-GMTI/SAR satellites and will conduct a one-year, on-orbit demonstration with the satellites in FY 2005. Most significantly, the Discoverer II program will demonstrate for the first time the feasibility of fielding these capabilities at a cost that will make deploying a large operational constellation of Discoverer II follow-on satellites an affordable reality. The program leverages heavily on past and on-going DARPA investments in sensor and information technologies and capitalizes on the considerable systems engineering and space program experience and talents of the Air Force and NRO. In November 1999, an independent cost analysis performed by cost analysis teams from the NRO and Air Force determined that the program’s planned budget and the teams’ cost estimate were within one percent of each other. The analysis teams predicted a demonstration program cost of $706 million (not including launch costs).

The program is sponsoring three phase-one concept development teams headed by Lockheed Martin, Spectrum Astro, and TRW. In FY 2000, contractors are completing preliminary designs and continuing technology risk reduction activities and studies to determine optimum operational concepts. In FY 2001, the program will conduct a competition and award Phase II contracts to begin construction of the research and development spacecraft.

The **Micro Adaptive Flow Control** (MAFC) program is developing strategies to control large-scale flow characteristics using small-scale actuators and smart materials. The program is beginning to reap the benefits of revolutionary performance improvements for aerospace and marine applications, and is exploring the possibility of increased thrust and reduced weight for aircraft engines by controlling stall on engine blades to reduce the overall weight and cost of an engine. In addition, MAFC technologies hold promise for improved payload capacity for tiltrotor aircraft, enhanced aircraft maneuverability, extended vehicle range and decreased fuel burn at lower total system cost.

After selecting a number of concepts for preliminary investigation, the program is now initiating work on promising concepts for systems-level integration and demonstration. A promising application now in full-scale testing reduces the temperature of the hot engine exhaust of the C-17 during ground operations, which must be diverted or cooled for safe loading operations. The control of jet-mixing using MAFC techniques is a lightweight way to lower the engine exhaust temperature instead of the current practice of diverting the hot exhaust with heavy and expensive thrust-reversers. In FY 2001, the program will demonstrate open-loop flow control, and will initiate activities in the area of closed-loop control.

The Army After Next and the U.S. Marine Corps' concept for Operational Maneuver from the Sea both envision the use of forces rapidly deployed by air and sea. These units need the capability to rapidly deploy precision, responsive firepower in combination with protection from hostile aircraft and missiles and beyond-the-horizon targeting. The **Advanced Fire Support System** program is a concept for a family of small, container-launched missiles to provide massive, responsive, precision firepower early in a conflict. Because the program is addressing cost, military effectiveness, logistics and survivability, we believe the program will compare favorably with alternative approaches. The container-launcher can easily be transported, and, because the shipping container is also the launcher, missiles can be fired immediately after delivery to the desired location. The container-launcher does not require a unique platform -- it can be fired remotely from trucks, HMMWVs or a variety of other platforms. Using the same general missile design, the program will develop a family of missiles with different capabilities.

To date, the program has started design work for the seeker, missile, and launcher, and, in conjunction with the Navy, has tested a full-scale, concentric launcher. In FY 1999, the program completed its preliminary design and conducted a variety of tests to demonstrate system feasibility and evaluate program risks. This year, the program will test a variable thrust motor, complete detailed designs, conduct several risk reduction demonstrations, and start building both launchers and missiles. Initial flight-testing is planned for FY 2001 and 2002.

The **Robust Passive Sonar** (RPS) program goal is to increase significantly the performance of sonar systems by canceling out surface shipping noise, which is the primary cause of interference. The RPS program accomplishes this precision cancellation by innovative and optimal processing techniques coupled with multi-dimensional receive arrays and other external information. The expected net system performance gain is 10 to 20 decibels, and the system is expected to dictate future array and acoustic sensor field designs. Last year, the program completed the investigation of the feasibility of RPS processing and array concepts. In FY 2000, the program is beginning development of the space-time processing algorithms to reject interference, and, next year, the program will conduct data collection exercises and a preliminary performance assessment.

The **Buoyant Cable Antenna Array** program is an example of DARPA/Navy collaboration at its finest. This jointly funded effort, which has evolved out of work originally initiated independently at DARPA and the Office of Naval Research, seeks to develop a high-performance ultra-high frequency (UHF) antenna array capable of both transmitting and receiving messages while floating on the ocean surface. Such a capability will provide U.S. submarines with worldwide digital and voice connectivity equivalent to current telephone lines even while the submarines are operating at their usual speeds and depths. Last year, the program completed a strong side-by-side test campaign comparing DARPA and Navy concepts, where, among other things, receive communications from an existing UHF satellite were successfully demonstrated in Sea State 3 to the bandwidth limits of the satellite. This year, the program is developing a prototype antenna system to be deployed and tested on board an operational submarine by the end of FY 2002.

The intent of the **Netted Search, Acquisition, and Targeting** (NetSAT) program is to provide major improvements in the attack performance of existing torpedo inventories by networking the torpedo with an independently deployed pattern of sonobuoys. The ability to observe the scene through both the torpedo and sonobuoy sensors together permits rapid, high-quality situational understanding during the torpedo attack sequence. For example, torpedo countermeasures deployed by the target can be classified and localized extremely quickly, and the weapon routed around them to the target. Last year, the program conducted a first set of end-to-end technical tests at underwater ranges in the Pacific Northwest. The lessons learned are currently being incorporated into the prototype equipment. A second set of technical tests will be conducted this year, to be followed by testing to address more operational issues in FY 2001.

Hard and Deeply Buried Target Classification

Underground facilities are a serious and growing asymmetric threat to our security and our ability to achieve operational dominance. The objective of the DARPA **Counter Underground Facilities** program is to evaluate and develop appropriate technologies to characterize underground facilities for defeat, with particular emphasis on the location of critical systems and subsystems such as power, water- and air-flow, as well as orientation and depth of structure. As this program begins this year, it is initiating rigorous modeling and data collection of passive seismic, acoustic, and electromagnetic observables and effluents associated with operation of critical underground facilities systems. In FY 2001, the program will validate the models and initiate prototype demonstration system developments.

Combined Manned and Unmanned Operations

The joint DARPA and Air Force **Unmanned Combat Air Vehicle** (UCAV) Advanced Technology Demonstration program will demonstrate technical feasibility for a "man-in-the-loop" UCAV system to effectively and affordably prosecute 21st century suppression of enemy air defenses (SEAD) and strike missions. During the first phase, completed a year ago, industry teams designed a system-of-systems based on anticipated threats. Starting from a clean sheet of paper, four teams conducted an exhaustive set of engineering trades to define an operational vision for a UCAV weapon system. These operational concepts indicated that air vehicles one-half of the size of today's counterparts displayed compelling mission effectiveness and affordability potential. The results fully validated the program's initial hypothesis that, in the 2010 timeframe, the acquisition cost of the UCAV would be one-third of today's Joint Strike Fighter acquisition cost, and that operational and support costs, compared to a current manned fighter squadron, would be reduced by 75 percent.

The program began its second phase last year, selecting a single contractor to conduct a comprehensive series of simulations, ground tests, and flight tests using a surrogate aircraft, two full-scale air vehicle demonstrators, and a reconfigurable mission control station. In this 42-month phase, the UCAV program will demonstrate: compatibility of the unmanned system with the envisioned 2010 battlespace; robustness and security of communications with the air vehicle; feasibility of adaptive, autonomous control of the air vehicle, with advanced cognitive decision-aids for the "man-in-the-loop" system operators; feasibility of coordinated, multi-vehicle flight; affordability of operations and support costs; and deployability of the system. The program has completed the preliminary design review for the full UCAV system, and has finalized the design of the air vehicle portion. Both air vehicles are under construction, with rollout of the first vehicle planned for later this year. First flight will occur in FY 2001. Due to the success of the DARPA/Air Force UCAV program, the Navy has also begun collaborating with DARPA to conduct an initial study of a Naval SEAD/Strike/Surveillance UCAV for the post-2010 timeframe and identify leveraging opportunities with the Air Force.

The **Tactical Mobile Robotics** program is developing robotic technologies and platforms designed to revolutionize dismounted action and urban warfare by projecting operational influence and situational awareness into previously denied areas. It will combine traditional soldier skills with portable robot efficiency to create highly effective human-robot teams that can address the many daunting national security challenges that await us. In the past year, the program outfitted several surrogate mobility platforms with revolutionary perception aids such as

Omni-cameras and laser scanners and developed algorithms to enable semi-autonomous navigation in non-GPS settings such as indoors, underground and in thick vegetation. In FY 2000, the program will integrate enabling technologies into functional platforms in support of an aggressive experimentation effort. In FY 2001, the program will conduct demonstrations of portable robots to determine their operational capabilities for maneuvering in confined spaces (such as in sewers, collapsed buildings or ventilation ducts), three-dimensional mapping, performing tasks under fire, and climbing up stairs and over obstacles and rough terrain.

The **Distributed Robotics** program is developing microrobots that work together in groups in dynamically changing environments. These small robots will be five centimeters (two inches) or smaller in any single dimension. They will work cooperatively together in groups, be capable of different modes of locomotion (land, water, vertical climbing, etc.) and will adapt their behavior based on remote user inputs or onboard sensors. The program currently has 13 contractor teams investigating different approaches, such as crawlers, jumpers, vertical climbers, and airborne systems, as well as robots that can change their shape and locomotion mode. All contractors demonstrated initial mobility and sensor capabilities at the Marine Corps Warfighting Laboratory in September. During FY 2000, contractors are optimizing energy consumption for various military missions, and next year, will demonstrate collaborative tasks with multiple robots operating together to perform a specific mission.

Because DARPA believes that robotics and unmanned warfare will become increasingly important to DoD as a way to reduce costs, increase warfighting capabilities, and minimize the risk to our warfighters, we have a number of efforts to develop the hardware and software necessary for advanced robotics. For example, we are developing software technologies that can enable machine-learning strategies automatically to generate sophisticated robot behaviors such as autonomous navigation and real-time obstacle avoidance. These sensor-mediated behaviors will mitigate the dependence on remote control, even when robots are employed in complex, dynamic environments. This program will also revolutionize how autonomous robot control software is created. Some learning strategies will employ virtual learning, whereby the control software is created in simulation. The resulting code can then be ported directly to one or more actual robots for execution. Another program is developing robot software technologies to allow a single soldier to interact naturally with and intuitively control a large swarm of very small micro-robots performing a collective task. Both programs are starting this year. In FY 2000, the **Mobile Autonomous Robot Software** program is demonstrating a suite of off-line learning technologies that can rapidly generate desired robot behaviors with minimal hand-coding of the control software. In FY 2001, the program will demonstrate a suite of on-line learning techniques that can automatically generate desirable, adaptive behaviors without any human intervention required. This year, the **Software for Distributed Robotics** program is demonstrating statistically grounded, probabilistic control algorithms suitable for directing the actions of several micro-robots. By next year, the program will have demonstrated the ability of a single soldier to control the behavior of a robot swarm consisting of no less than 100 micro-robots.

In October 1999, Army Chief of Staff General Eric K. Shinseki announced the Army’s vision – “to develop a force that is deployable, agile, versatile, lethal, survivable, sustainable and dominant at every point along the spectrum of operations.” DARPA and the Army are working collaboratively on a program to design and demonstrate Army **Future Combat Systems**. U.S. ground forces need robust, rapidly deployable systems capable of seizing, retaking, and/or defending territory occupied or threatened by mobile, well-armed, determined adversaries. The dynamics of world events today also dictate that U.S. forces must respond in a matter of days with systems that can adjust to a changing set of missions, ranging from warfighting to peacekeeping. In addition, these systems will likely be deployed in desert, wooded, tropical or urban combat zones, as previous U.S. deployments during the past two decades have shown. The U.S. Army Training and Doctrine Command has developed a draft Mission Need Statement that outlines the need for Future Combat Systems to meet these future military challenges.

The jointly funded, collaborative DARPA/Army FCS demonstration program will define the FCS concept design and its associated concept of operations; develop a preliminary design and fabricate and test an FCS Demonstrator with the overall goal of developing an FCS suitable for transition to Engineering Manufacturing Development; and, develop radically innovative enabling technologies for insertion in the Demonstrator. These jointly funded enabling technologies will provide mobile, networked command, control, communications capabilities; autonomous robotic systems; precision indirect fires; airborne and ground organic sensor platforms; and precision, three-dimensional, adverse-weather reconnaissance, surveillance, targeting and acquisition. In FY 2000 and through FY 2001, the program will conduct a competitive concept development phase and a series of government-run experiments to evaluate the potentially revolutionary impact of various technologies on land warfare. In addition to this design and demonstration effort, this year, DARPA is continuing the Advanced Fire Support System, A160, Combat Hybrid Power Systems, and Small Unit Operations programs to provide supporting technologies.

DEVELOPING AND EXPLOITING HIGH-RISK, HIGH-PAYOFF TECHNOLOGIES

In the third track, Developing and Exploiting High-Risk, High-Payoff Technologies, DARPA continues its traditional investments in information technology, microsystems technologies, advanced materials, advanced lithography and MEMS. It is the results of these investments that allow us to build the systems and capabilities for operational dominance in the future. We are also just starting investments in two exciting areas—Beyond Silicon and BioFutures.

INFORMATION TECHNOLOGIES

DARPA's investments in information technologies will provide information superiority to the Armed Forces through revolutionary advances in:

- Design methodologies for <u>embedded and autonomous systems software</u>;
- <u>High performance computing</u> and communications components;
- <u>Networking and information assurance</u>;
- <u>Seamless computer interfaces</u> for the warfighter; and
- <u>Ubiquitous computing</u> and communication resources.

Information technologies such as computing and networking have come a long way, but their future remains unlimited. New technologies such as wireless and power- and energy-aware computing devices, embedded computers (that is, computers interacting in real-time with networks of sensors and actuators), wideband optical networks, MEMS, quantum devices, cognitive neurophysiology, and computational biology and bio-informatics offer great promise, but also require additional technology development if DoD's future computing systems are to be able to take full advantage of these new technologies.

Embedded and Autonomous Systems Software

As computers are increasingly embedded in the real world with networks of actuators and sensors interacting with physical devices in real-time, it is important to design middleware for connecting the computing intelligence to the physical system. As the functionality of military systems grows either for reasons of greater autonomy or higher performance requirements for the warfighter, we must develop methodologies, tools and technologies for embedded software that are:

- Verified and validated by design so as to reduce the need for extensive testing;
- Reasonably well separated from the underlying computing platform to enable their upgrade as new processors become available; and
- Composable so as to allow for the addition of new functionality without extensive rewriting of the legacy code.

In the **Systems Environment** area, the Quorum program is developing advanced resource management, middleware, and operating systems technology that will allow mission-critical applications with widely varying characteristics to share a common pool of networked, commercial-off-the-shelf processors while still meeting their real-time deadlines. This technology allows resources to be dynamically allocated to the most critical applications when experiencing workload surges, failures, and threat or mission mode changes, and while still ensuring that other applications receive acceptable quality of service. This technology is being transitioned to Aegis Baseline 7 to provide a common, distributed, computing environment to support, simultaneously, multiple missions, including anti-air warfare, land attack, and theater ballistic missile defense. In FY 1999, the program demonstrated that dynamic resource management techniques were able to maintain real-time responsiveness during an anti-aircraft air warfare scenario even under dramatic increases in workload. In FY 2000, we are developing the integrated reference implementation to support mission-critical applications. In FY 2001, the program will demonstrate the ability to dynamically manage mixed workloads of critical and non-critical applications on platforms such as the Naval Surface Weapons Center Hiper-D test bed and for multiple aircraft time critical target prosecution.

The goal of the **Model Based Integration of Embedded Software** program is to synthesize large, embedded software applications from high-level engineering models that capture both functional and physical characteristics of the systems to be developed. Model Based Integration technology will enable us to increase practical, achievable, reusable functionality for embedded systems such as avionics and vehicle control systems, and will decrease the life-cycle cost for embedded software by an order of magnitude.

Many DoD applications of networked systems of sensors, actuators and processors will perform data dissemination and fusion operations that could most efficiently be performed at nodes within the network. Advancements in **Mobile Code** technology will leverage the capabilities of a programmable network to deploy middleware that is mobile in nature and can go where network connectivity permits. This capability will permit network elements to host services on behalf of embedded and autonomous devices, off-loading processing from these smaller systems. In FY 2000, research focuses on mobile agents that autonomously negotiate the assignment and customization of resources under real-time constraints, such as those encountered in logistics and electronic countermeasures. In FY 2001, the program will demonstrate the ability of autonomous software to utilize negotiation in a logistics scenario.

The **Software-Enabled Control** program will leverage increased processor and memory capacity to increase vastly our ability to maintain control over very high performance, airborne platforms. This research will yield new technology to allow us to achieve satisfactory mission performance for extreme environments and for use in highly autonomous, cooperating mission systems. Military applications include integrated avionics design for airframes such as the F-22 and the Joint Strike Fighter, as well as upgrades to the avionics for existing platforms such as the F-15E and AV-8B. In FY 2000, the program is developing an architecture for a hybrid control system that synthesizes the control law approach with computationally enabled, mode logic advanced avionics. The challenge of developing real-time, embedded code for avionics is to have it be adaptable and predictive and allow the aircraft to switch automatically between different modes of operation to keep the pilot engaged in combat-specific functions. In FY 2000, we are developing active transition control and joint mode logic/control law designs for switching between different flight modes to perform complex maneuvers. We will also develop parametric adaptive and predictive control frameworks and do a prototype implementation on an open control platform for use in a number of current and future manned and unmanned aircraft. The goal of the open control platform is to dramatically reduce the costs to the DoD of developing real-time avionics support.

Program Composition for Embedded Systems (PCES) is developing new technology for programming embedded systems with greatly reduced programming effort and reduced brittleness of the resulting code. The technology produced by the PCES program starting in FY 2001 will leverage human effort to rapidly produce higher-quality, more adaptable software. It will increase DoD's assurance that the resulting software achieves required properties and will enable the production of high-performance yet high-confidence military systems when they fundamentally depend on software operation. In FY 2001, the program will develop static analysis techniques for real-time embedded systems' properties and develop intermediate representations and mechanisms for code composition and transformation.

High Performance Computing

DARPA's investments in information technology are also providing technology and tools to design high performance computing components that are adaptable (that is, the computer hardware can be modified by its own software), with processors embedded close to the memory to prevent data starvation and allow power- and energy-aware computing.

Many defense applications such as dynamic, sensor-based processing, battlefield data-processing integration, and high-speed cryptographic analysis are data-starved, that is to say, the processor is so fast that it has to wait for memory to be accessed from RAM between operations thus slowing down the computation. Prior analysis showed that memory access was growing at the rate of seven percent annually, while Moore's Law predicted the doubling of processor speed every 18 months. This program is aimed at reducing this imbalance. The problem of data starvation for the processor is especially critical in image/radar processing applications in target detection and tracking. The **Data Intensive Systems** program is developing innovative data access techniques to solve this problem and enable new military capabilities. For example, if the processing portions of the computer architecture are closer to the memory location, data can be retrieved more quickly. In FY 1999, we developed new memory architectures and data manipulation instruction set concepts. In FY 2000, the program is performing detailed design, fabrication, and implementation of prototype intelligent memory controllers, adaptive caches, and memory systems. In FY 2001, we will demonstrate a 16-fold improvement in the speed at which memory is made available to the processor.

The **Power Aware Computing/Communication** (PAC/C) program is developing a novel, integrated software/hardware technology suite using innovative, energy-reduction technologies. This will enable embedded computing systems to reduce energy requirements by a hundred- to a thousand-fold in such military applications ranging from hand-held computing devices to unmanned aerial vehicles. The program is beginning this year, and is researching power aware components, architectures, middleware, operating systems, and algorithms. For FY 2001, the program will demonstrate and prioritize individual power aware technologies for potential incorporation into demonstrations.

Networking and Information Assurance

The **Next Generation Internet** (NGI) program is developing the key enabling technologies in both software and hardware to allow the network to scale in bandwidth, size, and range of applications it supports. DARPA's NGI program is focused in particular on removing bottlenecks for delivering ultra-high capacity end-to-end systems and in automating the network management and operations functions. In FY 1999, we established and deployed the NGI SuperNet testbed comprising approximately 20 sites across the U.S. This advanced testbed is capable of delivering greater than one gigabit per second streams to end applications. This speed is 100 times faster than today's Internet. The testbed is being used to test both new applications and to field next-generation switches and routers. We have also successfully demonstrated new technologies in optical burst switching where the data transfer rates are approximately two orders of magnitude greater than today's electronics-based switches. In FY 2000, we are demonstrating 100 gigabit-per-second all-optical switches in a regional area network testbed, and testing a non-intrusive network-monitoring tool. In FY 2001, the program will develop network architectures and management tools for robust, heterogeneous gigabit networks with the view of ensuring maximum end-to-end system survivability. For the military, NGI technologies will enable virtual radar consoles tied to a physical radar and remotely accessible via a wide-area network; real-time, high-resolution imagery transferred over multiple streams of multi-gigabyte flows; and raw (undigitized) sensor signals streamed over wide-area links.

The **Gigabyte Applications** program is developing the technology to enable robust operation of DoD's mission-critical systems and platforms to permit gigabytes and terabytes of data to be transferred seamlessly over heterogeneous wide-area networks. The project will also develop robust, survivable inter-networking architectures to minimize the vulnerability of today's networking architecture. In FY 2000, this program is developing an architectural framework for ensuring maximum end-to-end system survivability. As a test application, the program will stream ultra-high capacity radar signals over wide-area links. For FY 2001, the program will address high-speed network security. For the gigabit multi-link, we will demonstrate an order of magnitude increase in wireless efficiency and the feasibility of 10 gigabit-per-second transmission over a 10-kilometer wireless link.

Another program will develop and test a protocol network architecture that allows rapid and dependable creation, reconfiguration, and deployment of new networking services. Such deployment is not possible with today's networking infrastructure, which relies on a uniformly standardized software base. The **Active Network** concept will completely change the deployment strategy for network software, enabling specialized tailoring of network resources with greatly reduced staff-time and configuration-control costs, and increased speed of propagation of the software changes. This concept of rapid, easy deployment may be the only viable approach for making major improvements to today's Internet technology and assuring information dominance throughout the next century. In FY 1999, we extended the operation of the Active Network testbed and demonstrated active node execution for security and survivability. For FY 2000, we are providing the initial release of prototype active network toolkits for end-users. We are also analyzing active network performance. FY 2001 plans include demonstrating 100 percent performance improvements for large multicast sessions for high-level architecture

(HLA)-compliant simulations. The program will collaborate with the Defense Modeling and Simulation Office for a joint demonstration of the technology.

DARPA is developing other modeling and simulation tools that are trustworthy and able to predict, with known accuracy, network behavior for different network sizes and compositions. These tools, along with an appropriate on-line network measurement methodology that will also be developed, will provide a basis for on-line network control, dramatically reducing the time and cost required for network management functions. In FY 2000, the **Network Modeling and Simulation** program is initiating the development of multi-scale modeling and simulation of networks and the development of network measurement methodologies. For FY 2001, the program will demonstrate prototype tools.

Seamless Computer Interfaces

The goal of the **Communicator** program is to overcome the technical barriers of dialog-style communications between a computer and a human. This requires technologies that understand human speech, take action based on that speech and have the ability to respond to the user with natural speech. In FY 1999, the program created an architecture for spoken language dialog system research. This architecture has now been made "open source" available to researchers as part of the program. In FY 2000, the program is experimenting with real users accomplishing real tasks using live, multi-modal web data, including auditory and written components. We also plan to conduct experiments in driven vehicles. In FY 2001, we will develop spoken dialogs to allow small units to interact with computers to accomplish logistics tasks. These experiments will be conducted during the course of RIMPAC exercises.

The **Translingual Information Detection, Extraction and Summarization** (TIDES) program will automatically provide English access to relevant and timely information contained in documents currently available only in other languages and translate to English both textual and spoken information in other languages. The program addresses the need for access to the exponentially increasing amount of foreign language materials that exceed the capacity of human linguists to translate in a timely manner. As DoD is called on to respond to crises around the world, this ability to rapidly translate foreign language materials will become key to a rapid understanding and response to these crises. The TIDES program is starting in FY 2000. This year, the program is designing an overall architecture that supports information extraction, topic detection, summarization, and machine translation of information across languages. The main problem that we will address in FY 2001 is to collect state-of-the-art modules for being able to do automatic translation from one language to another (cross-lingual information access) and a comprehensive architecture that supports end-to-end capability. Languages that will be featured include Korean, Chinese, and accented English.

The goal of **Web-in-a-Box** is to provide access to global information in the face of limited or no bandwidth connectivity. The program will develop technologies for a local information repository to provide local, unlimited, fast access to information and technologies for a next-generation proxy server that will intelligently deliver updated global information based on the users' needs. Web-in-a-Box will enable deployed fleets and remote command posts to have access to urgently needed information. In FY 2001, the first year of the program, we will produce the initial global information testbeds, and the first set of rules for the local information repository. This will provide a common set of material for the researchers to use in developing and measuring their algorithms.

The **Information Management** program is supporting DARPA's crisis management thrust by making computers able to access, organize, analyze and disseminate information contained in large, dynamic, multi-media document streams. The program has two main goals: to develop data-driven information organization technologies and analysis environments. In FY 1999, the program developed the framework for federation of text, image and relational databases and demonstrated presentation aids for military documents in English, Korean and German. This year, the program is demonstrating the persistent query of audio and video streams to detect user-defined significant events and to generate alerts; conducting a feasibility demonstration of combined translingual, multimedia content-based information retrieval; and demonstrating easy integration of new sources into analysis environments. Next year, the program will evaluate developed technologies in large-scale, scenario-based testbeds.

Ubiquitous Computing

DARPA created the Internet and spurred the creation of the information-based economy. The next grand challenge for information technology is to make computers easy to interact with, ubiquitous, and able to organize for collaborative or hierarchical situation assessment and decision making. Mobile users must be able to reliably and quickly access data regardless of the user's location. In addition, the military's hierarchical and team-oriented decision-making structure would benefit from technologies to enable secure collaboration. The **Ubiquitous Computing** program is starting this year, during which it will build small operating systems that will allow ubiquitous computing devices to adapt their functioning to the resources available. In FY 2001, we will study the formation of trusted collaborations and coalitions of groups of users in a ubiquitous computing environment and build testbeds to test the scalability, reliability and fault tolerance of these environments.

In the **Information Technology for Sensor Networks** program, we are producing software that enables flexible and powerful sensing capabilities for networked micro sensors. Small sensors will become more capable and pervasive in future military systems, for example to detect ground moving targets and bio-chemical warfare agents, and for military operations in urban terrain. To fully utilize these sensor capabilities, we must develop software that can create an ad-hoc network of deployed sensor devices, and process collected information to achieve accurate and timely detection. FY 2000 is the first year of this program. We will develop techniques for low-latency networking, as well as dynamic querying and tasking and techniques for ad-hoc micro-sensor networks. In FY 2001, the program will demonstrate multi-node sensor network software.

MICROSYSTEMS TECHNOLOGIES

The objective of the **University Opto-Centers** program is to establish multi-investigator university optoelectronic centers with programs closely coupled to photonic industry researchers to develop and demonstrate chip-scale optoelectronic integration technologies. The development of advanced chip-scale optoelectronic modules is essential for future, high-performance military sensor and information processing systems. University-based research provides the knowledge base and the highly capable expertise to both innovate and support the development of these capabilities within industry. In FY 2000, the University Opto-Centers are being established to create new capabilities for the design, fabrication and demonstration of chip-scale modules that integrate photonic, electronic and microelectromechanical systems-based technologies. We are also establishing university technology research goals and identifying methods of facilitating access by industry to these technologies. In FY 2001, the program will evaluate specific chip-scale integrated module designs and assess the success of engaging industry commitment to the program.

The **Flexible Emissive Display** program was established in FY 1999 and is focusing on the development and demonstration of large-area, high-resolution, flexible, emissive, rugged displays for DoD applications. The development of rugged, lightweight, inexpensive, flexible displays will be useful for aircraft, ships, land vehicles, and foot soldiers. In FY 1999, the program selected six contractors to investigate technology areas that are key to the development of flexible displays, and demonstrated the self-assembly of a flexible backplane using fluidic transport nanoblocks. In FY 2000, the program will conduct demonstrations in all three key technology areas, backplanes, emissive materials, and substrates. In FY 2001, the program will demonstrate a low-cost, high-speed, roll-to-roll assembly process for plastic film liquid crystal displays and will demonstrate a flexible, lightweight, emissive, color, electroluminescent display based upon plastic material.

The **High Definition Systems** program is continuing to develop leading-edge display technology to meet diverse but specific DoD needs. The program has two goals: develop display technology that will enhance DoD system performance but which is not expected to be commercially available in the foreseeable future, and to improve power efficiency, reduce weight, and improve ruggedness, all attributes extremely important to the military. Early implementation of these new technology capabilities will provide DoD systems with superior access to digital information.

During FY 1999, the program demonstrated the active matrix liquid crystal display for the Comanche head-mounted reflective display, which exceeded the technical requirements for color and video rate. Thin-film electroluminescent displays developed by the program have been integrated into the M1A2 main battle tank System

Enhancement Program and active matrix electroluminescent displays were demonstrated in the Land Warrior Integration and Operational Test and Evaluation. In FY 2000, a 10.4-inch active matrix liquid crystal display developed for the Navy High Speed Assault Craft's Integrated Bridge System passed arduous environmental tests. Also, the program demonstrated a reflective display using holographic polymer-dispersed liquid crystal material to provide a full-color image. In FY 2001, the program will emphasize integrating HDS-developed technology into military system demonstrations to improve the performance and/or operational capabilities of existing systems.

As the information and data processing capability of electronic and optoelectronics chips increases, the power consumption and therefore the waste heat generation of systems based on these chips increases. Waste heat generated by chips limits their efficiency and hence overall performance. The **Heat Removal by Thermo-Integrated Circuits** program aims to develop thermal management devices that are co-located with the chips generating the heat. This approach to thermal management will allow cooling to be programmable, on-demand, and applied where it is needed most, prolonging life and increasing efficiency for advanced information and communication systems. In FY 1999, the program demonstrated the first solid-state integrated electronic device with its own on-board cooler and cooling with micro-fluidic channels designed into a power electronic chip. This year, the program is developing packaging and integration technologies for the coolers and electronics/ optoelectronics. In FY 2001, the program will demonstrate new thermal management schemes in actual microprocessors and radio-frequency power amplifiers for military communications systems.

Traditional approaches to electronic interconnects based on wire interconnection lead to information processing systems that are bulky, heavy and power hungry. The communication bandwidth and speed possible with these electronic interconnects is lower than that of the processor itself, leading to bottlenecks within the system. The **VLSI Photonics** program will develop photonics technology to use optical links instead of electronic wire links for chip-to-chip and board-to-board communications. This new technology will allow data transfer rates faster than a terabit per second. These communication speeds are crucial for high-speed processing applications such as synthetic aperture radar and automatic target recognition. In addition, VLSI Photonics will enable a 100- to 1000-times reduction in power and size for these systems.

In FY 1998, the program demonstrated the integration of vertical-cavity lasers on top of driving electronics, together with the necessary micro-optics to achieve an optical interconnect. These were then scaled to 16-by-16 smart-pixel arrays of optical communication blocks for the chip-to-chip interconnects. In FY 1999, these smart-pixel arrays were used, for the first time, to demonstrate links between chips using only optics (light); the aggregate communication link demonstrated had a capacity of over 250 gigabits per second. The 16-by-16 laser arrays have since been scaled to 34-by-34 arrays -- that is, over 1,156 lasers on a single chip.

The most important accomplishment in the VLSI Photonics program has been the demonstration of the capability to manufacture vertical-cavity surface-emitting lasers with yields of over 99 percent on large-area (three-inch) wafers. Technology for manufacturing conventional lasers will never achieve this low-cost, large-area capability. Surface-emitting lasers have demonstrated the lowest threshold currents (25 microamperes) of any lasers ever manufactured, with estimated lifetimes of well over 50 years.

In FY 2000, optical links will be used to demonstrate the transfer of useful data between chips to allow benchmarking performance against traditional electrical approaches. The two major capstone demonstrations of the program will begin in FY 2001. The first involves data processing in synthetic aperture radar and the second involves hyperspectral imaging. Both of these applications generate large quantities of data that are currently difficult to process in real-time. The use of optical interconnections will speed-up the data processing because of the large bandwidth capacity interconnections among the processing units.

Thermal imaging remains a cornerstone technology for most military missions that rely upon image information. Uses include small unit operations, ground, air and sea target acquisition, missile seekers, and threat warning. Significant strides have been made in converting thermal imaging technology from cryogenically cooled detectors to uncooled thermal detectors. The **Uncooled Infrared Integrated Sensors** program has catalyzed a major shift in focal plane array technology. For many years, the standard uncooled array was based upon a pixel size of 50-by-50 micrometers and an array format of 320-by-240 picture elements. This relatively large pixel size limited both the system resolution and target acquisition range, and most importantly, restricted the options available to the system designer. In the past year, this program demonstrated for the first time the ability to fabricate uncooled infrared sensors with a pixel size of 25-by-25 micrometers, a 75-percent reduction in area. Although thermal sensitivity should be reduced for smaller pixels, the sensitivity was maintained at 0.050 degrees, exceeding current uncooled performance. These efforts will truly revolutionize thermal imaging, providing lower cost sensors for current systems and allowing the integration of imaging micro-sensors into novel platforms, such as micro-air vehicles and robotics. A 320-by-240 array incorporating this structure demonstrated two times the target acquisition range of the typical uncooled infrared sensor. Also, a field test held in the fall of 1999 (under the Tactical Aircraft Directed Infrared Countermeasures program), demonstrated the detection of missile firings with the uncooled infrared camera, establishing the potential of a low-cost missile-warning sensor for the next generation of combat aircraft.

The ability to integrate thermally sensitive micro-structures-based detectors with state-of-the-art low-noise electronics forms the micro-system, which is the basis for this technology. New concepts for a near-ideal, thermally sensitive structure will be explored within the next year. These devices have the potential to realize the full capability of uncooled thermal devices, which is greater than an order of magnitude (factor of 10) better than current performance.

In FY 2000, the program is investigating new concepts for thermally sensitive microstructures. The objective is the realization of unique designs to maximize the thermal response by developing near-ideal thermal isolation structures that permit reading the signal with minimum physical contact. In FY 2001, small arrays will be fabricated, with the objective to achieve less than 0.005-degree sensitivity, greater than an order of magnitude improvement over the current state of the art. This will prove that uncooled infrared can replace many of today's cooled sensors while meeting demanding requirements for the next generation of micro-imaging systems.

The objective of the **Photonic Wavelength and Spatial Signal Processing** program is to develop integrated electronic and optoelectronic device and module technologies that allow the dynamic and reconfigurable manipulation of both the wavelength and spatial attributes of light for adapting, sensing and image pre-processing. The reconfiguration and data pre-processing capabilities of these technologies will allow the design and manufacture of real-time sensing and imaging systems. This will be a significant improvement over the current generation of sensing and imaging systems, most of which are not capable of real-time data collection, analysis, and presentation. The availability of these technologies will enable rapid detection, identification, and classification of chemical and biological agents, for example; the same suite of technologies can also be used in the detection and recognition of targets and objects that are otherwise obscured from viewing.

During FY 2000, the first year of the program, we are developing the basic source and detector device technologies that cover the spectral bands between 350 nanometers and 18 micrometers. In FY 2001, the program will begin fabrication of the passive micro-optical elements required for integration with the sources and detectors. Two approaches to the fabrication of these elements will be studied: one approach will use micro-machining, and a second approach will use two-photon laser writing. Of the two approaches, the one amenable to large-scale manufacturing will be used to fabricate arrays of the passive elements.

The **Photonic Analog to Digital Converter Technology** program will develop and demonstrate applications of photonic technologies aimed at advancing analog to digital converter performance to achieve 12- to 14-bit resolution at sampling rates of up to 10 giga-samples per second. This level of capability provides better resolution and improved target imaging from radar signals, and far exceeds the existing or projected level of performance resulting from entirely electronic signal processing approaches. The ability to directly perform analog to digital conversion of multi-gigahertz signals at their source, while preserving their entire spectral content, will have significant impact on the performance of a wide range of radar, electronic warfare, and communication systems and create new architectural possibilities for these systems. In FY 1999, the program initiated research of individual components (lasers, modulators, photodetectors, and electronic quantizers) required to demonstrate enhanced analog to digital performance and demonstrated an initial, complete, optoelectronic analog to digital converter capable of operating at 200 mega-samples per second with 12-bit resolution and excellent linearity. In FY 2000, the program is continuing development of analog to digital components and evaluating alternative designs for the optical clock, optical sampler, and electronic quantizer modules. In FY 2001, we will evaluate the performance of components to better estimate the capabilities of a full-up system, and complete development of the optical clock, optical sampler, and electronic quantizer modules.

The **Molecular-level, Large-area Printing** program is investigating novel processes for the inexpensive fabrication of thin-film structures with nanometer dimensions on arbitrarily shaped surfaces. As an example application, the weight and complexity of an imaging system is significantly reduced if a curved, rather than flat, focal surface detector array is incorporated. In FY 1999, the program demonstrated fabrication tooling for deep, sub-micron printing over whole wafers, with sub-micron alignment. In FY 2000, the program is demonstrating fabrication technology for curved focal arrays and quantifying defect propagation in sub-micron printing. Next year, the program will demonstrate an imaging system incorporating a curved focal surface array and fabricate sensor elements on spherical surfaces.

The objective of the **Three-Dimensional Imaging** program is to develop the ability to rapidly capture a three-dimensional image of a target, and determine a detailed target profile. This will enhance significantly the ability to identify targets in cluttered backgrounds and to correctly identify friendly versus unfriendly targets. Imaging from fast-moving platforms and the requirement to rapidly engage multiple targets necessitates the development of an imaging array, which, with a single flash of laser illumination, provides both intensity and target depth information. The Three-Dimensional Imaging program focuses on the materials, detector, and unique electronics technology required to obtain, in a single pulse, a target depth-profile or three-dimensional image of the target, illuminated with a temporally short, eye-safe laser pulse. Key innovations in the technology are the ability to incorporate gain into the detector structure, fabricate focal plane arrays of high-gain detectors sensitive at short-wave infrared wavelengths, and to integrate range-processing circuitry into the unit cells at each detector. In FY 2000, the program is analyzing fundamental materials properties necessary to fabricate high-gain detection devices in the short-wave infrared wavelengths, with a focus on material defect reduction and the uniformity enhancement necessary for array development. The following year, the program will fabricate prototype arrays and evaluate them in the laboratory and in controlled field tests to assess the ability to obtain three-dimensional images and perform the target identification task.

The goal of the **Steered Agile Beams** (STAB) program is to develop small, lightweight laser beam steering technologies for the replacement of large, mechanically steered mirror systems for freespace optical communications and infrared countermeasures systems. New solid-state/micro-component technologies such as optical MEMS, patterned liquid crystals and micro-optics will provide the opportunity to incorporate small, ultra-light, rapidly steered laser beam sub-systems into a broader range of military platforms and man-transportable applications. These advanced subsystems will enable laser designators to simultaneously engage multiple targets, increase both smart weapon kill ratio and delivery platform stand-off distance (and, therefore, launcher survivability), allow full 360-degree infrared countermeasures coverage around aircraft and other high-value military assets, and provide a secure, covert means of high-bandwidth transmission programs for special operations forces and scout intelligence preparation of the battlefield. During FY 2000, the program is determining the optimum mix of technologies to be developed, and is establishing STAB system architectures and performance objectives for sub-system components to form the basis for managing risk and technical progress. In FY 2001, the program will develop, fabricate and evaluate the beam steering, emitter, and detector components and downselect to the most promising approaches.

The goal of the **Radio-Frequency Lightwave Integrated Circuits** (R-FLICS) program is to produce photonic technology that will enable development of high-performance radio-frequency components that can route, control, and process analog radio frequency signals in the very broad, but militarily crucial range of 0.5 to 50 gigahertz. Applications include antenna remoting, antenna beam-forming (scanning, null scanning and multifunctional-shared apertures), signal synthesis, frequency conversion and channelization, as well as very wideband remote processing. High-performance radio-frequency systems are critical to a wide range of advanced military radar, electronic warfare and secure communication applications, but are currently restricted to deployment on large weapons platforms due to the size, weight and power characteristics of electronics-based radio-frequency components. The R-FLICS program will develop smaller, lighter, yet higher performance photonics-based radio-frequency components capable of operating over a much broader range of radio frequencies, while also providing the form factors required by the small and rapidly mobile weapons platforms of the future. This program, which is beginning in FY 2000, is identifying promising approaches to photonic components or enhanced radio-frequency applications. The first year will also be spent developing radio-frequency-photonic modules that enable links with zero net radio-frequency loss from input to output and demonstrating optically integrated modules capable of performing complex radio-frequency functions such as signal channelization or single-chip generation of multiple radio-frequency signals. In FY 2001, the program will identify key applications for integrated radio-frequency photonic modules, produce initial prototypes, and demonstrate methods to evaluate their performance.

ADVANCED MATERIALS

The objective of DARPA's **Structural Materials** program is to tailor the properties and performance of structural materials to lower the weight and increase the performance of defense systems. Technologies are being pursued that will lead to ultra-lightweight ground vehicles and spacecraft as well as provide improved body armor for the individual soldier. In FY 1999, the program identified advanced concepts for ultra-lightweight body armor that will reduce weight by 50 percent, and transitioned low-cost, solid freeform manufacturing of titanium to the Navy for F-18 spare parts and to the Army for M1 hatch covers. In FY 2000, the program is investigating concepts for using multifunctional materials to greatly reduce the parasitic weight of structures in Defense systems as well as exploring new analytical and simulation technologies for the development and insertion of improved materials for Defense applications.

Three ultra lightweight body armor concepts, two of which use active armor techniques, have been presented to and are supported by the US Army Training and Doctrine Command Systems Manager-Soldier. The DARPA program is the first to investigate how active armor systems could be safely and effectively employed for personnel protection. The second phase of this program is now underway with the goal of demonstrating a full armor system in three years. If successful, this program will dramatically improve soldier protection, and the concepts developed might well extrapolate to armor for the Army's Future Combat Systems. In FY 2001, the program will demonstrate an ultra-lightweight body armor system against 30-caliber armor-penetrating rounds and begin transitioning the technology to the Army.

The objective of the **Mesoscopic Integrated Conformal Electronics** (MICE) program is to be able to create electronic circuits and materials on any surface, for example, on the wing of an airplane, the skin of a helmet, or the back case of a cellular phone. To do this, we are developing manufacturing tools to directly write or print resistors, capacitors, inductors, antennae and batteries on a wide variety of substrates. The MICE technology will also lead to more rugged electronics since there will be no need for solder, which tends to be brittle and to break easily. The program will go beyond writing on smooth, flat surfaces to being able to write on rough, curved surfaces. This year we have been able to print electronic parts on step edges as large as one-half of an inch, over 10 times the size previously done last year. We have also been able to print lithium-ion batteries on plastic, and these batteries have eight times the power density of any battery on the commercial market. Plans for next year include printing high-gain antennas on conformal surfaces and showing the ability to directly deposit living tissue on surfaces so that we can start the process of a printing a "living" machine.

The **Smart Materials and Actuators** program is generating new classes of materials and structures capable of responding and adapting to mission needs and the environment by integrating sensors and actuators. This technology is being developed to suppress vibrations and actively tune structures to reduce noise in systems like torpedoes and rotorcraft. Researchers are investigating shape-changing and shape-adaptive structures to increase speed, range, maneuverability and reliability, and decrease signature in rotorcraft, aircraft engine inlets, unmanned air vehicles, and selected marine systems. This program is currently demonstrating the benefits of these smart materials in systems of interest to the military. The program is demonstrating torpedo quieting using an active "sleeve" in underwater tests this year. We will also begin fabricating full-scale rotor blades with an active flap for a whirl-stand test and wind-tunnel test in FY 2001; a flight test is planned for FY 2002. The program is demonstrating the benefits of rotor blade twist, active aircraft engine inlets, and continuous control surfaces on unmanned vehicles in wind-tunnel tests this year. FY 2001 efforts include additional wind-tunnel tests of smart materials and actuator concepts for engine inlets and unmanned vehicles. The program completed efforts to develop a wake mitigation scheme for submarines using smart material-based actuators in FY 1999; this shape adaptive concept is now being transitioned to the Navy.

The objective of DARPA's **Functional Materials** program is to develop non-structural materials and devices that will enable significant advances in communications, sensing and computation. Examples include: magnetic materials for high sensitivity, magnetic field sensors and non-volatile, radiation-hardened magnetic memories; light-emitting polymers for flexible displays; and frequency-agile materials based on ferrite and ferroelectric oxides for high sensitivity, compact tuned filters, oscillators, and antennas. In FY 1999, DARPA demonstrated a high-speed, radiation-hardened, non-volatile giant magneto-resistive (GMR) magnetic memory that will have the speed of static random access memory (SRAM) with the density of dynamic random access memory (DRAM), applicable for space applications as well as "zero-time" boot-up of weapon systems computers. This program also demonstrated a number of concepts for novel actuation using polymeric materials. In FY 2000, the program is investigating light-emitting polymers that will form the basis of flexible displays. It will also will demonstrate a frequency-agile, lightweight patch antenna for UHF satellite communications that has 20 times less volume than existing antennas and thus is suitable for low-profile mounting on the roof of military vehicles. Permanent magnet materials for applications such as the "more electric aircraft" are also being explored. In FY 2001, the program will expand its work in electroactive polymers to include the development of thin-film spatial filters. In addition, it will begin to explore applications of meta-materials for artificially producing materials with electromagnetic properties unobtainable in nature.

The **Spins in Semiconductors** project aims to develop revolutionary new semiconductor electronic devices based on the spin of the electron, rather than the charge of the electron (as in all other conventional electronics). This project will develop new magnetic semiconductors, understand the fundamentals of spin transport across semiconductor interfaces, and demonstrate simple structures showing robust spin transport across interfaces. If successful, this project will offer unprecedented opportunities for very high-performance data processing, storage and transmission, ultra-secure communications and efficient data base management.

ADVANCED LITHOGRAPHY

The **Advanced Lithography** program is seeking solutions to critical technical barriers in emerging microcircuit fabrication technologies that are essential to improving the computational speed, functionality, size, weight, and power requirements of microelectronics. These performance improvements will benefit essentially all advanced military systems, including computation and signal processing for communications, sensing, and guidance systems. In 1999, two lithographic approaches pioneered by this program (157-nanometer optical and projection electron) moved from the laboratory to commercialization paths for prototype tools. The program also installed x-ray lithography at the Sanders production line to demonstrate a substantial reduction in fabrication cost for microwave circuits for the Air Force F-22 and the Army Longbow. In FY 2000, the program is pursuing aggressive approaches toward maskless lithography, which offers reduced fixed-tooling costs for the low-volume microelectronics production typical of military system acquisitions. In FY 2001, the program will demonstrate microcolumn components of an electron-beam pattern-writing design suitable for integration into an array of 32 parallel columns for a maskless writer with high wafer throughput (numbers of wafers written per hour).

MEMS

As I mentioned earlier, DARPA has played a pivotal role in the rapid expansion and military demonstration of Microelectromechanical Systems (MEMS) technology, which enables new ultra-miniaturization of mechanical components and their integration with microelectronics, at the same time improving performance and enabling new capabilities. The MEMS program is currently focused on developing integrated, micro-assembled, multi-component systems for applications such as aerodynamic control, signal-processing using electromechanical computation, inertial measurement and guidance, and microfluidic chip-technologies to be used for biological detection, toxin identification, DNA analysis, cellular analysis, drug preparation and drug delivery. The program is also exploring a greater variety of materials for MEMS devices and subsequently for integration of the MEMS devices with electronics. An example of system implementation enabled by MEMS technology is the ultra-miniaturized satellite (pico-satellite) previously discussed, which measures one inch by three inches by four inches and weighs only 250 grams. Two prototype pico-satellites were launched in January to demonstrate a new paradigm of space-based defense augmentation. Another successful demonstration includes a MEMS fuze/safing and arming device in a submarine torpedo counter-weapon.

This year, the program is developing micro-power sources and micro-communications components and will begin a demonstration of micro-airborne sensor/communications devices. These devices will form a massively distributed and completely autonomous sensor network. These new microsystem chips will provide the warfighter and unmanned reconnaissance vehicles with geolocation, communications and extended awareness capabilities. In FY 2001, the MEMS program will conduct remote-sensing and satellite inspection demonstrations with pico-satellites, and explore the use of nanotechnology for ultra-low-power molecular-level sensing and mechanical signal processing.

The objective of the **BioFluidic Chips** (BioFlips) program is to demonstrate technologies for self-calibrating, reconfigurable, totally integrated bio-fluidic chips with local feedback control of physical/chemical parameters and on-chip, direct interface to sample collection. In FY 2000, its first year, BioFlips is identifying promising approaches to integration of fluidic chip components and demonstrating several sub-system approaches to achieve system specifications and to perform modeling of microscale fluidics to evaluate designs. In FY 2001, BioFlips will fabricate initial microfluidic chip components that enable total on-chip integration and demonstrate chip interfaces with body fluids for collection and delivery.

BIOFUTURES (BIO:INFO:PHYSICAL)

DARPA's **BioFutures** thrust is a new effort in FY 2001, building on ongoing programs that have shown the glimmer of revolutionary advances for national security. This effort, which aims to combine biology with DoD's traditional investments in information technologies, electronics, optoelectronics, sensors, and actuators, offers tremendous potential. Each of these technical fields has reached a capability level where the combination can enable both fundamental and applications breakthroughs. Progress in biology will be greatly aided by the ability to understand and manipulate the massive data inherent in living systems. Microelectronics and sensors have reached the level of systems sophistication and miniaturization that they can directly interface with biological cells. The field of biological science and technology offer an understanding of systems complexity and robust operation using fundamentally unreliable components. We can use information technologies' increasing sophistication, combined with microsystems to better understand and measure biological systems. Understanding and learning to mimic the biological approach will enable new approaches for information technology, computers, and electronics, for example. We believe that pursuing this research combination may allow fundamentally new ways to design and manufacture materials and devices; design, control and interact with artificial systems; capture, store and process information; monitor humans and living systems; create fault-tolerant software.

The **Biomimetics** program is an example of an ongoing program that is combining these disciplines. Its goal is to extract and mimic design principles, materials, form, and function of biological systems in order to engineer new systems with enhanced structural and functional capabilities. The focus of the biomimetics efforts in FY 1999 was on fault-tolerant locomotion and sensing and actuation systems.

Biomimetic studies of force dynamics of winged locomotion have resulted in fundamental breakthroughs in our understanding of the aerodynamics principles of winged flight in flies and moths. Based on this knowledge, researchers were able to fabricate the first generation of winged components for micro air vehicles. These winged components operate using the principles demonstrated in flies and moths (this work appeared on the cover of the journal *Science*, June 18, 1999). Force dynamics studies have also increased our understanding of legged locomotion for omnidirectional walking, agile running, or vertical climbing. Researchers are now testing an omnidirectional underwater walking platform mimicking the motion, postural states, and behavior of the lobster in actual littoral zone conditions. Another project developed a vertical-climbing platform based on the force dynamics of the gecko. Researchers were able to recreate the dry adhesive structures and the unique foot that the gecko uses to climb vertical surfaces. Finally, researchers demonstrated a fast, dynamically stable, agile-running, legged platform based on the gait and force dynamic principles observed in cockroaches.

Sensing and actuation principles in biological systems have provided fertile ground for mimicry and engineering of new systems for Defense applications. Studying the principles used by biological systems to navigate and find targets in their environment has provided significant opportunities for mimicry and implementation in hardware and software systems. Researchers have learned that insects use the passing of visual cues as an odometer. This knowledge will provide new algorithms and principles to design image processing tools for unmanned guidance systems for navigation, grazing landings, and maneuverability of micro air vehicles (this work appeared on the cover of the journal *Science*, February 4, 2000). We also have learned how biological systems find targets in their environment, and have reproduced these algorithms in microelectronic controllers that allow robotic platforms to themselves find targets. Some insects have very sensitive infrared detection capabilities, and researchers have built detectors based on these biological systems, whose capabilities far exceed our current capability in infrared detection.

Other researchers are exploring marine invertebrate tissue that shows unique dynamic elasticity, and mimicking this material with synthetic fibers or liquid crystals. This could provide a new class of soft materials with which to fabricate biomimetic systems of interest to the DoD. The combination of the unique advantages of smart materials with other electro-mechanical concepts and appropriate power electronics has led us to develop highly efficient, compact hybrid actuators. Such innovative actuators could provide enabling capabilities for many systems including adaptive airframes, aerodynamic control surfaces, robotic locomotion, high-fidelity articulation of dexterous manipulators, and vibration isolation devices.

We will now extend these efforts to build an "exoskeleton" to augment human performance (i.e., increase the speed, strength, and endurance of soldiers). This program will develop technologies to enable a soldier to handle more fire-power, wear more ballistic protection, carry larger caliber weapons and more ammunition and supplies further, etc. This will provide increased lethality and survivability of ground forces in combat environments, especially for soldiers fighting in urban terrain. We plan to explore systems with varying degrees of sophistication and complexity, ranging from an unpowered mechanical apparatus to full-powered mechanical suits. The program will address key issues such as development of energy efficient actuation schemes and power sources with a relevant operational life, active control approaches that sense and enhance human motion, biomechanics and human-machine interfaces, and system design and integration. In FY 2000, the program is evaluating innovative actuation concepts using chemical energy sources such as hydrocarbon fuels to provide mechanical motion and is evaluating the efficacy of a complex system as well as some of the piece parts. In FY 2001, researchers will develop, characterize and test integrated technologies.

BEYOND SILICON

The **Beyond Silicon** program is a new effort. It is aimed at maintaining the phenomenal progress in microelectronics innovation that has served military systems designers so well over the last 30 years. Taking advantage of advanced materials deposition and processing techniques, techniques that enable increasing control over material and device structures down to nanoscale dimensions, the principal goal of the Beyond Silicon program is to achieve low-cost-to-manufacture, reliable, fast, and secure information systems critical to meet future military needs. Specifically, the program will investigate the feasibility, design, and development of devices and systems using approaches to electronic device designs that extend beyond today's practices that rely on scaling traditional complementary metal-oxide semiconductor devices. With a goal to develop new device capabilities, the program will explore options such as non-silicon-based semiconducting materials, including organic and amorphous materials. Components and systems leveraging quantum effects, and innovative approaches to computing designs incorporating these components will allow low-cost, seamless, pervasive computing, ultra-fast computing, and sensing and actuation devices. The program will start in FY 2001 by establishing program milestones to allow early identification of promising approaches that can lead to prototype demonstrations. In FY 2002, the program will demonstrate non-silicon-based transistor technologies using low bandgap materials capable of multi-gigahertz operation at bias voltages of less than one volt, as well as nanostructured materials for quantum-based electronic and optoelectronic device applications.

The rapid miniaturization of electronics has driven much of the development of advanced computation, communication and information systems for the DoD. To continue this trend far into the future, we believe that computers will be assembled using components such as molecules, and that the assembly will be accomplished using inexpensive chemical processes as opposed to today's painstaking fabrication methods. As a result of this thinking, DARPA is sponsoring a program in **Molecular-scale Electronics** (Moletronics). The long-term goal of the DARPA Moletronics program is to provide moderate computational power and high-density memory in an extremely small, low-power format (e.g., "a Pentium on a pin-head"). The opportunities are real; for instance, it is possible to perform calculations one billion times faster than the present generation microprocessor with significantly less power. Therefore, though some may argue that the silicon age is coming to an end in the not-too-distant future, it may well be that the real electronics era is still only in its infancy. It is quite exciting that the end of the silicon-based sovereignty presents great opportunities for discovery and to re-think computers and computer architectures. Moletronics will have high pay-offs in many applications. These include swarms of micro-robots and micro-sensors, high-speed image and data processing, wargaming simulations, archival storage, movies and compact disks smaller than a candy mint, and military applications where low power consumption is essential, such as unmanned vehicles and autonomous decision-making systems.

CONCLUSION

I appreciate the time here today to tell you a little about the important new technologies we are pursuing at DARPA and how they might impact our Nation's warfighters. As we invest in solutions to National-Level Problems, in technologies that Enable Operational Dominance, and in High-Risk, High-Payoff Technology Development and Exploitation to build the operationally dominant military systems of tomorrow, DARPA takes its role as the technical enabler for innovation for national security very seriously. I appreciate your support in providing the Agency with tools to exercise and grow our "change leader" talents. Our role is key to the success of the warfighter of the 21st century.

Thank you. I would be happy to answer your questions.

APPENDIX A – EXAMPLES OF SCIENCE AND TECHNOLOGY INVESTMENTS IN SUPPORT OF OUR WARFIGHTERS

QUICK-REACTION EFFORTS

- Two Tactical Mobile Robotics prototypes were recently deployed to Bosnia in response to an urgent request following the deaths of two Explosive Ordinance Detachment technicians attempting to recover highly sensitized grenades and explosives from inside overstocked bunkers. The robotic platforms' ability to deploy rapidly and operate in confined spaces enabled the 766th explosive ordinance detachment to set a record for the number of explosive devices recovered in a single day.

RESULTS FROM SHORT-TERM RESEARCH

- The DARPA Semi-Automated Imagery Intelligence Processing Program (SAIP) has developed and demonstrated advanced image analysis automation technologies to aid intelligence analysts in interpreting airborne radar imagery from systems such as the U-2 and the Global Hawk unmanned aerial vehicle. SAIP permits tactical analysts to interpret real-time radar data much faster and more accurately than ever before possible. Two DARPA SAIP systems have been deployed and are in operational use: one with the Army Enhanced Tactical Radar Correlator ground station and one with the Air Force Contingency Airborne Reconnaissance System Deployable Ground Segment ground station.

- The Small Unit Operations Situation Awareness System program has demonstrated a method to provide accurate geolocation of dismounted warfighters inside buildings and in other restrictive terrain where GPS is not available. The method uses communications ranging signals from other soldier team members and provides relative accuracy of two to three meters, which is sufficient to allow warfighters to know what rooms their teammates are in. Current experiments show that the system provides accuracy to within three meters 40 percent of the time. Detailed simulations show that a newly discovered signal processing technique will increase the probability of highly accurate geolocation to 95 percent.

- In 1999, DARPA transitioned knowledge-based scheduling algorithms to the Air Force's Air Mobility Command to support more efficient management of airlift tasks and enhanced deployment and resupply capability. These scheduling algorithms work 200 times faster than previous algorithms, automating what had previously been a manual decision-making process. The more efficient schedules produced with DARPA technology mean that three percent of the airlift missions need not fly, translating into savings of $63 million annually, or, alternatively, there is three percent more airlift capacity available for our military forces.

- A DARPA-developed prototype quadrupole resonance landmine detection system demonstrated 100 percent detection of all antitank and antipersonnel landmines with no false alarms after a single rescan of initial alarms. The U.S. Army Project Manager for Mines, Countermine and Demolitions will further develop and field quadrupole resonance equipment for landmine detection on roads, and the U.S. Marine Corps plans to pursue a program to field quadrupole resonance for handheld detection applications.

- DARPA's Tactical Mobile Robotics program has developed what may be the world's first autonomous stair-climbing robot. This achievement is destined to have a huge impact on urban operations because of the tendency for stairways to confine vertical passage and amplify weapons effects with ricochets, intense overpressures, etc. Current platforms can climb stairs about as fast as a human walks, and have more stamina than a human. Future enhancements will improve the robots' power efficiency and their ability to avoid trip-wires and booby traps.

- The jointly sponsored (Air Force/Office of the Secretary of Defense/DARPA) Miniature Air-Launched Decoy (MALD) Advanced Concept Technology Demonstration began four years ago with the objective of providing an affordable radar spoofing system. The ACTD has achieved this objective. MALD successfully completed developmental testing and operational demonstration while establishing the average unit flyaway price of $30,000 (based on a purchase of 3,000 units). During the operational demonstration, the Air Force Flight and Operational Test Center assessed the system to be "potentially operational effective," and to provide "tactically significant capabilities for the Air Force." Furthermore, Air Force Studies and Analysis concluded that the system has "significant military worth" and provides a return on investment of 13-to-one on saved manned aircraft hardware. General Michael Ryan, Air Force Chief of Staff, is considering low-rate initial production in FY 2003-2004.

RESULTS FROM LONG-TERM RESEARCH

- DARPA sponsored a program to demonstrate the operational reliability and system level benefits of advanced ceramics in fielded military systems. The Air Force is now evaluating ceramic fiber reinforced ceramic matrix composites to replace the current metallic exhaust nozzle divergent flaps on F110 engines for the F-16C. Repair and replacement of metallic flaps are a major contributor to operation and support costs for the F110 family of engines.

- Fuel cells are a promising alternative for ship service power and propulsion as they offer higher efficiencies and lower thermal signatures than diesel generators and gas turbines. A major technological hurdle that must be overcome is the conversion of high-sulfur-containing heavy fuels into clean hydrogen for introduction into the fuel cell. DARPA pioneered the development of fuel processing technologies that have converted high sulfur (3,000 parts per million) Navy distillate to hydrogen that has been successfully consumed by a fuel cell to generate electricity. This technology has been transitioned to the Navy for its fuel cell ship service and propulsion program, which intends to install fuel cells aboard Navy and Coast Guard vessels.

- If one could fabricate transistors and logic as easily as printing ink one might enable a myriad of new devices from paper-thin, rollable, disposable electronic displays to extremely inexpensive logic and radio frequency identification tags that could be imbedded in everything from items on a supermarket shelf to clothing to paper. The Jacobson group at Massachusetts Institute of Technology's Media Lab working in the Amorphous Computing program has developed the first inorganic transistors and logic fabricated by printing. This will allow semiconductor chips to be printed on a desktop printer, leading to much lower costs for the specialized chips necessary for unique military applications.

- In March 1999, Nomadics demonstrated the first-ever detection of buried landmines using a chemical sniffer. The system uses self-amplifying polymers developed at the Massachusetts Institute of Technology specifically for the detection of TNT. At present, laboratory tests indicate that the Nomadics sniffer, aptly named FIDO, is capable of 100 parts per quadrillion detection of explosive vapors, which is equivalent to the ability to detect one drop from an eyedropper in 25 Exxon-Valdez-sized tankers. It is hoped that detection of the explosives materials in the landmine (rather than the metal content or disturbed ground) would reduce the extremely high false alarm rates experienced with conventional detection techniques.

- The Solid Freeform (SFF) Manufacturing program demonstrated the capability to produce ceramic components with form, fit and function comparable to components produced by commercial, high-volume processes. SFF machine capabilities include three-dimensional printing, fused deposition, shape deposition manufacturing, stereolithography, and laminate object manufacturing. A 30-fold reduction in both prototyping time and cost have been demonstrated using SFF compared to conventional manufacturing methods for components with complex geometries.