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Before The

Committee on Armed Services
Subcommittee on Acquisition and Technology

United States Senate

March 12, 1998

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Mr. Chairman, Members of the Senate Armed Services Subcommittee on Acquisition and Technology. I am very honored to have been invited here today to explain the Agency's strategies and programs, to discuss our FY 1999 plans, and to brief you on some of our recent accomplishments.

INTRODUCTION

The Defense Advanced Research Projects Agency was chartered in 1958 as the central research and development organization of the Department of Defense. Its responsibility at that time, and today, 40 years later, remains the same: to maintain U.S. technological superiority over potential adversaries.

DARPA has been responsible for technological innovations that have revolutionized the military and changed the lives of the average American. The most obvious example is our development of packet-switching technology, the technology on which the Internet and World Wide Web is based. The military, as well as the civilian world, has been transformed by the ability to so easily and quickly share information and data.

Some of the most important military innovations of the last 25 years resulted from DARPA's investments in early science and technology demonstrations.

The concept of an airborne, target acquisition, weapon delivery radar was first initiated as a joint DARPA/Air Force program called Pave Mover. Pave Mover incorporated moving target indication radar and synthetic aperture radar. This program provided the basis for today's Joint STARS, a system that has proven so important to commanders that it was deployed in support of Operation Desert Storm while still in development. Subsequently, Joint STARS was used again to give NATO Peace Implementation Force commanders insight into the activities of the warring parties in Bosnia.

DARPA championed the cause of low-observable characteristics for aircraft long before anyone in the Services believed that such a concept was possible, feasible, or even necessary. When a DARPA-sponsored study in the early 1970s concluded that U.S. aircraft were vulnerable to detection by enemy radar, DARPA embarked on the HAVE BLUE program to demonstrate technologies for a stealthy aircraft. After a successful flight, and demonstrations of the aircraft's decreased radar cross section, the Air Force started the development of the now operational F-117 stealth fighter.

DARPA even had an impact on the Army's choice of the M-16 rifle as the main assault rifle for the last 30 years. DARPA demonstrated the enhanced capabilities of the AR-15 rifle in field trials in Southeast Asia and showed that the AR-15 was superior to the M-14, which had been the Army's original choice to replace World War II-era M-1 and Browning Automatic rifles. The design of the current M-16 is based on the AR-15 design.

In 1996, I commissioned a study to investigate the methods by which DARPA technologies have transitioned over the years into systems used by the operational military. The object was to understand how the transition process could be improved. The results of that study, *Technology Transition*, have recently been provided to this Committee. The study documents over 75 transitions of DARPA technologies into the Military Services since DARPA's founding.

DARPA's science and technology investments complement those of the military Services and research and development agencies. We work with these other organizations in the development of the DoD Science and Technology Strategy. Our investments are fully characterized and integrated in the Joint Warfighting Science and Technology Plan, the Defense Technology Area Plan, and the Basic Research Plan. In addition, we work closely with the unified commanders and the Joint Staff as they implement Joint Vision 2010.

DARPA has, for the last 40 years, taken on the role of investing in the most speculative technologies, that is, those that offer a spectacular pay-off to the military if successful, but that are high risk. We are driven by ideas, and we manage our efforts as discrete projects, each with a defined outcome and transition strategy. In contrast to other science and technology agencies, we do not respond to formalized requirements, nor do we program our investments to build up particular disciplines. At DARPA, a sustained investment in a particular technology area is often characterized by consecutive projects, each with an identifiable outcome. Although we learn much from our failures, true success comes when a DARPA technology investment culminates in a transition to a military customer.

DARPA is a small organization made up of personnel with the highest possible credentials in their disciplines. Our program managers come and go, bringing with them new ideas and new approaches and perspectives to solve the military's and technology's most intransigent problems. As program managers leave DARPA, they take with them the unique experiences they have gained here, helping the most advanced technological ideas transition into industry, academia, and the Military Services.

I have spoken to you in the past regarding our difficulty in recruiting and hiring the most outstanding talent from industry. This continues to be an issue with which we are grappling. We are successfully using the Intergovernmental Personnel Act to recruit highly capable program managers from within academic, non-profit and state and local government circles. We are examining alternatives to our personnel and salary structures to be able to aid in the recruitment of the best talent from industry.

It is crucial that DARPA retain its current size. Much larger, and the common bureaucratic impediments that inflict larger organizations will prevent us from quickly capturing and capitalizing on technological innovations. There are other science and technology organizations within DoD, but DARPA's small size, lack of bureaucracy, and strategy of investing in high-risk, potentially high-payoff technologies makes it unique. Over the last 40 years, these characteristics have allowed DARPA to have some truly outstanding successes. These characteristics must be maintained for the future.

One of DARPA's highest priorities is the development of technologies and systems that will give Joint commanders comprehensive awareness of the battlespace. We define "comprehensive awareness" as an ability to dynamically manage sensors for optimum collection of data. Comprehensive awareness embodies: a wide variety of sensors and platforms to collect the data needed by commanders; systems to filter, fuse and fully exploit the data and transform it into information; and systems to disseminate the proper information to commanders when and where needed. All of these systems rely on an underlying dynamic database that has access to all types of stored data and can quickly access the information needed by various systems. You will see our investments in these areas reflected throughout the Precision Engagement pillar of Joint Vision 2010.

In addition, we place a high priority on full-dimension protection. Adversaries in the next 20 years will find new ways to challenge U.S. forces. Adversaries are likely to use weapons of mass destruction, especially biological and chemical warfare, and will seek to target U.S. information systems through information warfare. Accordingly, DARPA has key investments in the area of biological warfare defense and information survivability and protection.

The Revolution in Military Affairs and the Department's concept of transformation anticipates that the world 20 years from now will be very different and will be populated by uncertain and asymmetric threats. Our military strategies are evolving, and the technological underpinnings must be there to support these new visions. To enable these visions, DoD must invest now in a robust and varied — but carefully selected — science and technology program to enable the RMA transformation of the future.

There is much talk about the readiness of today's forces and the need for an increased investment in modernization. I think we can all agree that today's readiness and equipping U.S. armed forces with the most advanced military systems are paramount. What seems so often lost in the debate is the realization that the capabilities we have today to modernize and equip today's forces are based on science and technology investments made 10 or more years ago. It is clear that today's science and technology investments are the only way to prepare DoD for an uncertain future. There will be no RMA without the technological options and new ideas that today's science and technology investment will provide. DARPA lies at the heart of this preparation, as it develops winning technologies on behalf of current and future U.S. soldiers, sailors, airmen and Marines.

THE MILITARY "PULL" OF JOINT VISION 2010

Joint Vision 2010 is the Department's template for the world of 2010. It describes four concepts that will allow future forces to achieve full spectrum dominance: Dominant Maneuver, Precision Engagement, Full-Dimension Protection, and Focused Logistics. Many of DARPA's investments are oriented toward providing systems and capabilities in support of these concepts. In addition, we have additional projects to develop enabling technologies that are key to a broad spectrum of future warfighting capabilities. So let us use Joint Vision 2010 as the organizing framework for describing the many DARPA programs influenced by the warfighter's view of our nation's future defense environment.

DOMINANT MANEUVER

The concept of Dominant Maneuver envisions U.S. forces that are widely dispersed, yet highly capable. Several DARPA programs support Dominant Maneuver.

One particular thread that DARPA sees as key to successful Dominant Maneuver in the world of 2010 is the use of unmanned and minimally manned systems. These systems will use the most advanced technologies to let machines perform the today's hazardous missions, thus minimizing casualties to the military's most important resource, its people.

The Miniature Air-Launched Decoy (MALD) Advanced Concept Technology Demonstration is developing an affordable decoy that can be carried by any tactical aircraft for the suppression of enemy air defenses. The MALD, when launched, appears to ground-based enemy radar to be an aircraft, causing the air defense radar to turn on. The air defense radar can then be targeted by a weapon such as the High-speed Anti-Radiation Missile (HARM). MALD's required unit flyaway price is $30,000 per decoy, which is one-third of the cost of DoD's most advanced current decoy. MALD will weigh less than 100 pounds, enabling tactical aircraft to carry multiple MALDs externally or internally. This year, we will conduct the critical design review, followed by the start of flight tests. At the end of FY 1999, flight tests will conclude, and 100 MALDs will be provided to Air Combat Command for additional testing. To ensure a successful transition, DARPA is producing all the documentation necessary for a DoD Acquisition Category III system to enter into the DoD acquisition system and be approved for Milestone III (production/fielding/deployment).

So far, I have talked mostly about the MALD capabilities for the warfighter, and our acquisition strategy. A more interesting highlight about MALD is the program's use of commercial technologies in order to meet the $30,000 unit flyaway price. The flight management computer is the same computer that soft drink manufacturers use in their vending machines. MALD is using an inertial measurement unit from commercial television camera stabilizers, The Global Positioning System receiver in MALD is the same one used by the automotive industry for their upscale option to indicate the car's location. The decoy is made almost entirely of plastic with a metallic coating, and the plastic parts are manufactured beside automotive parts. All in all, we estimate that 85 percent of MALD is produced by commercial vendors. This is revolutionary. We hope, when we fly, to show the DoD acquisition community the exceptional possibilities open to DoD as we move away from Military Specifications and Standards and leverage the manufacturing capabilities and technological know-how of commercial industry.

The air defense threats of the future will have a greater lethal range, be more mobile, have more advanced capabilities and be more plentiful. These facts, coupled with a decreasing number of U.S. tactical fighter aircraft due to decreasing budgets, led DARPA and the Air Force to initiate the Unmanned Combat Air Vehicle (UCAV) Advanced Technology Demonstration program. The joint program will demonstrate the technical feasibility of a UCAV system to effectively and affordably prosecute 21st century, lethal strike missions within the emerging global command and control architecture. The unmanned nature of UCAV is expected to allow more than a 65 percent reduction in aircraft acquisition cost, and more than a 75 percent reduction in operations and support costs (because operators will not have to fly the vehicle to train and maintain currency). The program envisions mission control that permits rapid mission planning and retasking, multiple vehicle control, and weapons authorization, all based either on the ground, onboard ship, or in an airborne platform. The technologies we envision for the air vehicle include: seamless control surfaces without a vertical tail; fly-by-light; thrust vectoring; electric actuators; advanced digital processing; robust command and control; built-in test; and low-cost manufacturing. This year, we will award multiple contracts for preliminary design development and risk reduction studies to define the operational system's effectiveness and affordability. In FY 1999, we will select a single contractor to finalize a design and build two test vehicles. Flight tests are expected to start in FY 2002. UCAV will serve as a force enabler by conducting preemptive — as well as reactive — suppression of enemy air defense and strike missions in support of post-2010 manned strike packages.

In another effort to develop unmanned systems that will help U.S. forces facing the asymmetric threats of the future, DARPA is developing Tactical Mobile Robots that would be useful in an urban assault operation. These autonomous robots would work together in teams. Each robot would have advanced sensors for “vision” and navigation and mapping capabilities, and would be able to climb stairs and move at a tactically useful speed, while doing a significant amount of on-board processing. This year, we will further develop the concept and perception, autonomy, and locomotion technologies. In FY 1999, the program will conduct demonstrations of the perception, autonomy and locomotion capabilities in urban scenarios and refine the system design.

In addition, DARPA is developing technologies for micro-robots that would remove the warfighter from harm’s way, enhance and expand the users’ capabilities, and go where humans and larger systems cannot go. The Distributed Robotics program is focused on developing small (less than five centimeters in any one dimension), inexpensive and limited capability robots that can operate collaboratively to achieve results that are superior to those possible with larger, more expensive robots. Technologies that will be stressed in this program include locomotion, power, computation, behavior algorithms, and the platform design itself. The applications of these small systems will be myriad — surveillance and tactical information collection, unexploded ordnance detection, building penetration, tags for tracking, biological warfare and chemical agent detection, and perimeter protection. The Distributed Robotics program is starting this year. We have selected 12 proposals for funding, ranging from the development of a wireless micropower communications system, to a number of different control schemes for distributed robotics. In FY 1999, researchers will build a variety of robotic platforms and demonstrate their ability to perform multiple, cooperative functions in groups.

The Micro Air Vehicle program is developing fully functional air vehicles that are less than six inches in any one dimension. They will provide situational awareness for small units, especially in urban terrain and inside buildings. We envision these systems as useful for the Army, Marine Corps, and Special Operations forces for reconnaissance, surveillance, targeting, and biological and chemical warfare agent detection. The technical challenges for this program are myriad: controlling flight at these very small sizes; providing the vehicle with high energy and power density from the propulsion system; integrating the necessary avionics for geolocation and autonomous guidance, and developing sensors and payloads that are functional, yet small and light. We are supporting work in micro- and mini-turbine engines (the smallest of these engines is less than an inch in diameter), solid oxide fuel cells, thermoelectrics and small internal combustion engines. We are also developing a number of vehicle concepts, ranging from a disk-shaped, propeller-driven vehicle, to a "flying saucer"-like vehicle, to three efforts with flapping wings. This a truly exciting program, as it opens a new arena for flight with revolutionary technologies while providing outstanding local situational awareness to the platoon-level unit facing tomorrow's asymmetric threats.

The Advanced Tactical Targeting Technology (AT3) program will develop and demonstrate a passive tactical targeting system for the lethal suppression of enemy air defenses (SEAD). U.S. warfighters are being faced with threat radars that illuminate U.S. aircraft and then quickly turn off, making the enemy air defense radars difficult to engage. Another common threat tactic is to shoot-and-scoot, shortening the available time for SEAD targeting. Current SEAD targeting approaches are limited by targeting accuracy and timeliness. AT3 will develop technology that enables the targeting of mobile air defense systems with sufficient rapidity and accuracy that current and planned weapons can be aimed at the target coordinates and destroy the threat despite emitter shutdown. AT3 leverages advanced technologies in precision clocks, tightly coupled Global Positioning System and inertial navigation systems and digital receivers to develop distributed, long-range, passive emitter location techniques to accomplish this mission. Critical objectives are affordability and the ability to perform within an air-strike package with minimal constraints on tactics or prior knowledge of target locations. In FY 1998, contractors will develop the preliminary system design. In FY 1999, they will finalize the design, conduct critical component demonstrations and begin brassboard fabrication.

In support of the Small Unit Operations, the Army After Next, and Sea Dragon concepts of operations, DARPA is developing a Situational Awareness System (SAS) to enable the land warrior to fight effectively anywhere, even in urban environments, restrictive terrain or if being jammed. The SAS will provide robust, secure, covert communications, precise navigation and geolocation information, assured fire support, and the ability to collaborate while planning and executing missions. The situational awareness provided will be tailored to the needs of the warfighter, to give him only the information he needs and wants. Most importantly, the system will be low-power, using one-half kilogram of batteries each day, and low-weight, weighing only one kilogram (without batteries). This year, contractors will develop preliminary, competing designs. In addition, enabling technology work on human-machine interfaces, programmable, ultra-low power radios, power-efficient communications protocols and other areas will be completed. In FY 1999, we will conduct proof-of-concept demonstrations of individual technologies to prove the underlying principles of enabling communications and geolocation in restrictive terrain. We will then downselect to a single contractor and will build several prototype SAS systems for user tests in FY 2000.

The Advanced Air Vehicles program is exploring innovative design concepts that offer significant advances in performance, affordability and military utility for the Navy and Marine Corps' vertical take-off and landing (VTOL) unmanned air vehicle for littoral and urban warfare missions. We are supporting two approaches that can operate at longer ranges, higher altitudes or higher speeds than current VTOL systems, with a reduced signature. In this three-year Advanced Technology Demonstration (ATD), we are capitalizing on past contractor independent research and development spending, as well as industry cost-share. The Canard Rotor Wing (CRW) concept is a small vehicle which takes off as a helicopter and transitions to fixed wing flight. This program will conduct risk reduction activities and design, fabricate and flight-test two CRW vehicles. This year's activities include sub-scale stability and control testing, full-scale engine testing, and control law development. Next year we will conduct detailed design of the demonstrator vehicles, initiate the development of a hardware-in-the-loop simulation, and begin vehicle fabrication. The ATD program will culminate in hover, transition, and fixed-wing flight testing in mid-FY 2001. The Hummingbird Program to develop an unmanned helicopter with 24-hour endurance, will develop advanced rotor technology with analysis and ground-testing in the first 12 months of the 30-month program. Concurrent flight-control avionics testing will also take place during this period. After successful whirlstand testing, the program will build three flight articles to demonstrate the expected gains in endurance, range and altitude.

The Affordable Rapid Response Missile Demonstrator (ARRMD) program will demonstrate a low-cost ($200,000 average unit flyaway price) missile capable of speeds of Mach six to eight. ARRMD will be able to undertake rapid response, long-range missions against time-critical, heavily defended or hardened targets. We are designing the missile so that it can be launched by all tactical fighters, strategic bombers and Navy shipboard launching systems. ARRMD will be able to reach targets 600 nautical miles away in less than 10 minutes, compared to the best current cruise missile travel-time of approximately 75 minutes. During its flight time, ARRMD will continue to receive targeting updates from a variety of off-board sensors. This spring, we will select two contractors to design competing concepts. In FY 1999, the contractors will demonstrate critical components, finalize the design, and conduct engine ground tests.

In an effort to revolutionize the way small missiles are manufactured, transported and fired, DARPA is developing and demonstrating a system of containerized missiles that can be remotely fired directly from the container, as recommended by the Defense Science Board. The Advanced Fire Support System's containerization concept eases transport and deployment, requires minimal force structure for deployment, and the same missile system can easily be used on multiple platforms. In addition, because a modular family of related missiles could be used, procurement and life cycle costs should be lower. Concept definition and feasibility studies are currently being conducted. In FY 1999, we will conduct simulations to model the entire system, including fire control and communications, in order to: determine the operational impact of tradeoffs between size and range; establish tactics, techniques, and procedures; quantify the value of the optimized system; and simulate and assess virtual firings. We will also begin the design and development of objective systems for small (four feet long) or medium (eight feet long) missile systems.

The Affordable Multi-Missile Manufacturing (AM3) program is developing and demonstrating innovative design, manufacturing, business practices and systems concepts that can substantially reduce the cost of DoD's portfolio of tactical missiles and smart munitions. Last year, the program entered its final phase, when two contractor teams were selected to demonstrate improved missile manufacturing concepts on existing missile programs. By the end of the program in FY 2000, we hope to demonstrate a 25 to 50 percent reduction in missile acquisition cost and a 50 percent reduction in development time. The Military Services have agreed to insert AM3 technologies and business practices into ongoing missile programs when the program goals are substantiated through AM3 tests and demonstrations.

FY 1998 is the last year of funding for the Electric and Hybrid Vehicle Technology program. The DoD follow-on programs, the Combat Hybrid Power System program and Reconnaissance, Surveillance and Targeting Vehicle, will enable combat vehicles offering a 50 percent reduction in fuel consumption.

The Combat Hybrid Power System program is developing an integrated power system for a 15-ton Future Combat Vehicle for Army After Next concepts of operation. In addition to providing hybrid electric power for propulsion as demonstrated in the retrofitted combat vehicles, this new power system will also provide high-energy pulsed-power for electric guns, directed-energy weapons and electromagnetic armor. To date, the program has designed the notional power system architecture, and has developed the required enabling technologies. During FY 1998, contractors will build and test critical components, and next year, will demonstrate the initial power system configuration.

Last year, DARPA initiated a joint program with the Marine Corps to develop a lightweight, highly maneuverable Reconnaissance, Surveillance and Targeting Vehicle that will use hybrid electric propulsion, have advanced survivability features, and be rapidly deployable in the V-22 Osprey. The vehicle will be useful for small unit operations, and will support extending the littoral battlespace and Army After Next concepts of operations. The vehicle’s cost goal is $105,000 unit rollaway (without sensor or targeting systems); this cost goal becomes $750,000 for a vehicle equipped with a full reconnaissance, surveillance, target acquisition electronics suite, associated communications systems and advanced survivability features. The advanced, hybrid electric propulsion will give the vehicle superior speed and fuel efficiency. The goals are double the acceleration speeds of the HMMWV, with more than double the fuel efficiency. For the first phase of the program, two contractors are developing competing designs. In FY 1999, we will select one contractor to build and test its design.

In support of undersea littoral warfare, DARPA has developed and tested an active acoustic system for enhanced detection, classification and targeting of submarines in the difficult littoral regions. The system uses an air-droppable sound-source that generates a sound wave; multiple listening sensors; and a torpedo linked via a fiber optic tether. The information from multiple sensors is fused and processed using advanced signal processing algorithms and neural networks processing to allow a superior detection probability. Then, because of the datalink to the torpedo, the submarine track can be provided to the torpedo after launch, enhancing the probability that the torpedo will find the submarine and destroy it. Last year, we demonstrated the sound-source, multiple sensors and advanced processing at sea, with excellent results. The Distant Thunder demonstration used Navy sonobuoys and towed arrays, with DARPA providing the sound-source and the signal processing capabilities. This year, DARPA will improve the sound-source and modify a Mk 46 torpedo to add the fiberoptic tether. In FY 1999, the total system will be demonstrated in an operational scenario. This a joint program with the Navy, and will transition to the Navy following demonstrations.

FY 1999 is the last year of DARPA funding for the MARITECH program. As you recall, MARITECH was started in FY 1994 as a national initiative to assist the U.S. shipbuilding industry in improving its international competitiveness. During the 1970s and 1980s, the U.S. shipbuilding industry was busy building Navy ships. As the Defense budget decreased, the industry needed new business from other sources, but could not compete with overseas shipbuilders to get this new business. MARITECH, by improving the competitiveness of the U.S. shipbuilding industry, insures that the U.S. Navy has access to the most advanced shipbuilding technologies at competitive prices. In MARITECH's five years, U.S. shipbuilders have developed more than 30 designs for commercial vessels, with 21 commercial ships now under construction. Nine of these ships are for foreign customers. New, more productive build strategies have been implemented and shipbuilding efficiencies have begun to improve. The average time required to build a ship has decreased by approximately one year, with 20 percent fewer man-hours. U.S. shipyards are investing hundreds of millions of dollars to modernize their facilities, and there are MARITECH projects underway that will put into place an industry-wide electronic infrastructure. This all translates in a more competitive U.S. industry. DARPA's last year of MARITECH funding will put into place the beginnings of a national shipbuilding technology consortium and devise a strategic plan for future shipbuilding technology development investments. In FY 1999, DARPA MARITECH funding will be used for the Navy to begin a follow-on MARITECH initiative which the Navy is calling MARITECH Advanced Shipbuilding Enterprise. This will allow the competitive efficiencies begun under the DARPA MARITECH effort to continue and be more quickly realized in Naval ship construction. The Navy plans to fund the continuation of this initiative beginning in FY 2000.

In another innovative maritime program useful to littoral warfare, DARPA is demonstrating a method that destroys mines in the littoral area using sound waves, allowing in-stride mine-clearing of a wide area. Destroying mines in the littoral area today requires time consuming and hazardous diver operations. The transition of sea warfare closer to shore makes the clearing of mines and obstacles in the littoral an increasingly critical function. DARPA's Water Hammer program will develop and demonstrate a concept that uses a high-energy pressure-pulse that will rapidly destroy bottom and moored mines and other objects tens of meters away, reliably clearing a lane along which forces may advance. Last year, one type of pulse generator tested in a quarry was able to buckle an empty sea mine casing. We have now demonstrated a newer pulse generator that can generate the proper pressure shock wave repetitively. We will first demonstrate an array of four of these new generators to verify that we can control the mutual timing and waveforms with sufficient accuracy to obtain a cumulative destructive effect. In FY 1999, the program will develop, deploy and test a second array of nine or 16 generators working together.

The Joint Vision capability of Dominant Maneuver foresees the use of widely dispersed forces that are highly capable and versatile. DARPA and the Services are developing systems that provide more capability to these dispersed units. But additional capability often comes at a price — energy and power. The Defense Department accounts for 75 percent of the total energy used by the Federal government. Half of the DoD's energy goes to support fixed bases, and half goes to forces on the move. The average soldier carries a total of 80 pounds of equipment, 10 pounds of that total is devoted to batteries. DARPA is keenly aware of the limitations imposed by batteries, and has, for a number of years, been investing in alternative energy sources — fuel cells and technologies to convert logistics fuels into useful power. Energy conversion devices such as fuel cells have advantages over batteries because the soldier can carry one device for energy conversion plus the amount of fuel required for the mission. For long missions, this approach is far superior to carrying the equivalent amount of energy in the form of multiple batteries. Researchers are continuing to validate various approaches and increase the power output to useable levels. In FY 1999, we will demonstrate a direct methanol oxidation fuel cell that can replace the military's non-rechargeable battery (BA-5590).

The newest effort is looking at "harvesting" energy sources from the environment. We are in the early stages of investigating systems that use biological catalysts such as enzymes for transforming biological matter into fuels that can then power a fuel cell. In addition, two researchers are trying to devise methods to capture useable energy from linear motion and vibrations. These could potentially be placed in the boot of a soldier to capture energy dissipated during walking. In FY 1999, we will expand on these concepts and begin to integrate energy harvesting components with small energy-consuming devices.

PRECISION ENGAGEMENT

The second Joint Vision pillar is Precision Engagement. The Joint Vision concept of precision engagement assumes that joint forces have near-real-time information, a common awareness of the battlespace for responsive command and control, more precise targeting capabilities, and the ability to rapidly and accurately assess battle damage. DARPA is providing a number of technologies and system demonstrations that will implement the Joint Vision precision engagement pillar to provide comprehensive awareness and planning and command and control capabilities across the battlespace.

Comprehensive Awareness

Our comprehensive awareness efforts include dynamic sensor management systems, sensors and platforms for data collection, analysis and fusion tools for data exploitation, and systems for information dissemination. The future battlefield will be observed by a variety of sensors — video, synthetic aperture radar (SAR), moving target indicator radar, foliage penetration radar, and visible and infrared spectral sensors. As the number of fielded sensors and platforms continues to grow, commanders increasingly require the ability to efficiently manage sensors for optimum data collection. Commanders must also be able to sift rapidly through massive volumes of multisensor data to keep pace with changing tactical situations. The timely extraction, correlation, and dissemination of information from the mountain of available data is vitally important to realizing the objectives of Precision Engagement within Joint Vision 2010. Our ultimate aim is to provide technologies and systems that will enable fully automated data processing and information extraction for future commanders.

The Dynamic Database (DDB) program will develop and demonstrate a prototype system that allows warfighters to make use of all available multisensor data to continuously monitor dynamic situations. Situation dynamics include changes associated with stationary targets, moving targets, electronic emissions, and terrain attributes. The DDB will produce a multisensor history of the battlefield by developing technology that mines, spatially registers, and efficiently stores essential situation information from all sensor data collected over a region of interest. Initial multisensor data will consist of synthetic aperture radar, infrared, electronic and communications intelligence, and moving target indicator radar. Essential situation information includes raw multisensor data, as well as battlefield information gleaned from both automated and semi-automated data exploitation technologies. The DDB will also develop advanced change detection algorithms that allow users to keep pace with rapidly changing multisensor history by alerting them to significant battlefield changes. The program will start in mid-FY 1998 with the selection of multiple contractors for an initial 18-month performance period. In late FY 1999, we plan to demonstrate database technologies that ingest large volumes of raw multisensor data, align and register the data to a common spatio-temporal reference frame, detect and cue the database user to data changes, and provide the user ready access to historical multisensor data.

The Dynamic Multi-user Information Fusion (DMIF) program will develop next-generation capabilities to support operational fusion systems. The program will strategically control automated fusion of information from multiple sensor sources and from multiple situation awareness applications (or “fusion engines”). The common operational picture produced by DMIF will improve interoperability and reduce commanders’ information overload. This year, the program will characterize the performance of an initial set of fusion engines to find the conditions under which they achieve peak performance. The program is also “encapsulating” those fusion engines (including deployed systems from multiple Services and agencies), i.e., it is providing software to make the systems interoperable. A laboratory demonstration that uses multiple fusion engines to provide real-time situation awareness to an operations application (Joint Forward Forces Air Component Commander) is planned for later this year. Next year, encapsulation and performance characterization will be extended to additional fusion engines, along with development of a “fusion strategist” that is used to configure data and determine which fusion engine to use for a particular task. By selecting fusion engines and tuning their parameters based on the real-time context, users get peak performance over a much broader range of conditions than any single fusion engine could provide. By sequencing multiple fusion engines (using the output of one fusion engine as the input for another), strategically controlled fusion creates previously unavailable fusion capabilities and unprecedented interoperability.

The Advanced Intelligence Surveillance and Reconnaissance (ISR) Management (AIM) project will provide commanders with the capability to more efficiently and effectively manage ISR assets and produce timely information tailored to their operational needs. AIM will improve the management process by dynamically responding to changing priorities, resources, and environments. AIM will allow commanders to use the objectives as stated in the operations plan to determine efficient and effective use of ISR collectors and exploitation resources. In a recent simulated military engagement, AIM technologies optimized routes and collection schedules for multiple U-2 aircraft and high altitude endurance unmanned air vehicles. AIM will conduct an information needs development demonstration in FY 1999 in cooperation with the U.S. Army Intelligence and Security Command.

Imaging sensors provide two-dimensional arrays of values that measure properties of a scene. Examples of these properties are intensity, range, or phase. Image understanding algorithms create a description of the world from images, suitable for particular purposes. The goal of the Image Understanding project is to produce the information technology required to enable comprehensive battlefield awareness by developing and demonstrating technology to extract information from imagery. Specifically, the program will demonstrate the feasibility of automated site monitoring using visible, infrared, and SAR imagery from unmanned aerial vehicles, and reduce the time and effort required to construct high-resolution, three-dimensional models of buildings and terrain by selectively automating time-consuming tasks.

The Moving and Stationary Target Acquisition and Recognition (MSTAR) project is inventing the next generation of automatic target recognition systems by enabling the identification of the most challenging targets, those that are articulated or partially obscured, by using computer-stored, three-dimensional models of target vehicles. By the end of last year, the MSTAR system had demonstrated the capability to correctly identify 80 percent of targets in difficult positions. This is the first time that an automated system using SAR imagery has been able to match the performance of an experienced human analyst. This year, performance will be tested against more targets, under more challenging conditions. In FY 1999, the MSTAR system will be moved to high-performance computers to increase the speed of identification, with the goal of providing target identification in near-real-time, something not possible today.

The goal of the Semi-Automated Imagery Intelligence Processing (SAIP) Advanced Concept Technology Demonstration (ACTD) is to provide an order-of-magnitude improvement in imagery analyst throughput by using automatic detection, force-structure analysis, and template-based target recognition techniques. The program has had major successes over the last year. It participated in the Operation Desert Capture exercise and the Roving Sands '98 exercise with elements of the U.S. Army 18th Airborne Corps. In both experiments, SAIP received and processed U-2 imagery. Operational analysts and unit commanders viewing SAIP's capabilities were confident that the system would be a significant aid to their exploitation work. This year, the enhanced SAIP system will participate in U.S. Atlantic Command's military utility assessment, with a series of exercise events planned around unit rotations at the Army National Training Center and the Air Force Green Flag exercise. Live testing will be augmented with playback events utilizing taped data from operationally deployed sensor systems. Enhanced SAIP will also, for the first time, demonstrate its capabilities using Global Hawk unmanned air vehicle sensor data and will demonstrate interoperation with the Air Force Contingency Airborne Reconnaissance exploitation system. The ACTD military assessment will continue into FY 1999, with a utility determination planned in the second quarter of FY 1999 and the delivery of an operational configuration of SAIP to Air Force users at the end of the year.

The Battlefield Awareness and Data Dissemination (BADD) Advanced Concept Technology Demonstration (ACTD) is creating an operational prototype system that will allow commanders to prioritize information delivery and give commanders an accurate, timely, and consistent picture of the battlespace. BADD will provide forward warfighters access to worldwide data repositories and the capability to intelligently search and forward-stage the data they need when they need it. When fully demonstrated, BADD will enable the network-centric warfare envisioned in Joint Vision 2010. BADD, which started in 1996, participated in the 1997 Joint Warfighter Interoperability Demonstration (JWID), providing a secure direct broadcast extension to the coalition communications network to support simultaneous, wideband broadcast of imagery, map and intelligence data to JWID participants. Commanders also used the BADD infrastructure to support generation and dissemination of Air Tasking Orders among multiple sites and then monitored and controlled execution through video collaboration. In December, BADD pilot services were available in the continental U.S. through the Global Broadcast Service testbed. Later this year, BADD technologies will be delivered to U.S. Atlantic Command to complete the ACTD's final military assessment. Immediately following that activity, the BADD software will be delivered to the Defense Information Systems Agency to begin transition into the Defense Information Infrastructure. Technology transition will be completed in September 2000.

The Adaptive Spectral Reconnaissance program will develop and demonstrate hyperspectral sensors as an adjunct to electro-optic and infrared sensors for unmanned air vehicles. Hyperspectral sensors can perform wide-area, low-resolution searches, and cue the other sensors for high-resolution spot coverage. The program will also develop real-time, on-board processing to isolate potential targets. This year, we will finalize the design concept, and start concept verification data collection flights. System development will continue in early FY 1999, with a demonstration of the prototype system in a range of operational scenarios.

The goal of the Counter Camouflage, Concealment, and Deception (CCC&D) program is to provide the warfighter with the ability to detect targets hiding in foliage. To do this, we are developing a Foliage Penetration (FOPEN) synthetic aperture radar that can provide all-weather, day/night detection of targets. The FOPEN radar will be tested onboard a manned aircraft but will be designed to be compatible with the Global Hawk unmanned air vehicle. In addition, the program is developing image processing technology in support of the Senior Year Electro-optical Reconnaissance Systems (SYERS) multi-spectral imaging, visible-medium-wave infrared sensor to utilize this high spatial resolution imagery from a U-2 aircraft. The five-year contract for development of the FOPEN radar system was awarded last Fall. During FY 1998, the program will demonstrate, as an interim verification of the CCC&D objectives, the ability to georegister and fuse images from FOPEN and SYERS sensors in a Multi-Sensor Exploitation Testbed. After completion of subsystem tests, the FOPEN synthetic aperture radar will be integrated into an Army RC-12 aircraft for late FY 1999 flight integration and radar tests.

DARPA's Millimeter Wave Targeting and Imaging Sensor program is developing a sensor that will be capable of day/night, all-weather operation, and will provide high-resolution imaging and targeting coverage in tactical environments. The system will be able to identify and illuminate targets of interest and assess battle damage immediately after the targets have been attacked. The project will develop a payload that can operate at the highest imaging and targeting resolution in the crucial all-weather tactical environment. The sensor will be designed to fit on a Predator or Global Hawk unmanned air vehicle. This year, we will conduct concept definition and initiate a technical design phase. In FY 1999, we plan to begin ground and airborne demonstrations to validate the targeting and imaging concept for joint platform use.

Although the Department has an increasing number of radar systems able to image the battlefield, it is still difficult to positively identify friendly forces, especially in the Joint Vision 2010 concept of dominant maneuver, where forces may be widely dispersed and very mobile. DARPA's Radio Frequency Tags program will develop a low-cost, miniaturized unit that can be carried by ground forces or attached to their equipment. When interrogated by Joint STARS, Global Hawk, F-22 or other radars, the unit will provide details about the friendly unit, allowing these radar systems to accurately track and identify units in the chaos of a battlefield. We will develop units that can respond to both moving target indicator radar and synthetic aperture radar interrogation, while ensuring that the response is secure and does not jeopardize U.S. forces. This year, we will start a two-year program to develop low cost tags. The cost goal is $300 per tag, which will make it economical for all friendly forces to carry a tag. We will also investigate methods to reduce the required tag signal extraction signal processing so that the impact to the radar platform is minimal. At the end of FY 1999 and during FY 2000, we will conduct exercises with large numbers of tags to validate the concept in an operational environment.

In the Tactical Radar program, DARPA will develop space-based radar that can detect ground targets deep in denied territory, beyond the ranges of airborne air surveillance assets. The radar will simultaneously collect synthetic aperture radar imagery and high-resolution ground moving target indicator radar data at very high data rates, with a resolution of one meter or less. The system design would be based on a constellation of 24 satellites in low-earth orbit, allowing the radar satellites to have revisit rates of 15 minutes or less anywhere in the world. This radar satellite constellation concept, also known as STARLITE, is being undertaken as the joint DARPA, Air Force, and National Reconnaissance Office Space-Based Radar program. The program has as a primary goal the achievement of revolutionary system performance and a decrease in satellite acquisition costs to a goal of $100 million per satellite. Such a Space-Based Radar system has the potential to substantially enhance U.S. information dominance in support of both indications and warning, and ongoing military operations. Research suggests that a combination of ground moving target indicator and synthetic aperture radar imaging capabilities will help U.S. forces to obtain timely and precise dominant battlespace awareness through theater surveillance and flexible, real-time tasking. FY 1998 efforts will begin the critical risk reduction tasks associated with the Active Electronically Scanned Array Radar, the communications subsystem, and the overall system architecture design. Beginning in FY 1999, system integration teams will begin to design the system while continuing technology risk reduction efforts.

DARPA is investing in a number of unattended ground sensors that will be able to provide increasing insight into the battlefield for dismounted forces. The sensors will be low-power and low-cost and packaged to meet the size and weight requirements of a 40-mm round. They will either be stationary or mobile and capture images or chemical or acoustic information. These small sensors will be particularly useful to small units operating covertly. The unit can place a network of the sensors in a particular area, and the sensors will send information short distances to a handheld unit. To date, the program has demonstrated seismic and acoustic sensors in the desired size in field tests against U.S. vehicles. Later this year, we will test the sensors against threat vehicles and demonstrate how multiple sensors can work together. Next year, we will demonstrate survivability of munition-launched sensors after launch and emplacement.

Planning and Command and Control

The planning and command and control systems that allow the commander to make timely, accurate decisions and transmit those decisions to Joint forces are key to precision engagement. DARPA has several programs that focus on assuring battlespace dominance through preemptive management of information. Our programs will provide information-centric command and control, with continuous updates, to manage an integrated planning and execution process that is based on the overall strategic objective.

The Joint Forward Forces Air Component Commander (JFACC) project will provide a continuous planning process that is based on the commander's overall prioritized objectives. It will allow the commander to efficiently use of all assets. At full implementation, the JFACC project will reduce the time necessary to task aircraft from today's "72 hours" to "minutes," will enable immediate response to opportunities on the dynamic battlefield, will allow the reduction of an Air Operations Center staff from over 1,000 people to fewer than 250 people, and will reduce the time necessary to write an air tasking order from today's "72 hours" to the point of achieving air tasking orders in real-time, i.e., orders that are continuously updated and always ready for implementation. Last year, we selected our contractors and gained the support of key Air Force and Navy leaders. This year, we plan a June 1998 concept demonstration in which geographically distributed planning elements will collaborate together to create and manage a common plan. By the end of FY 1999, JFACC will conduct an initial demonstration of an total integrated planning, scheduling and execution system.

The Command Post of the Future (CPoF) will improve the speed and quality of command decisions, while reducing the number of staff members required, thereby enabling a smaller and more dispersed command structure. The CPoF will provide an intuitive, well-integrated, decision-centered information environment in which the commander and his staff can quickly understand the changing battlefield situation, select the best course of action, communicate that course of action to the implementing units, and monitor the its execution. Key technologies include: adaptive visualization systems that present information tailored to the needs of the commander, systems that enable the commander to interact via speech and gesture, and decision support tools. This year, Army and Marine Corps users will participate in a proof-of-concept demonstration of key technologies and will help refine the operational concept. In FY 1999, contractors will develop an experimental prototype system based on the results of the proof of concept demonstration.

Project Genoa is working toward a new order for crisis management (including transnational threats) at the Unified Commander level and above. The highest military and national decision levels must filter, focus, organize and interpret a daunting amount of information from numerous open and classified sources in order to detect, avert, or mitigate nascent crises. In order to deal with these events, the analysts, policy makers and decision makers must rapidly form interdisciplinary teams to analyze, assess, and develop options for responding. Project Genoa is developing and demonstrating tools that will accomplish this process more efficiently and effectively. The key technologies being developed are: content-based information search; finding patterns and structure from multimedia data sources; evidential reasoning; and meeting transcription. This year's effort will develop techniques for addressing three areas of crisis management: rapid crisis reasoning using structured search of multimedia data sources in a collaborative environment; capturing analyst arguments, and using decision trees and evidential networks for postulating and evaluating alternative courses of action. During FY 1999, we will begin to transition and evaluate the more mature technologies within the Defense Intelligence Agency's Joint Intelligence Virtual Architecture environment.

These systems aid the commander in formulating his decisions. It is also important that the battlespace has a full information flow between and among the commander and his forces. DARPA is participating in the Department's Joint Tactical Radio System (JTRS), which will procure, verify, produce, field, and support a family of modular, software-programmable, multi-band, multi-mode radios to meet the functional objectives required by the users. This family of radios will support five military applications: airborne, ground mobile, fixed station, maritime, and portable-manpack. The JTRS builds on DARPA's experience with the SPEAKeasy radio, the first fully software programmable digital radio. The SPEAKeasy effort started in 1990, and reached fruition last year during the Army Task Force XXI Advanced Warfighting Experiment. SPEAKeasy, with two software programmable channels, was able to replicate the Air Force's high frequency single side-band, VHF FM, SINCGARS and HAVE QUICK I and II radios, and UHF satellite communications, cellular telephone, GPS and limited data networking, all in a single package. SPEAKeasy was able to act as a bridge so operators using one type of system could communicate with those using another. During the experiment, Air Force operators asked if SPEAKeasy could be reprogrammed to act as a bridge between administrative walkie-talkies and an aircraft's HAVE QUICK radios. Because of SPEAKeasy's software programmable technology, this additional capability was added in only four days.

The Airborne Communications Node (ACN) is a communications payload for a long-endurance unmanned air vehicle such as Global Hawk. ACN is designed to provide a quick-reaction, robust communications capability for early-entry forces. For example, during Desert Shield, it took six months, 24 ships, and 40 C-5s to bring the necessary communications infrastructure equipment into the theater of operations. ACN will provide the military with multiple communications services in a mobile, self-deploying package. It will provide data networking services, act as a surrogate satellite for satellite-based radio communications, provide interoperability between dissimilar radio types, provide high-speed and high-throughput communications services, extend the range of available communications systems by acting as a relay, and provide multicast services to tactical users. Technical challenges in this program abound — the integration of multiple communications technologies; size, weight, and power limitations; and remote, real-time security management. This year, we will select multiple contractors for system design, with the critical design review planned for mid-FY 1999. A proof-of-concept flight demonstration is planned for FY 2000. The results of this flight demonstration will be used for further design refinement and fabrication of a fully functional, pre-production prototype to be flight-tested aboard the Global Hawk unmanned air vehicle.

Precision Targeting

Thus far, I have described projects and demonstrations that focus on providing comprehensive awareness and command and control and planning capabilities for commanders. An additional piece of precision engagement is precise targeting capabilities. The Global Positioning System (GPS) Guidance Package is providing this capability.

The GPS Guidance Package (GGP) program will be completed in FY 1999. It has been very successful. The program developed and demonstrated affordable, robust GPS navigation tightly coupled with an inertial navigation system through a digital processor. GGP Phase 1 units were successfully demonstrated on a ground platform, the Army's M981 Fire Support Vehicle, in June 1995. They also were demonstrated on an F/A-18 in December 1996. The Navy will use a GGP Phase 2 derivative as its Advanced Navigation and Control Package, while the Army will use a GGP Phase 2 derivative on its Bradley Fire Support Team Vehicle. Both Army and Navy missile applications are also possible. In FY 1999, we will conclude integration and testing, and deliver eight GGP units.

We now plan to push the state-of-the-art even further by developing and demonstrating robust miniature GPS receivers capable of direct P(Y) code acquisition. This is enabled through the development of multi-correlator, fast-acquisition integrated circuits and high-performance clocks. In FY 1999, the program will fabricate and demonstrate the robust miniature receiver.

Last year, we started a program to develop inertial navigation systems based on microelectromechanical systems (MEMS). MEMS technology offers low-power, lightweight, tactical-grade inertial navigation, in a package that is less than 10 cubic inches in size, and that costs less than $1,200 each in large-volume production. Having such a navigation system will truly revolutionize warfighting — it offers navigation systems for individual soldiers, micro air vehicles, small robots, hand-held sensors, artillery shells and missiles. Getting the cost and power requirements down are key challenges. We currently have three contractors working on different approaches, and we will add two additional contractors this year. Next year, we plan to iterate MEMS inertial sensor foundry fabrication processes and test procedures.

FULL-DIMENSION PROTECTION

The third Joint Vision concept is Full-Dimension Protection, offensive and defensive capabilities that protect all forces from all types of threats, allowing freedom of action during deployment, maneuver and engagement. DARPA has a number of programs that contribute to full-dimension protection of our forces. In fact, three of the Agency's highest priorities fall in this area — biological warfare defense, information survivability, and detection of unexploded ordnance. Of these, biological warfare defense and information survivability present two of the most pressing problems facing our nation today.

DoD's strategy of technological dominance depends on its information systems. DoD systems are large-scale systems-of-systems involving thousands of interconnected, networked computers. The continued operation of these systems and the security of their data are critical to achieving DoD's mission. However, DoD systems are increasingly vulnerable to information attacks by hostile forces. Our systems are increasingly connected to one another and to civilian networks using Internet technology. Commercial technology is often used in DoD systems, and commercial hardware, software and networking systems are not always engineered to the levels of security and robustness needed by DoD. While the concerns of commercial users have led to some level of security technology, standard security services are not able to withstand the information warfare attacks of concern to DoD.

In addition to these concerns for protection of DoD information systems, there is an increasing realization that DoD relies on the national information infrastructure, just as do all U.S. citizens, and that the national security of the U.S. can be threatened by an attack on the national information infrastructure, as it could by a traditional military attack on U.S. forces and their information systems. It is essential that such national systems as the commercial telephone system, electrical power grid, banking and financial networks, and the Internet itself be appropriately protected.

Accordingly, the President's Commission on Critical Infrastructure Protection was established by Executive Order in July 1996 to examine physical and cyber threats to, and vulnerabilities of, the critical infrastructures in the U.S. The Commission recommended that DoD increase its research and development investment for information assurance and infrastructure protection for the national information infrastructure. FY 1999 is the first year of the DARPA Joint Infrastructure Protection project, which will focus on the development of intrusion detection and prevention technologies applicable to the national information infrastructure. DARPA's program in this area will be organized around three general thrusts: (1) development of technologies and tools for warning and detection of intrusion attempts; (2) development of automatic modes for responding to intrusions, once detected; and (3) development of protocols and architectures that resist intrusion. DARPA will work with the commercial sector to ensure that the commercial infrastructure has access to, and successfully implements, newly developed technologies and strategies. Work sponsored under the joint program will also be closely coordinated with the Military Services to ensure transition into military infrastructure programs where applicable.

DARPA's Information Survivability and Assurance program is a two-pronged effort that is focusing specifically on protection of DoD systems. Information Survivability will develop enabling technologies for next-generation systems and will transition successful technologies to industry and to DARPA's Information Assurance project. The Information Assurance project will innovatively integrate, refine, and apply such advanced technologies to reduce risk to DoD systems by 50 percent.

DARPA's Information Survivability program will develop strong barriers to attack, methods to detect malicious and suspicious activity, systems that isolate and repel such activity, and methods to guarantee continued operation of critical system functions in the face of concerted information attacks. Our researchers have innovative, speculative ideas that have the potential to make a major impact on a variety of next-generation DoD systems. One project that developed a method for secure communications through the use of secure access wrappers is being tested by contractors collaborating on the F-22 program. The wrappers securely encapsulate data, allowing the companies to move toward electronic exchange of information, instead of a paper-based process, with significant cost savings expected over time. Another DARPA-developed technology that protects and authenticates domain names is planned for deployment to the ".gov" and ".mil" Internet domains. This technology ensures that a computer system that appears, for example, to have the address "www.darpa.mil" is truly a military computer system and not a hacker assuming that identity. As technology efforts prove worthwhile, they are transitioning into commercial products, or are used by other DoD and DARPA command, control and computing systems programs.

The Information Assurance project has developed a security architecture that will make information assurance an inherent part of prototype information systems that migrate from DARPA into the Defense Information Infrastructure (DII), providing a strong, security foundation for the DII. This project will also invest in nearer-term techniques to develop defensible computing enclaves for Defense systems, prevent attacks, detect and trace those attacks that do occur, allow safe collaboration between sites, respond to and recover from attacks, and manage security services automatically. Successful technologies will be transitioned into the next available version of the Defense Information Infrastructure Leading Edge Services as a step toward eventual use by the DoD.

Another effort, Quorum, is developing technologies to allow critical Defense applications to achieve predictable and controllable quality of service. (By quality of service, we mean an assurance to applications that their essential requirements can be dynamically satisfied even with limited, shared resources. This is in contrast to today's "best effort" technology, where a task's completion time or communication across a network varies widely depending on the system or network load.) Quorum technologies will be used in the Navy AdCon-21 demonstration series. Quorum is developing the resource management tools and software to establish communication between a variety of Navy systems to enable them to share a common tactical picture. The AdCon-21 demonstration last fall successfully established a common tactical picture between combat systems and command and control functions in a Naval Surface Fire Support scenario. In FY 1998 and FY 1999, the program will demonstrate integrated dynamic resource management of the two systems on a shared resource pool.

Moving from the protection of information systems to force protection, our unexploded ordnance detection program is developing sensors that mimic and improve upon the capabilities dogs have to detect explosives in unexploded ordnance and mines. Most current approaches to the detection of mines and unexploded ordnance use sensors that attempt to exploit physical properties associated with the threat. These types of sensors all suffer from large false alarm rates even at modest detection probabilities. Canines, on the other hand, are one of the most effective means of mine detection used today. This results primarily from the canine's ability to smell, and therefore locate, explosive material. Despite their effectiveness, there are severe limitations associated with the use of canines. However, for artificial systems, sensitivity sufficient to detect low vapor pressure explosives is the challenge. In the eight months since researchers started work, the program has experienced exciting breakthroughs. In January, researchers demonstrated the robust detection of parts-per-billion level quantities of explosives at a signal to noise ratio of hundreds to one. We believe that detection of hundreds of parts-per-trillion is possible. In another project that uses depositions of colorimetric sensor materials in thin films, researchers were able to measure di-nitrotoluene (an explosives-related chemical compound) in the air in seconds, a measurement that previously would have taken days.

While chemical "sniffing" techniques are the primary focus of the DARPA program, other chemically specific detection techniques are also of interest. Nuclear quadrupole resonance, or NQR, is one such technique. In NQR, a transmitter emits a pulse of low-intensity radio waves, which causes nuclei in the substance of interest to tip out of alignment. As the nuclei come back into alignment, they produce a characteristic radio signal that is picked up by the receiver. The signal is unique for each chemical substance, allowing very precise identification. The first milestone in the NQR program is to detect small antipersonnel land mine quantities of RDX (an explosive) at a probability of detection of 90 percent and a false alarm rate of 10 percent. If this goal is achieved in May, we will have succeeded in producing the first prototype of a reliable plastic antipersonnel land mine detector. Future developments will expand the capability of the NQR system to antipersonnel land mines containing a variety of explosive compounds, to antitank mines, and to metal-encased mines.

The Unexploded Ordnance Detection program includes laboratory and field testing in incremental phases depending on the maturity of the individual technologies. This spring, we plan to take prototype systems to the Combat Engineer's School at Fort Leonard Wood, Missouri, for their first tests in controlled field conditions.

Turning now to Biological Warfare Defense, I would like to update you on last year's early success in our Unconventional Pathogen Countermeasures program. Last year, I reported to you that a heteropolymer bound to red blood cells had reduced the concentration of a simulated virus by over a million times in less than an hour. This year, we plan to study live biological warfare pathogens in live animals in cooperation with the United States Army Medical Research Institute of Infectious Diseases. A number of our other efforts are starting to bear fruit. For example, a researcher demonstrated the efficacy of attaching enzymes to red blood cells, which then cleared the blood stream of toxins. Once again, we saw excellent results in animal models. In another effort, a researcher developed a lipid formula (a cream) that is non-toxic to humans, plants, and animals, but that kills both gram positive and gram negative bacteria within 10 minutes. The lipid, which also seems to prevent anthrax spores from causing organ damage, can be either applied to the skin or ingested. In addition, we have developed a system that can take any pathogen genome and turn it into a vaccine candidate in two to three hours, instead of the two to three weeks now required. The system also develops vaccines that engender antibody responses and cellular responses that are three to six orders of magnitude higher than traditional vaccines. The greater the antibody and cellular response to a vaccine, the greater the protection the body will have against the pathogen. And, of course, this speed of developing vaccines is crucial if our forces encounter a genetically modified pathogen for which no vaccine yet exists. These successes are very gratifying. During FY 1999, we plan to continue the important work of these researchers as they devise more stringent and realistic tests of their results. We will also continue our efforts to create techniques that target common mechanisms of pathogenesis, thereby developing therapeutics that are effective against both known and unknown (including bioengineered) threats.

Under the Advanced Medical Diagnostics effort, DARPA will develop techniques that can rapidly, i.e., in near-real-time, identify a soldier infected with biological warfare agents or other pathogens even before the onset of symptoms. I would like to describe a few of the techniques that we are pursuing. One researcher is developing a method to separate single DNA and RNA molecules and then identify the pathogen or virus from the DNA or RNA. Another approach is using red blood cells as a tool to bind to pathogens and cause the release of an enzyme that then causes a macro event in a human or animal, so that the pathogen infection is amplified and detectable. During FY 1999, we will continue to develop this technology and identify new probes and sampling strategies to be used in a potential diagnosis system.

We are also investing in the development of advanced Biological Warfare Sensors that are robust, can operate autonomously, in real-time, and with extreme sensitivity to multiple agents, while being small, low-cost, and generating few false positives and no false negatives. To-date, we have seen good results from a variety of techniques in a laboratory setting. One laboratory instrument that was able to detect as few as 100 microbial cells on a surface such as meat is of interest to the meat-packing industry. Another instrument, able to detect a small concentration of pathogens in a liquid (e.g., river water or environmental sewage), is transitioning to the Air Force and the intelligence community. Our efforts are closely coordinated with the Counterproliferation Support Program and the Joint Program Office - Biological Defense. During FY 1999, we will further increase the sensitivity and specificity of these instruments.

In addition to man-made sensors, we are also investing in research to develop tissue-based sensors to provide early warning for chemical and biological warfare agents. This effort, just getting started, is focusing on single and multicelled sensor arrays based on biological organisms and interfacing them with silicon-based microelectronics. In FY 1999, we will examine and select strategies to stabilize cell systems in artificial environments (for example, on integrated circuits) to allow long-term functional response.

FY 1999 is the last year for the Accelerated Consequence Management effort, which is exploiting DARPA information technologies to augment operational awareness during biological threats or attacks and to provide medical personnel the knowledge they need for rapid, correct medical responses. The Enhanced Consequence Management Planning and Support System (ENCOMPASS) was used by the U.S. Marine Corps' Chemical Biological Incident Response Force as their command and control system during exercises and missions last year, including the Summit of the Eight in Denver, Colorado. ENCOMPASS was also in place for the State of the Union Address in January. ENCOMPASS is now being hardened for deployment with the 1st and 2nd Marine Expeditionary Forces, and Air Combat Command and U.S. Central Command are interested in using the system for base and force protection of forces deployed to Southwest Asia. During FY 1999, we plan to finalize these efforts and add transitions to other parts of the Armed Forces.

DARPA has a long history of involvement in the area of cruise missile defense. Many of our efforts have transitioned to the Services. However, we continue to investigate low-cost cruise missile defense technologies and work with the Ballistic Missile Defense Organization and the Joint Theater Air and Missile Defense Office as they develop future cruise missile defense architectures and demonstration strategies.

The Low Cost Cruise Missile Defense program is using emerging propulsion, sensors, and guidance and control technologies to provide a cost-effective way to counter a proliferated cruise missile threat. The focus of this program is on the countering of an evolution of the cruise missile threat where an adversary buys, builds and deploys large numbers of unsophisticated weapons to overwhelm and penetrate U.S. defenses. The program began in 1996 with the investigation of three different approaches to defeat this threat at a significantly lower cost than by increasing the number of current U.S. air defense systems. The objective was to identify advanced concepts and technologies that would substantially reduce the unit cost-per-kill without requiring major modifications to existing air defense architectures. One of the three concepts contained an advanced seeker utilizing microelectromechanical phase shifters. This seeker is designed to be integrated into the Miniature Air Launched Decoy low-cost missile interceptor airframe. This concept is proceeding toward a detailed design in FY 1998 and partial fabrication of the advanced seeker in FY 1999, with the goal of conducting a captive-carry flight test in FY 2001. Another low-cost seeker concept, termed the "Noise Correlation Seeker," is under development with a captive flight test scheduled for FY 1999.

FOCUSED LOGISTICS

The last key concept of Joint Vision 2010 is Focused Logistics, which aims at using information technologies to develop state-of-the-art logistics practices and doctrine. DARPA, with our history of involvement in information technologies, is a natural participant in the Department's efforts to provide tools for advanced logistics planning and management.

DARPA is engaged in two major efforts directed toward facilitating changes in the business process necessary for achieving Focused Logistics and reducing costs. The Advanced Logistics project will provide advanced technologies to gain control of the logistics pipeline during execution as well as during the planning process. Specifically, we need to plan, manage execution, and provide visibility into the pipeline at all echelons for all phases of operations. DARPA's approach uses autonomous agents as the key technology. These "agents" work together in a group. Each agent has a specific function, but together the group accomplishes the set of logistics business processes that model an organization. The agents and groups are distributed on computers all over the globe but work together to create an integrated logistics plan. Last year, the project demonstrated 12 agents at three sites working together for a simple planning process. This year, 35 groups at six sites will automatically create a detailed logistics plan for a medium-sized deployment. We are confident that this technology will reduce the time and increase the fidelity with which logistics plans are generated. This will reduce costs and ensure more efficient execution. By the end of FY 1999, over 100 agents at a dozen sites will be constructing more complete, detailed plans in shorter time periods than ever before.

The Advanced Logistics project is looking forward many years and pursuing a radical change in the way logistics is performed for the future.

In the nearer term, the Joint Logistics Advanced Concept Technology Demonstration (ACTD) will transition fairly mature logistics decision support tools and emerging web technology into the Global Combat Support System to make these techniques quickly available to the warfighter. The ACTD will also provide a mechanism to transition technologies developed in the Advanced Logistics Project into operational use.

TECHNOLOGY "PUSH"

In addition to responding to the needs of the warfighter as articulated in Joint Vision 2010, DARPA has a robust program to create and support critical enabling technologies. DARPA takes advantage of new technological breakthroughs, and undertakes research and development to bring the newest technology to the point that it can be applied to military problems. We are continuing our long-standing involvement in information technologies, including projects to improve the *understanding, dissemination* and *sensing* of information. In the area of computing and electronics, I will highlight projects developing improved *information processing* technologies, *optics and optoelectronics* projects and efforts to develop new *microelectronic components and devices*. The last two technology "push" areas that I will discuss are our projects in *advanced materials* and several projects in what we call *hybrid technologies*, in which two or more traditional disciplines are coupled for a new result.

Understanding

The information superiority and dominant battlefield awareness mentioned in Joint Vision 2010 depends on timely, filtered and fused information, but humans do not easily analyze and sift through mountains of data. Add to this the fact that, even as more and more data sources are becoming available, DoD is downsizing, and has fewer people to actually do the analysis. DARPA is funding efforts to make computers more able to access, organize, analyze and disseminate information contained in large, dynamic, multi-media (text, numeric, imagery, maps) databases. These technologies will add to capabilities for command and control, planning and replanning, and situational awareness. This year, DARPA demonstrated cross-media search and retrieval, integrating relational database queries with map searches and content-based image retrieval. In FY 1999, a system will be delivered to U.S. Forces Korea for automated translation of military briefings between English and Korean.

In another program aimed at bringing the most advanced information technologies directly to soldiers and Marines, the Warfighter Visualization program is developing technologies to give dismounted soldiers access to imagery and video from UAVs. We are capitalizing on earlier investments in head-mounted display technology to bring small displays to the soldier that will present him with overhead and ground-views, in a see-through, fly-through perspective, all accurately registered with actual locales. The system will be designed to provide useful information without disorienting the user and overloading him with too much information. This system is technically challenging — we will need to achieve localization that is extremely accurate, even as the soldier turns and tilts his body.

Another application of warfighter visualization technologies will be what we are terming the "glass turret" for a tank. In this case, we plan to place cameras on all sides of the outside of the tank. The cameras will feed images to the crew's head-mounted displays. Thus, as the soldier turns his head, he will see on his head-mounted display exactly what is outside of the tank in that direction — the crew will, in effect, have a "see-through turret" even while completely enclosed inside the tank. Once again, investment in high definition display technologies will be put to use in a unique military application. The knowledge and awareness provided by these visualization efforts will make a significant difference in a combat situation.

DARPA has had extraordinary successes in the High Definition Systems program. The U.S. industry is the world leader in thin-film organic materials, in large part due to past DARPA investment. Commercial technology in a number of areas is advancing quickly enough to allow the military to piggy-back on commercial technology for many of its needs. There are, however, still uniquely military applications that are not being addressed by commercial industry, and it is on these areas that DARPA now intends to focus. In particular, large, organic, interactive, smart displays that are rugged and flexible are not being driven by commercial applications and, therefore, require investment by DARPA. Smart, interactive displays offer a number of possibilities — local information processing on the display to improve graphics, built-in optical sensors to interact with laser pointers, or optical communication across the display to use the display as a network to pass information.

In last year's accomplishments, researchers demonstrated a five-fold improvement in brightness of electroluminescent blue phosphors, and bone-density measurements were taken using a DARPA-funded digital X-ray imager that now continues in the Food and Drug Administration approval cycle. In addition, two companies are collaborating to develop and market low-cost, low-power, portable communications flat-panel display products based on a product developed for the Army Land Warrior and Force XXI Soldier programs. The small displays will allow portable communication devices, cellular telephones and pagers to display text, electronic mail, graphics and video. The large civilian market for these devices will reduce their cost for future military applications. In FY 1999, we will continue to emphasize the development of displays on flexible substrates. Areas that will be addressed include flexible active matrix backplanes, emission materials that are compatible with flexible substrates, and new concepts on how to interact with displays. Improvements in these areas will lead to lighter weight, more rugged, and lower power displays for DoD applications.

Dissemination

DARPA is continuing its long-standing work in innovative networking technology. The Active Networks effort has been ongoing for approximately one year. Active networks, a fundamentally new approach with the potential of making a major impact on DoD networks, allows information to find the best path and exploit new services as it traverses the network. This network specialization is done “just in time,” through the use of “smart packets.” We are all familiar with a “packet,” the small increment of data that has an address and that travels from the sender to the receiver through many different pathways for instantaneous delivery. As I mentioned earlier, packet-switching is the technology that was demonstrated in the original ARPANET in 1969, and that has spawned today’s Internet and World Wide Web revolution. Smart packets, however, carry more than just an address. They also contain software and handling instructions that tell the network how to optimally transmit the information. Users gain added efficiency, speed, quality and security. In the past year, we have put in place a virtual testbed network, known as the ABONE, linking researchers across the country. Researchers are using this testbed for experiments that validate the processing efficiency and utility of the smart packet processing environments. In FY 1999, video services and IPv6 (Internet Protocol version 6) will be demonstrated.

Because of the military’s unique needs for a mobile computing environment, DARPA is continuing its Global Mobile effort to make the mobile environment a first-class citizen in the Defense Information Infrastructure. The goal is to develop technology that will provide user-friendly connectivity and access to services for wireless, mobile users. The military cannot rely on a deployed infrastructure (fixed base stations). Rather, it must contend with a changing environment (weather, terrain, foliage), having only sporadic connectivity and intentional interference, all while remaining mobile. The Defense wireless environment thus poses many technical challenges. The Global Mobile program is investigating a number of approaches, such as proxy servers, that compensate for the limits of the wireless environment, networks that automatically organize so that users on the move can be located at all times, and radios that include features to adapt to the environment. This year, we plan to demonstrate an adaptive modem for wireless communications that will process data at up to 60 million bits per second on a chip that is just 45 square millimeters in size and consumes only 800 milliwatts of power while performing 8 billion operations per second. This is less than five percent of the size and power that would be required to provide the same functionality today. In FY 1999, we plan to demonstrate a software radio with a “smart antenna” for mobile wireless networks.

DARPA's portion of the inter-agency Next Generation Internet (NGI) program is focused on experimental research for advanced network technologies and ultra-high performance network technologies and connectivity. These are Goals 1 and 2.2, respectively, of the inter-agency NGI Implementation Plan.

In the first activity, DARPA will define a novel approach to network-based computing to ensure that: (1) the network infrastructure is able to adapt and configures itself to the needs of the many different applications; (2) the individual applications using this infrastructure are able to adjust their operation to make the most of network resources; and (3) it will be possible to reason about the overall quality of service of the network. These assurances are particularly important to the military, since commanders must have assured response if mission-critical applications, such as weapons guidance, are to share the same Internet infrastructure and technology base as tasks such as logistics and planning. In FY 1999, we will implement a prototype network management system that leverages on-line simulations in its operation.

The second portion of DARPA's NGI program will develop and demonstrate the ultra-high-speed multiplexing, transmission, and control technologies necessary for terabit-per-second networks. To demonstrate these new technologies, we will develop a small testbed network. SuperNet will feature dynamic, real-time reconfigurability and self-healing capabilities for a richer, more flexible network capability, and will be available for use by a variety of DARPA demonstration efforts. We will commission the first five nodes of the SuperNet testbed in FY 1999.

Sensing

In the area of infrared sensing, DARPA continues to focus its investment in uncooled infrared devices. Although the military has a robust capability in infrared sensors, these are all sensors that require low-temperature cooling systems, which are high-cost, consume large amounts of power, and have potential reliability problems. On the other hand, uncooled infrared systems are much lower cost, easier to maintain, and have the potential for extremely small, low power applications. However, the current uncooled infrared is approximately ten to 100 times less sensitive than the cooled systems. The DARPA program is focused on increasing the performance of uncooled infrared systems to be comparable to cooled systems. To date, we have demonstrated a three- to five-fold improvement in the sensitivity of uncooled sensors. With these encouraging results, there is the potential for uncooled infrared sensors replacing cooled sensors in selected applications. This would occur first in short-range ground applications, and in the future, even for missile seeker applications. Last year, DARPA demonstrated a high sensitivity microbolometer, which is an uncooled sensor that changes its resistance with temperature. This device was integrated into a 240x320 array, which demonstrated the sensitivity required for the Army's medium-range thermal weapon sight.

In another imaging application, operators from the 5th Special Forces Group participated in an evaluation of a solid-state, low-light-level imager with blooming protection that could "see" targets even when they were obscured by bright lights, a task that conventional cameras find very difficult. In FY 1999, researchers will demonstrate and test a solid-state, low-light-level array integrated with an uncooled infrared camera, as a first step toward an integrated sensor. This dual-mode sensor will allow our forces to continue to see when others cannot.

One of the goals of DARPA's Cryo-Systems effort is to develop dependable, inexpensive cryocoolers. Performance and reliability of DoD's electronic components can be increased dramatically through cryogenic operation. Cooling decreases electronic "noise" and improves electrical and thermal conductivity of conventional integrated circuits. In addition, cryogenics enables the use of high-temperature superconducting materials in a variety of military electronic systems. For example, to date we have demonstrated a cryoradar with eight decibels of dynamic range beyond the capability of the current SPQ-9B ship-defense radar; we believe that the performance can be extended to about a 15 dB improvement (a 32-fold improvement). In FY 1999, we plan to demonstrate cryogenic components for the Navy High Frequency Surface Wave Radar Advanced Technology Demonstration. In addition to conventional cryocoolers, DARPA is investing in new classes of thermoelectric materials and devices that offer the promise of at least an order of magnitude improvement in performance. Currently, these materials cannot compete with conventional cryocoolers, but, with further investigation, we believe that they will ultimately offer the advantage of all solid-state operation (no moving parts) making them vibration-free, silent, reliable, and environmentally acceptable. In FY 1999, we plan to test a cryocooler, operating at temperatures below 100 degrees Kelvin, made of these new thermoelectric materials.

Information Processing

DARPA continues its historical role at the forefront of information processing, the area of optics and optoelectronics and the development of advanced microelectronic components and devices.

It became clear in the late 1980s that the demand for high-end computing power was increasing faster than the performance growth of traditional mainframe computing systems. To address this problem, the Scalable Computing Systems program, which began in the early 1990s, pioneered the development of massively parallel machines which, today, have penetrated through industry to become the preferred approach to mid- and high-capacity computation. DARPA's effort in this area is ending this year. Some of the accomplishments in this program include: an approach to integrated, scalable distributed, shared memory and message passing that has been adopted by Silicon Graphics, Inc., and incorporated into their Origin 2000 processors; a $10 multicomputer capable of one million floating-point operations per second; and Hewlett Packard demonstrated a graphics accelerator capable of generating 50 million triangles per second for engineering and animation applications. One of the most dramatic demonstrations of the power scalable computing holds for the military occurred in Synthetic Forces Express. In November 1997, high performance computers at four locations, tied together by five high-speed networks, demonstrated a sustained simulation of 66,239 different entities. This is more than 12 times what was possible using conventional processing and networks.

Associated with the development of scalable computing systems is the DARPA project to develop software technology that exploits the power of scalable computing. The Systems Environment effort has pioneered numerous languages, language compilers, scalable software libraries and experimental applications that have been adopted by industry.

Another project, Embeddable Systems, is aimed at providing cutting edge, timely, and affordable technology to meet the demands of the military by leveraging and influencing the efforts of the commercial sector. The project has succeeded in transitioning scalable processing products and environments to traditional Defense contractors. Improved performance made possible through embedded high performance computing systems has been demonstrated for radar processing, automatic target recognition, sonar processing and other military applications.

Evolutionary Design of Complex Software (EDCS) technologies will make the delay and cost of effecting an incremental change to a large software system proportional to the size of the change, as opposed to the size of the overall system. In one example, the Air Force's Arnold Engineering Center and Vanderbilt University collaborated to use EDCS technologies to reduce from months to hours the time needed for test setup and execution. The software is being used for Pratt and Whitney engine testing and Lockheed Joint Strike Fighter airframe tests. The Air Force has documented over $10 million in cost avoidance in 1996.

In the Adaptive Computing Systems effort, we are looking at a new paradigm in information processing that will provide orders of magnitude improved performance. Today's computers use general purpose and fixed architectures that allow them to perform a variety of tasks. Adaptive computing focuses on the development of information processing elements that can change and adapt based on the type of problem they are being asked to solve. The hardware itself will change into an optimized configuration. The goal for the automatic target recognition application, a particularly stressing information processing application and one that is of critical importance to DoD, is to improve performance 500 times, while shrinking the size of the processor to a single cubic foot. In a demonstration last fall, researchers realized a ten-fold performance improvement over commodity digital signal processors.

As Defense gains access to more and more data, and processing speeds improve, we can begin to try to develop information processing technologies for the most challenging applications. Model-based automatic target recognition, which computes thousands of different models of how a threat system appears to radar, and compares these known images to the newly acquired "mystery" image to determine the identity of the new image, is an incredibly stressing real-time application. The ability of current computer memories to find and deliver the stored information needed for this application has reached its limits in many cases. In FY 1999, DARPA is starting an effort to develop a new memory architecture to allow applications to manage the placement and flow of data, and to manipulate data within the memory subsystem. Users of applications such as model-based automatic target recognition and object-oriented data bases can expect to see a three order-of-magnitude increase in performance.

We are even investigating the possibilities of computing that is not based on silicon. This is our UltraScale Computing effort, which is investigating quantum computing and hybrid computing based on DNA. In the area of DNA computing, researchers have actually used DNA to solve a simulated problem. DNA computing, if perfected and harnessed, offers incredible improvements in performance on certain types of problems, some of which are very difficult to solve using conventional technologies. In FY 1999 we will develop specialized, experimental protocols to reduce the projected error rate presently associated with DNA computing.

Optics and Optoelectronics

Optoelectronics is the use of light to transmit information, both inside a computer processor (a micro-network) and between computers in a larger network. DARPA is collaborating with both commercial and defense industry to develop advanced optical interconnections within high performance computing systems. DoD gains access to commercial-off-the-shelf systems and manufacturing, and can readily transfer technology into military applications through aerospace and defense contractors. Commercial industry gains extra funding so that they can field products more quickly. Optical interconnect technology is a key enabling technology for a variety of military programs. The Navy’s SC-21 and combat aircraft can benefit from the increased speed and bandwidth offered by optical interconnections in high performance processors. The Air Force’s Space Time Adaptive Processor will use optical processing for one to two orders-of-magnitude improvement in performance. In another application, DARPA, the Air Force and the Navy are all looking at Unmanned Combat Air Vehicles, which will also need the performance optical processing can provide.

In the area of optical networking, wave-length division multiplexing (WDM) is a way of multiplexing a large number of channels in a single optical fiber to increase bandwidth without laying additional fibers. WDM was originally developed under DARPA sponsorship and is now being used commercially by industry in the country’s long-distance networks. Lucent Technologies has demonstrated a record-breaking, experimental, ultra-wide-band optical fiber amplifier that spans almost seven times the optical bandwidth of today’s amplifiers. Networks using the new amplifier could handle 100 or more wavelength channels, instead of the eight or 16 now carried. The results underscore the potential of optical networks to deliver unprecedented network capacity. This year, MIT’s Lincoln Laboratory will team up with industry to push WDM switching technology to local access networks. The objective is to deliver broadband network service to end-users without the astronomical cost of a privately leased line. Although optical fiber can carry messages at terabit-per-second speeds, messages are slowed during the electronic switching process. In the past year, DARPA-sponsored researchers at Lincoln Laboratory, in collaboration with Lucent Laboratories and AT&T, demonstrated terabit-per-second switching, a major technical breakthrough.

DARPA has been working in compact lasers for a number of years, with good results. These lasers are used primarily in infrared countermeasures applications. To date, we have demonstrated greater than 10 watts of power at 10 kilohertz in the mid-infrared region, which has already exceeded the Army's requirements. This year, we plan to increase power levels to 20 watts at 20 kilohertz, to meet the Air Force’s and Navy's needs. In FY 1999, we will demonstrate a mid-infrared brassboard laser system for the Navy's Advanced Integrated Electronic Warfare System shipborne electronic warfare suite testbed. We are also developing a new generation of diode lasers called quantum cascade lasers. These lasers are tunable and operate in a single-frequency mode. They have applications for low probability of intercept target designators and for remote chemical sensing for non-proliferation monitoring.

DARPA's precision optics work is having a major impact on several military systems. This program is developing the mathematical design tools and fabrication strategies for conformal sensor windows (i.e., windows that blend with the shape of the platform). To date, we have studied the aerodynamic and radar-cross section impact of these advanced optical components. There is a 30 to 50 percent reduction in aerodynamic drag (and therefore up to two times the range now possible) and an increase in sensor aperture with a radar cross section no larger than that of the current platform. The Army is particularly interested in employing this technology for Stinger Block II Extended Range. This missile can only achieve the desired range with this new conformal sensor window. During FY 1999, we will develop and demonstrate affordable fabrication techniques for the Stinger conformal window.

Microelectronics Components and Devices

The goal of DARPA's Advanced Lithography program is to create advanced lithographic technologies for the creation and transfer of patterns to fabricate microelectronic structures and devices. DARPA started its program in 1990. Since that time, the semiconductor industry in the U.S. has become more robust and able to take a larger role in its own modernization. Accordingly, in 1998, DARPA turned its focus toward the most long-term lithography technologies, the ones that are too speculative and too long-term for industry to invest in on its own. One of these is maskless lithography. Current lithography uses a variety of techniques to make a mask, which is then used to etch the patterns on silicon to create the integrated circuit. Although there is work to decrease the feature sizes and position errors on these masks, a fundamental breakthrough would be to enable maskless lithography. Towards this end, DARPA is pursuing several approaches leading to direct computer control of parallel electron beams. DARPA has demonstrated both photocathodes (emission controlled by a switched laser) and emission from amorphous diamond films as sources for these programmable beams. In another approach, DARPA has used supersonic gas jets for direct patterned deposition of semiconductor material, eliminating several resist and etch processing steps. These maskless lithography developments offer faster prototyping and reduced fixed costs for the low-volume production typical of military system needs. These approaches offer the possibility of reducing semiconductor device sizes by a factor of 25. In FY 1999, DARPA will work to improve the robustness of these sources and begin initial testbed characterization to prove the concepts.

In the area of microelectronics, we are pursuing a variety of approaches. One is looking toward creating microelectronic devices that are 100 times smaller in area than are today's devices. Such small devices are key to the development of processors capable of gigabits-per-second speed, while being only a cubic centimeter in size. This type of processing is crucial to the DoD's most advanced signal processing applications. DARPA is creating devices that are to be stacked in extraordinarily dense, three-dimensional arrays with multiple layers of interconnections. Preliminary simulation results indicate that a three-dimensional, very high-density (seven layers in a 25-nanometer design) signal processing array will experience at least a 100-fold improvement in performance (measured as a combination of speed and reduced power requirement). This program was initiated in mid-1997 and the first devices will be completed and evaluated during FY 1999. FY 2000 plans call for a demonstration circuit.

The Ultra Electronics program is a project looking beyond traditional microelectronic approaches to achieve, at room temperature, extremely fast, extremely dense, low-power circuits. The program ends in 1999. The program is considering several facets of the technology, including: quantum devices, circuits and architectures; silicon-based nanoelectronics; nanoprobes; high-density memory, and innovative material and device processing. Results have been transitioned into a variety of DARPA and DoD programs: the Navy is benefiting with high-speed, low-power devices; the Air Force is using new process control and monitoring techniques for its infrared laser and detector program; and high-performance analog-to-digital converters have been created based on quantum devices coupled to conventional devices. Transitions to DARPA programs include vertical cavity surface emitting laser process control for the Optical

Interconnect Program, nanoimprint technology for the Molecular Level Printing Program, and nanolithography solutions (low-energy electron-beam microcolumns) for the Advanced Lithography Program. This year, several demonstrations are planned, including: devices made from novel silicon compounds and quantum metal oxide semiconductor technology; computation by quantum dot cells (quantum cellular automata logic), and the first functional electronic molecular device.

Advanced Materials

DARPA continues a long-standing investment into a variety of advanced materials. "Smart" materials, for example, can sense, and then adapt to, changing conditions. For example, they change shape when stress, electrical current, or heat is applied. DARPA is investigating a variety of different smart materials, such as shape memory alloys and piezoelectric materials. Applications include vortex wake control for aircraft and ships, spacecraft structures with integrated electronics, active quieting of submarines, solid-state actuators to replace hydraulic systems on aircraft, adaptive aircraft engine inlet nozzles, and flutter control for helicopter rotors. Demonstrations to date using active rotor blades on an MD900 helicopter have shown a 10 dB reduction in noise generated by blade vortex interaction, an 80 to 90 percent reduction in airframe vibration, a 10 percent increase in rotor performance, improved maneuverability, and increased maintainability. Last year, researchers discovered single-crystal electroactive ceramics that, under electrical control, change their dimensions by more than one percent. This is more than a factor of 10 higher than conventional piezoelectric ceramics and holds the promise of a revolution in essentially all Naval sonar systems — the increased strain capability and associated improvement in electromechanical coupling enables the design of compact systems with a broader frequency response. We are currently expanding our efforts in this area. In FY 1999, we will demonstrate solid-state actuators, along with a flight test of smart materials for spacecraft. Demonstrations are also planned for vortex wake reduction for submarines and acoustic noise reduction using smart materials tiles.

The Magnetic Materials program is developing random-access, non-volatile, radiation-hard memory chips for space, missile and avionics applications. (With non-volatile memory, information is retained when power is off — conventional random access memory (RAM) losses its information when the power is off.) These chips, which can replace conventional silicon chips, will eventually be able to access stored data in fewer than three nanoseconds, store more than four gigabits of information, and need only minimal power — all at an affordable cost. By the end of this year, we hope to demonstrate a test chip with an effective memory density of 16 megabits per square centimeter and access times on the order of 20 nanoseconds. By the end of FY 1999, we will push the technology to an effective 64 megabits per square centimeter memory density with access times of 10 nanoseconds.

We are also investigating new materials and defeat mechanisms for ultra-lightweight personnel body armor. Our goal is to demonstrate armor protection systems with an areal density (weight necessary to protect an area of a soldier's body) of 3.5 pounds per square foot. Current armor systems have areal densities of more than twice this, making them very difficult to wear while maintaining peak performance. If successful, our program should lead to materials capable of stopping 7.62 mm armor-piercing rounds.

Hybrid Technologies

This last set of projects include efforts that marry one or more traditional technology areas to produce what we call hybrid technologies. We are finding that the newest technologies are taking advantage of a variety of technology components and combining them for exceptional synergy.

A new technology that first emerged a number of years ago continues to progress, as we discover and demonstrate new applications, and develop new devices. This is the area of Microelectromechanical Systems (MEMS). MEMS devices combine components that sense, compute, and take an action onto a single chip that can be manufactured using traditional semiconductor manufacturing techniques. This means that a single chip can both perceive and control its environment, and can be fabricated in extremely high volumes and, thus, achieve a low single-piece cost. We have already demonstrated one MEMS-based inertial measurement and guidance device, and we plan to increase the device's accuracy to the more challenging navigation-grade accuracy level. A micromechanical radio filter and receiver will enable a “radio on a chip,” which will be key to a variety of military applications, such as very small communicators (perhaps mounted on the wrist) for small units engaged in urban warfare or communications systems for micro air vehicles. In another development, a honeycomb structure has been microfabricated that can store fuel, has 1/40th the mass of steel and 85 to 90 percent of its strength. The low weight with high strength and dual use (structural and carrying fuel) may well be crucial to successful development of micro air vehicles. As we move into FY 1999, MEMS devices will have an increasing level of integration, and we will be attempting to see if a micro power source can be integrated onto the chip and, perhaps, even onto the micro air vehicle. This, along with an integrated actuator, will make possible a miniaturized device that has sensing, actuating, computing, and control. The result is a totally autonomous sensor and communicator platform that has high mobility and low detectability.

One of the newest applications for MEMS and smart materials technology is for Micro Adaptive Flow Control. Micro-actuators are fabricated using MEMS and smart materials techniques and, although small, can control large-scale flow behavior in air and water. For aircraft, the technique can be used for flight control and signature reduction. With aircraft engines, flow control of the air entering the engine compressor permits lighter, more efficient engines. Micro adaptive flow control on missiles allows more precise control and can extend effective range. Ships and submarines can use the technique for wake, drag and noise reduction. This program is just starting. This year and next, we will develop, build and test actuators and control approaches, and assess their efficacy in a number of systems demonstrations.

MicroFluidics uses silicon, glass and plastic chips with engineered microscale fluid channels, and pumping and storage chambers to perform bio-chemical analysis and synthesis. The type of laboratory analysis for DNA/RNA extraction and biological warfare agent detection that now requires a bench-top instrument can be miniaturized using microfluidics. And, as the analysis process is miniaturized, it becomes faster. Last year, the program developed and tested fluidic transport hardware and methods for mixing, separating, filtering, extracting, and purifying biochemicals. This year, the program will demonstrate the actual use of a microfluidic chip to control liquids as they pass through a variety of micro-channels. In FY 1999, the program will demonstrate how microfluidic technology can be used to detect pathogens, analyze DNA or conduct blood diagnosis. The techniques enabled by microfluidics will be applicable to other DARPA and DoD programs for biological warfare agent detection and identification.

The Sonoelectronics program, starting in FY 1998, will develop underwater cameras that use acoustic energy to create images with high spatial resolution (less than one centimeter at short range). These acoustic imagers will be able to perform real-time imaging of targets such as sea mines, even in cluttered environments and limited visibility. We are focusing on making imagers that require very limited power so that they can be operated using battery power, are compact, lightweight, and stealthy. In FY 1999, we will fabricate arrays of micromachined ultrasonic transducers and integrated read-out electronics using two basic approaches: focal plane imaging (analogous to infrared staring arrays) and digital beamforming (similar to medical ultrasound imaging, but in two dimensions and in a much more compact fashion). In FY 2000, we will fully characterize the capability of these cameras in underwater environments.

The Mesoscale Machines effort is just starting this year. Mesoscale, or mesoscopic, machines are defined as those machines which straddle the size-range between microelectromechanical systems devices and conventional machines (i.e., machines in the size range between a sugar cube and a human fist). We are supporting investigators looking at mesoscopic, high-volume air pumps, vacuum pumps, cooling units, crawling systems, and fabrication techniques. All will demonstrate the advantages offered by this unique size-range and then design and build a mesoscale system. The pumps will be useful for battlefield chemical and biological warning systems. The figure-of-merit for the pumps, defined as pumping rate, power, and size, is up to 50 times better than that of commercially available pumps. This is largely due to the unique advantages of working at the mesoscale level and the ability to connect these smaller machines in both series and parallel. The mesoscale cooling unit has promise for a 60 percent decrease in weight with potentially five times greater coefficient of performance above the smallest normal-scale coolers. This type of low-weight, high-efficiency cooling capability is crucial to the development of a future individual soldier cooling system. During FY 1999, researchers will demonstrate the initial feasibility and performance of their prototype mesoscale machines.

Living biological systems have extremely complex and unique capabilities and interactions with their environment. In the Controlled Biological Systems program, we are attempting to mimic, control and influence these capabilities and capture them for Defense applications, such as sensing, reporting and delivering countermeasures. For example, snakes can sense heat with their tongues and are more sensitive than any mechanical system, lobsters have an unusual method of locomotion, gecko lizards are uniquely adapted for climbing and cockroaches are champion diggers. We have researchers investigating mechanical systems that mimic each of these biological systems, a discipline known as “biomimetics.” We see applications in intelligence for gathering chemical and biological agents and acoustic and infrared signals, and locating mines and buried targets. FY 1999 plans include defining principles of single and multi-leg walking and climbing, investigating the responsiveness of insect learning to chemical targets of interest, defining the principles of snake and insect electromagnetic detection, examining chemical control parameters to influence insect movements, and developing neurotechnology hardware to understand and influence motor control in animals.

CLOSING

I hope that this overview of DARPA's projects for FY 1999 has given you a better understanding of our activities and investment strategies for the future. DARPA is committed to providing the Department of Defense the technological options to enable it to fight future wars. We continue to support the key pillars of Joint Vision 2010, while also investing in the broad classes of enabling technologies that will ultimately permit the DoD to complete the Revolution in Military Affairs transformation. We plan to continue our record of successful innovations as we enter into our fifth decade of maintaining technological superiority over potential adversaries.

Thank you for the opportunity to meet with you today, and I look forward to your questions.