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Armed Services Committee, U.S. Senate

Statement by Frank Fernandez

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Frank Fernandez

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Before the

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Mr. Chairman, Subcommittee Members and staff: I am very pleased to appear before you to describe my goals for DARPA, to explain how these goals fit in with major DoD objectives, and, finally, to tell you how I plan to achieve these goals.

Introduction

In the 40 years since its creation, DARPA has been at the forefront of U.S. technology. For example, DARPA pioneered developments in ballistic missile defense, high-performance computing, stealth, remote surveillance, communications, and, our most well known activity, the Internet.

Since DARPA was created, many changes have taken place in our world. The Soviet Union has collapsed and is no longer a peer competitor for the United States. Multiple rogue states have emerged, and they use terrorism as a tool to achieve their goals. In addition, limited defense resources have made the *affordability* of military systems a major consideration – comparable now in importance to the emphasis we have historically placed on performance. Finally, the explosion of commercial information, transportation, and biological technologies has made the DoD a market-place *follower* rather than the world technology *leader* it has been in the past. These major changes – the changing and poorly understood threats, affordability's rise in importance, and the influence of the outside world – have triggered a great deal of debate in the Defense establishment concerning the correct business model for DoD today.

Recently, Peter Drucker published a review in which he concluded that, just as in defense, the general business world is at the stage where major, previously held "truths of management" need to be abandoned if institutions are to survive and grow in the future.[1]

Drucker argues that, in the future, institutions will have to realize that most of what affects them will be generated externally and will not be the result of their own knowledge base. He argues that in order to survive, institutions must pursue multiple tracks of organized improvement. These tracks consist of three, parallel activities:

- First, Drucker says that managers must conduct "systematic, continuing improvement."
- Second, managers must continually exploit successful endeavors to build a different tomorrow based on a proven today.
- Third, managers must organize for systematic innovation with a goal "to create a different tomorrow that makes obsolete and . . . replaces even the most successful products."[2]

[1] Peter F. Drucker, "Management's New Paradigms," Forbes, 162 No. 7, October 5, 1998, p. 152ff.
[2] *Ibid.*

Drucker's business paradigm can be directly applied to the DoD. The need for continuing improvement is reflected by our warfighters' emphasis on training and experimentation. The acquisition reform thrusts in the DoD and the requirements-based research and development performed by the Services aim to build a different tomorrow based on a proven today. And, DARPA's mission, restated for the 21st century, is to be DoD's technical enabler for revolutionary innovation.

DARPA's Priorities

First and foremost, my top priority is to attract excellent people to DARPA. DARPA's self-enforced rotation of personnel requires that we recruit about 20 percent of our technical staff every year – about 25 scientists and engineers. To be effective, we need very special people drawn from the military, universities, government, and industry. The special hiring authority granted to DARPA by the Congress in 1998 will go a long way towards helping me recruit these exceptional people, and I'd like to express my appreciation to you for providing that authority.

I also intend to foster an environment at DARPA that will allow researchers to compete fairly with each other to determine who has the best ideas, and to be rewarded for producing high-quality technical progress. Through such an environment, where all levels of management encourage and reward professional respect and scrupulous ethics, DARPA will continue to attract the best researchers and technologies from all sectors.

Another DARPA priority will be to maintain our flexibility and ability to quickly exploit emerging situations. I believe that, in the 21st century, events taking place outside of the customary DoD establishment may very well have the greatest effects on national security. In this regard, the Defense Science Board is performing a review of current DARPA investments and DARPA's relationship with the military, the commercial world and the intelligence community. The results should be available soon, and these insights will be useful as I plot DARPA's future course.

To avoid technological surprise in a manner consistent with the emerging world, DARPA's research and development investments must be characterized by <u>flexibility</u> and <u>adaptability</u> in order to exploit emerging situations and to nullify an adversary's potential advantage from the use of global technologies. Thus, another DARPA priority is to fully realize the importance of externally generated events and be able to take timely action in response. Working with the commercial sector in areas that affect the DoD, I am embarking on a new initiative to establish an on-going dialogue with Chief Technology Officers to discuss their views on significant trends, disruptive technologies, global technology influences, and technologically enabled innovation. Initiating this process is essential if we are to be aware of externally generated effects.

Lastly, DARPA is initiating partnerships with the Unified Commanders and the leadership of the Army, Navy, Air Force, and Marine Corps to use experimentation to evaluate some of our high-risk, high-return technologies and to help with the transition of these technologies into the acquisition system and, ultimately, to the warfighter.

We are in a time where revolutionary innovation in warfare is a necessity. Such innovation is needed because of the constrained resources available to our military, the increasing range of action in which they are expected to dominate, and the global nature of essential technology. Innovation is also necessary to realize the *Joint Vision 2010* focus on achieving dominance across the range of military operations – a concept I call ”operational dominance.” The major "warfare-business" model shift as envisioned in *Joint Vision 2010* requires iteration between operational concepts and technology at a systems level. The experimentation and analysis process – directly involving the warfighter – is a way to accomplish this iteration, if used correctly. Our military needs to be encouraged to learn how to perform experiments and analyze data from these experiments without known requirements and in equal collaboration with knowledgeable technologists.

We are in a time where neither "requirements pull" nor "technology push" alone will get us to the new business model we need. Neither the warfighter nor the technologist can be sure of the proper model – it must evolve as the result of the experimentation/analysis process. The military must be encouraged to learn how to define, execute, and analyze these <u>experiments</u>, not merely demonstrations, in collaboration with leading technologists such as those supported by DARPA. Together, the military can learn how to experiment and technologists can learn the art of warfare, and thus achieve the necessary warfare paradigm change.

Key Thrusts

To succeed as DoD’s enabler for innovation for national security, DARPA is pursuing two key thrusts:

The first thrust is to find technical solutions to national-level problems. These problems, deemed by previous DARPA Directors as "Presidential-Level" problems, represent areas that may impact our national survival. At present, protection from biological attack and protection from information attack are such problems.

DARPA plans to expand our work on protection from biological and information attack to include better modeling and networking of surveillance sensors and possible methods of determining who is responsible for the attack and responding appropriately. In particular, we will see if DARPA investments can have a substantial impact on the problem of characterizing underground facilities. Further, I am considering whether interdisciplinary research <u>combining</u> information, electronic, and biological technologies might provide useful synergies to solve national-level problems.

The second thrust is to be the technical enabler for the concept of "operational dominance" central to our future warfighting vision. This concept entails developing technical means to enable dominant maneuver, precision engagement, focused logistics and full-dimensional protection to allow our military forces to dominate over a broad range of military operations.

In the area of enabling operational dominance, DARPA emphasizes technologies and systems to support battlefield preparation, dynamic surveillance and re-planning; affordable, mobile, precision target kill; and mobile, distributed command, control and communications. This represents a shift in emphasis from battlespace awareness to the use of advanced sensors and information technology to affordably classify and attack non-stationary and buried targets and to rapidly adapt to changing situations. Furthermore, DARPA is focusing on technologies to enable future air, land and maritime warfare concepts such as combined manned and unmanned warfare. Lastly, DARPA continues to emphasize the development of core technologies reflecting our traditional strengths: information technology, microsystems technologies, and materials technologies.

I would now like to describe some of DARPA's ongoing investments in these key thrust areas. The arrangement of my description of these investments is as follows:

1. **Technical solutions to national-level problems**: protection from biological warfare attack and protection from information attack;
2. **DARPA's role as technical enabler for the concept of "operational dominance"**: battlefield preparation, dynamic surveillance and re-planning; affordable, mobile, precision target kill; mobile, distributed command, control and communications; advanced air, land, and maritime warfare concepts;
3. **DARPA's core technology development**: advanced information technologies, advanced microsystems technologies (including electronics, photonics and microelectromechanical systems), and advanced materials technologies.

Technical Solutions to National-Level Problems

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

Protection from Biological Warfare Attack

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

DARPA's Biological Warfare Defense program has five main thrusts: therapeutic countermeasures, advanced sensors, advanced diagnostics, consequence management tools, and air and water purification devices.

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

Last year, in the area of decontamination, we tested a lipid emulsion with good results against bacteria. Now, the emulsion is having extraordinary results against anthrax spores. In trials, the emulsion killed over 90 percent of seven different types of anthrax spores within 30 minutes and more than 95 percent within four hours. This is a kill-rate similar to bleach, the current decontamination method of choice, but the emulsion is non-corrosive and non-toxic, making its potential very exciting. In addition, early tests have shown that the emulsion seems to inhibit the germination of spores that are not killed.

Another researcher has developed a chemical immunomodulator that prevents some of the life-threatening inflammatory consequences of infection, one that may be useful against a variety of threats. Animal trials to date have shown good results against Staph enterotoxin B (SEB). The researcher will next conduct animal trials against live agents to include plague, anthrax and Ebola. In another project, DARPA-supported researchers have identified an enzyme that is necessary for the survival of a number of pathogens, ranging from military threat diseases, to "common" afflictions and plant diseases of concern to agriculture. The researcher has a promising inhibitor of this enzyme that will undergo further tests. In FY 2000, we will continue support of these innovative approaches and, in many cases, conduct testing against live agents. We plan to expand our efforts in current technical areas as well as solicit additional unique ideas and approaches. We especially hope to interest scientists, researchers and companies that do not normally work for the military, but who may have unique ideas that can help the U.S. respond to the threat of bioterrorism.

Sensors are important in dealing with every aspect of the biological incident – from warning of the presence of an agent in the atmosphere to determining whether a building is fully decontaminated and safe to reenter. No single sensor can satisfy the needs of the Intelligence Community, the warfighter and the civilian first responder, however. In order to detect the presence of a threat agent, DARPA is investing in the development of advanced biological warfare **Environmental Biosensors** 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 positive and no false negative alarms. DARPA's program in Environmental Biosensors includes a number of platforms for bioagent identification: a miniaturized time-of-flight mass spectrometer, a handheld detector, a flow cytometer, a biochip that identifies the bioagent using ribosomal RNA, and an aerogel platform that will provide revolutionary high-surface area materials for biosensing. In addition, the program is replacing the antibodies that are currently used to identify the bioagent threat in clinical and laboratory settings with smaller molecules that are more robust and, therefore, more useful in a tactical situation.

The Environmental Biosensors program has already demonstrated substantial success. For example, laboratory tests of the mass spectrometer have shown that it can differentiate between a wide variety of biological agent simulants. The program will continue to expand its efforts to identify specific molecules of unique molecular weight and mass to identify biological agents without false alarms and within a minute of injection into the mass spectrometer. Another project has developed a handheld biosensor that uses upconverting phosphor technology. The sensor provides results in approximately five minutes, needs only a small sample, and is inexpensive and easy to operate. Results to-date on agent simulants show a sensitivity that is 10 to 100 times that of deployed sensors. Tests on live agents in the presence of environmental contaminants are being conducted this year. The program has also synthesized a bio-aerogel with a wide range of pore sizes (0.01 microns to 10 microns) for use in biological agent detection. These unique, high surface area materials are able to capture chemical agents, toxins, viruses, spores and clusters of spores. In FY 2000, in coordination with the Joint Program Office of Bio-Defense, the mass spectrometer and flow cytometer sensor platforms will be evaluated in field trials.

A spin-off of the Environmental Biosensors program is an effort in **Tissue-Based Sensors**. This program aims to use a cell or piece of a tissue to identify a chemical or biological threat agent and to determine the threat's viability and how it causes harm. This will provide key information on the human health risks associated with exposure. Researchers have already made some key advances. They have demonstrated strategies to dramatically improve the stability of cells to be used in such sensors by genetically engineering cells to increase their survival and longevity. Cells have also been encapsulated to provide a natural matrix for their operation as a sensor element. Researchers have fabricated interfaces to cells and tissues in order to investigate the spatial and temporal pattern of activity following exposure to a chemical or biological threat. One system that employs neuronal cells and tissues has been used to identify mechanisms of neurotoxicity in known chemical toxins. This year, the program will design and test cell and tissue systems that reliably report on viral and bacterial exposures and investigate key sensor features that provide minimal false positives while maximizing signal strength. In FY 2000, the program will continue to focus on cell and tissue stability and investigate sampling issues associated with the autonomous collection of information.

The symptoms of exposure to biological warfare agents are often the same as those of the flu. To make matters worse, for most biological warfare agents, treatment must be provided very shortly after exposure in order to prevent death. The combination of these factors leads to the need for technologies that can detect the presence of pathogen infection and correctly identify that pathogen very early – perhaps even before symptoms appear. Furthermore, any major biological attack will place great stress on the medical system. Therefore, it will be important to be able to identify those individuals who have actually been exposed to biological agents. It will also be important to have ways to differentiate exposed individuals from what would almost certainly be a much larger number of "worried well" individuals who may present themselves for medical care because they understandably fear exposure, but who have not actually been exposed.

The **Advanced Medical Diagnostics** program aims to detect the presence of infection by any biological threat agent and identify the pathogen, in the body or in clinical samples, in real-time, while pathogen numbers are still very low. Ongoing efforts include investigations into ways to easily obtain and prepare samples for analysis, projects to miniaturize and speed-up sample analysis, and unique methods to determine infection, for example by identifying host responses that may be indicators of infection. One interesting technique is to measure nitric oxide in exhaled breath. It has recently been learned that the body produces nitric oxide when exposed to bacteria or viruses, even before the person feels ill. One group of DARPA-supported researchers will investigate whether elevated nitric oxide levels are useful as a marker for biological warfare pathogen infection, and will then develop a small, low-cost monitor to detect nitric oxide in exhaled breath to serve as a useful discriminator in cases of mass exposure. Another group of investigators recently developed a "gene chip" that can detect virtually all expressed human genes. In the coming year, they will test samples from a variety of infectious disease states to identify which human genes are turned on or off in response to infection. Pathogens have genes, too, so DNA, the material that makes up the genes, can be used to identify pathogens. However, preparing samples for DNA analysis is often slow and labor-intensive. Another DARPA-funded group, which has been developing a miniature, automated system to detect pathogen DNA, recently developed an integrated sample preparation cartridge to extract the DNA from a biological sample for analysis.

The **Consequence Management** project was extended last year as a result of the need to support domestic first responders (police, fire, and emergency medical personnel) and U.S. military bases. The recent spate of anthrax hoaxes shows that local first responders must manage these threats effectively. Both the quality of those responses and the tools used to manage them vary considerably from city-to-city. These facts have led to a new approach, namely, to provide spreadsheet-like computerized tools for consequence management that can be constructed and tailored by the local responders. Essential to this system are incident-specific playbooks that contain the best information we have to manage the specific kind of incident. These playbooks are being used by the U.S. Marine Corps' Chemical Biological Incident Response Force, and will be used by local first responders and local, state and federal agencies to respond to incidents in a number of testbed cities. In FY 2000, the Consequence Management project will expand the use of an Electronic Watchboard to share critical information about an incident for all responding units and agencies, regardless of location. The project will also develop Smart Checklists to ensure that all of the relevant information is captured by the system, and it will demonstrate these systems to protect military air bases.

In FY 2000, the ongoing Mesoscale Machines program will focus a significant portion of its resources on **Air and Water Purification** applications for biological and chemical warfare defense. To-date, the program has had excellent results in small cooling units and high-volume air pumps. Early results in compact water purification systems have led to the new focus. For example, one research team has developed a system for the individual soldier that is the size of a thick fountain pen. The system creates mixed oxidants that can purify contaminated water by killing waterborne pathogens. The disinfection pen will ultimately be tested against live agents and will be field-tested with the Marine Corps late this summer. During the next year, the program will develop prototype man-portable water systems that purify and desalinate brackish water, with the ultimate goal of desalinization of seawater. Further plans in the upcoming year include novel proof-of-principle demonstrations to generate water in arid desert climates from non-traditional means, such as condensing water vapor from the tailpipes of military vehicles.

We are also starting to develop pioneering approaches for an advanced gas mask. Mask filter canisters have essentially remained the same since World War II, even though there are some limitations. For instance, these masks have higher-than-desirable breathing resistance and are not effective against some industrial chemical vapors and/or potential future chemical warfare agents. In early results, novel, activated-carbon fibers appear to improve the ability to filter one of the most difficult blood agents, cyanogen chloride, by over 50 percent. This is quite encouraging, but more work is necessary to prove its viability. We anticipate even more significant breakthrough developments during the coming years.

In addition to this multi-faceted Biological Warfare Defense program, DARPA sponsors other efforts that investigate technologies that may prove useful in the effort to protect U.S. forces and population against biological warfare attack.

The **Controlled Biological and Biomimetic Systems** program, which started last year, includes aspects relevant to biological warfare defense. These include efforts to mimic, control and influence the capabilities of living biological systems to find threat agents in the environment. This program has had a number of interesting results in the past year. Researchers have demonstrated, for example, that moths can be trained by associative learning to move toward chemicals. This motion is associated with a natural feeding behavior. Early demonstrations of defense relevance include training insects to target and fly toward the source of unexploded ordinance compounds being released in a plume. The program is also examining the use of animal "sentinels" to collect real-time environmental information. Other researchers are studying the carrying capacity of a variety of insects and how these insects collect information as particulate matter. The program is also interested in insect subsystems – an insect antennae has been used in a hand-held sensor to track odorants. This year, the program will investigate the limits of detection for trained organisms, collection parameters, and interfaces for collecting information from animal sentinels. In FY 2000, a variety of systems will be tested in the field.

Underground facilities are a serious and growing concern, especially as increasing numbers of rogue nations begin to use such facilities to hide biological warfare activities. Underground facilities can also be used to hide other weapons of mass destruction, strategic command and control functions, and mobile missile launchers. With the threat of a biological warfare attack rising, and an increasing proliferation of these hidden facilities, it has become a national priority to be able to hold underground facilities at risk. The detection, characterization, and neutralization of such facilities all pose significant technical challenges, with the characterization function being the most daunting. In the past, a number of small experiments have been conducted elsewhere that show limited capability (and, at times, superficial promise) for determining the functional and physical characteristics of underground structures. Those experiments have lacked a rigid, methodical scientific approach.

DARPA's **Underground Facilities** program will provide a rigorous, disciplined investigation of characterization in hopes of yielding reliable, operationally useful solutions. We will methodically explore the potential signals emitted by underground facilities and the physics associated with the propagation of these signals. Our initial focus is on getting the science right by calling on the nation's experts in fields such as seismology, low-frequency electromagnetics, and spectroscopy. We plan to conduct studies to analyze electromagnetic, acoustic, seismic, and other characteristics associated with such facilities, develop detailed experimental plans, and initiate critical modeling activities. We will also evaluate the potential for seismic imaging to provide battle damage assessment after an attack by performing "change detection" to assess weapon penetration. The program will conduct field experiments, initiate concept evaluations, and explore novel characterization techniques such as long-range seismic monitoring of underground facilities construction, and both intrusive and remote sensing.

Protection from Information Attack

The Department of Defense strategy for "operational dominance" increasingly requires advanced, networked information systems. Simultaneously, the Department must be increasingly concerned with *protecting* those information systems. Weapons systems, networks, command and control links, communications nodes, and intelligence, surveillance and reconnaissance assets all rely on robust, timely information that must be protected from attack at all times.

Since 1995, DARPA has pursued a long-term strategy for investment in Information Survivability and Assurance technologies. The first phase of this strategy involves the closure of critical technology gaps in three areas: networking, information systems assurance, and intrusion detection.

In previous years, the program has devised mechanisms to harden the DoD's Internet-based networks by securing the exchange of routing and directory information that underlies the operation of these systems. These activities have been undertaken in conjunction with leading commercial vendors and network operators to ensure that the protection mechanisms can be extended to the public Internet, especially to the defense vendor base on which the DoD relies for a wide variety of products and services.

Similarly, we have worked to harden our information systems, through the development of tools that defend against some of the most common forms of attack. Here again, DARPA has worked with its researchers, including small businesses, to bring new types of security products to the market, where they can be acquired both by DoD entities and their critical suppliers. While hardening our customized information systems is important, we must also realize that DoD activities will sometimes purchase and use large bodies of commercial software. Accordingly, DARPA is developing software "wrapper" technologies that can be used to encapsulate untrustworthy software and automatically monitor its behavior to ensure that it operates within bounds and does not corrupt or disseminate sensitive data.

In the area of intrusion detection, the program has advanced the state of the art by developing new detection methods. Conventional methods, which rely on matching audit data against known attack patterns, are only able to detect attacks that have been previously observed and analyzed. Although these techniques are useful, they cannot alert us to new attack patterns that have not been catalogued. To address this gap in our warning capability, DARPA-funded researchers are developing a complementary approach based on statistical anomaly detection that compares audit data with statistical profiles of "normal" behavior. In 1998, five projects were evaluated in the first-ever quantitative assessment of intrusion detection methods. The tested prototypes correctly identified attacks 80 percent of the time with a false alarm rate of only 0.1

percent. This represents a significant improvement over today's capabilities, which can detect only 20 percent of attacks with an unacceptably high false-alarm-rate of 10 percent.

We realized that we cannot achieve an operational level of performance without cooperation among detectors of different types located at different points within the network. Furthermore, intrusion detection systems must be able to interoperate with security screens, such as network firewalls, and with response mechanisms that can be used to contain and/or mitigate the effects of an attack. To enable such interoperation, DARPA has developed a Common Intrusion Detection Framework that allows network components to exchange information and to work together to respond to network-based attacks. The Internet Engineering Task Force, the organization that maintains the standards that govern the Internet, will refine the specification and further its acceptance.

DARPA has also been laying the groundwork for the methodical insertion of newly developed technologies into future DoD systems. These Information Assurance activities involve the development of security architectures and innovative approaches to the integration of security technologies. For example, experimental technologies developed by DARPA-sponsored researchers are being combined with commercial security products to form layers of defensive components that allow interoperability between systems while assuring the integrity and confidentiality of our data and networks. Last year, we demonstrated improved software defenses against attacks on commercial grade systems. During FY 1999, the program will demonstrate automated capabilities to limit system access and protect data, detect and respond to intrusions, and reconstitute critical functions after an attack. In FY 2000, the program will demonstrate automated security and administration tools and the enhanced automation of the real-time detection and response functions. We will also investigate novel mechanisms to tolerate attacks so that we can maximize the residual capacity of damaged systems and reconstitute them quickly and automatically. In addition, we will focus on the dynamic aspects of our information defenses to provide both the systems and their operators with a significantly enhanced ability to respond to, and counter, attacks while they are in progress.

DARPA's Role as Technical Enabler for the Concept of "Operational Dominance"

In the area of enabling operational dominance, I mentioned earlier that DARPA emphasizes technologies and systems to support battlefield preparation, dynamic surveillance and re-planning; affordable, mobile, precision target kill; and mobile, distributed command, control and communications. Let me describe some of these efforts:

Battlefield Preparation, Surveillance and Re-planning

Operational dominance requires both information superiority and the ability to take action as a result of that information. Commanders must be able to prepare efficiently for military operations, survey every aspect of on-going operations, and quickly and accurately re-plan based on new developments. DARPA has a variety of technologies and systems developments that provide necessary information and control to operational commanders. These include the application of information technology to critical military problems such as controlling and automating the logistics pipeline, detecting and averting evolving crises, improving the decision process, and real-time, dynamic control of air operations. Underlying, enabling technology developments will increase the interoperability of large, heterogeneous information systems and will allow critical, real-time military users to share network resources. Lastly, new surveillance technologies will allow recent image understanding advances to be applied to the force protection problem and the improved exploitation of airborne video sensors.

One of the Department's key goals is a transformation of the entire DoD logistics system to enable a much more responsive and significantly lower-cost system. DARPA supports that goal through the **Joint Logistics Advanced Concept Technology Demonstration** (JL-ACTD) and **Advanced Logistics Project** (ALP), which aim to apply advanced information processing technologies to gain better control of the logistics pipeline during the planning and execution phases of major military operations. In October 1998, the JL-ACTD conducted an initial demonstration of web-based logistics decision-support tools that will provide the ability for commanders to assess actual mission capabilities while in the process of deploying forces. This year, the JL-ACTD will participate in an operational exercise with users in U.S. Atlantic Command, U.S. European Command, and U.S. Central Command linked via the SIPRNET to test the robustness of these web tools within that part of the Defense Information Infrastructure. In FY 2000, the final year of the JL-ACTD, we will conduct additional operational utility demonstrations with multiple Unified Commanders and complete the transition of JL-ACTD technologies to the Defense Information Systems Agency.

Whereas the JL-ACTD is developing methods to allow humans to better view, understand and manipulate existing logistics information, the **Advanced Logistics Project** (ALP) has a revolutionary approach to revamp antiquated, time-consuming and inaccurate methods that are used today as part of the "deliberate planning process" of generating requirements for logistics support to operational forces. The project is developing a highly distributed and automated logistic planning and re-planning architecture that is fully responsive and adaptable to change during operational execution. Last year, the program demonstrated a prototype distributed logistics information management system, which generated a 27,000-element logistics plan for deployment of an Army division and an Air Expeditionary Force. The ALP system developed this plan in less than an hour. Using current processes, it likely would have required several weeks to generate a comparable-sized plan. This year, ALP will demonstrate the capability to perform real-time execution monitoring and re-planning against an automatically developed and similarly detailed plan. During FY 2000, the project will demonstrate the concurrent generation and evaluation of logistics plans for multiple courses of action or contingencies.

Crisis management requires analysts to filter and interpret large amounts of information in order to detect and avert or mitigate crises quickly. As national security crises escalate, it is harder for authorities to devise preemptive or mitigating strategies. DARPA's **Project Genoa** will develop tools to allow analysts to collaborate and find relevant information rapidly in a format that is easy to use and understand. Through collaboration, analysts and decision-makers can quickly and efficiently compare interpretations of the information found and converge on a reasoned assessment that can lead to more effective response recommendations. During FY

1998, Project Genoa developed the foundation architecture for sharing data and enabling collaborating about hypotheses. This year, the project will demonstrate a search-engine that will allow analysts to rapidly search large data-sources to efficiently find data related to crisis-intent models. Also, crisis-intent models will be augmented to support evaluation of relationships between people and events, this providing early warning. During FY 2000, components of a prototype Genoa system will be deployed to the U.S. Pacific Command and within the Intelligence Community, where they will be evaluated by users involved in crisis evaluation and response.

During and leading up to a military operation, the ability of commander to make quick, accurate decisions, and efficiently transmit their decisions down the chain of command is crucial. The **Command Post of the Future** (CPOF) program hopes to increase the speed and quality of command decisions by "immersing" the commander into a complex information environment. CPOF will develop technologies to allow commanders to interact with multiple data and information sources, using speech and gesture, to quickly develop a thorough understanding of the battlefield situation and available courses of action. The visualization techniques developed by CPOF will allow rapidly evolving, complex situations to be easily understood by military commanders and their staff. During FY 1999, the program will develop and evaluate several core component technologies that will enable rapid understanding of the real-time battle-space. During FY 2000, highly valued, selected components will be integrated within a system framework that will enable evaluation as part of a selected Advanced Warfighting Experiment.

The **Joint Force Air Component Commander** (JFACC) program is designed to catalyze a revolutionary change in military command and control of the future by tackling one of its toughest problems – the operational control of large-scale, distributed dynamic systems operating in an uncertain and rapidly changing environment. During 1997 and 1998, the JFACC program made significant progress in many of the underlying planning technologies required for efficient and effective command and control. However, we have recognized that as planning and decision cycle times are driven toward very short time-lines, execution of planned operations has become the critical challenge. Therefore, this year we are refocusing program activities to concentrate on achieving real-time, dynamic control of all aspects of air operations. It is essential that we develop such technology if we are ever to be successful in addressing the critical mobile target problem. During FY 2000, the JFACC program will explore the unique applicability of control theory technologies to the air operations command and control problem. In a parallel effort, we will develop a comprehensive model of the dynamics within air operations. This model will serve as the heart of our detailed analysis for potential JFACC system design solutions. Together, these efforts will provide the initial building blocks for the development of prototype components, which will experimentally explore a re-engineering of military command and control, to be conducted as the final phase of the program in FY 2001 and FY 2002.

In addition to specialized military information tools, improving the underlying technologies is also important. For example, today, in many cases, DoD uses specialized networks and associated support equipment for varied information systems. Although providing a reliable information infrastructure, this approach is not cost-efficient and does not easily allow different systems to interoperate with one another. While a shared information infrastructure is more affordable and offers better interoperability, we are currently not able to guarantee full service to all users if there are limited network resources available. In today's systems, access and speed are degraded for everyone when availability decreases. This is an unacceptable condition for tactical military environments. The **Agile Information Control Environment** program will develop and demonstrate technologies to allow the appropriate allocation of network resources to the most important users. This, for example, will allow those military applications and users that require guaranteed real-time support to use a shared information infrastructure. This program is just beginning during FY 1999. By next year, the program will complete development of the initial software technologies, and will demonstrate sustained, real-time, quality-of-service over integrated commercial and DoD wide-area and tactical networks.

Intelligent software agents are gaining increasing importance as a key technology for military use. For example, agents can provide a “bridge” between heterogeneous information systems without requiring all systems to adhere to a specific standard. Agents can also provide interface tools for dealing with large and diverse information systems such as the World Wide Web. The DoD has a vast number of legacy and evolving information systems that must all operate together. Devising standards on which everyone can agree is time-consuming, slowing down the DoD’s ability to use the newest technology. This is especially challenging due to the increasing number of Coalition Force operations where participating forces have conflicting and incompatible information systems and architectures. Software agents help solve this dilemma by integrating these separate information systems. The **Control of Agent Based Systems** (CoABS) program is developing and demonstrating techniques to build, control and coordinate large systems of autonomous software agents. In the past year, the program designed and began the implementation of the “agent grid,” a testbed environment to support the development and control of large-scale agent systems. This year, CoABS will develop and test new control strategies and architectural components that will use the grid to coordinate the behaviors of agent-based systems. In FY 2000, we will demonstrate how our infrastructure significantly impacts modern military operations, and will explore scientific and mathematical issues that must be overcome in order to control a large number of diverse and increasingly competent agents.

Making better use of the sensors we currently have is one key to improved surveillance capabilities. The **Airborne Video Surveillance** (AVS) program, which started in June 1998, will develop and evaluate a set of video exploitation tools designed to improve the utility of airborne video (both television and infrared). Such systems are in use on collection assets like the Predator unmanned aerial vehicle, the P-3 aircraft, the Airborne Reconnaissance-Low systems, and the Army Tactical Unmanned Aerial Vehicle. On most of these platforms, video sensor control and exploitation are completely manual and the video systems have limited accuracy (approximately 100 meters) for locating objects on the ground. AVS technology will provide semi-autonomous video sensor processing that can simultaneously track multiple moving targets, monitor different battle-space areas for human and vehicle activity, and geo-locate such events with two-to-10 meter accuracy. During FY 1999, AVS will develop an experimental evaluation system that will be able to track three targets and perform site-area monitoring. The program will evaluate mission effectiveness using an airborne testbed and simulated military activity at Fort A.P. Hill, Virginia. In FY 2000, the prototype system will be used during a simulated military mission to demonstrate its ability to monitor activities over wide areas and precisely locate targets with an accuracy of two meters or less.

In 1997, a Defense Science Board Summer Study Task Force reported on "DoD Responses to Transnational Threats," stating that advanced technologies were needed for enhanced and extended perimeter security. The explosions at the U.S. embassies in Tanzania and Kenya are prime examples that augur the need for technologies to better protect our personnel and provide early warning to better prevent these events. The goal of the **Image Understanding for Force Protection** (IUFP) project is to develop and demonstrate advanced video (optical and infrared) surveillance that can automatically detect, characterize and track vehicles and humans within urban environments. IUFP technology will provide automated, multiple-camera surveillance sorted video-stream feature extraction, historical behavior analysis and activity-based operator cueing. By FY 2000, the program will demonstrate a "video sentry" at a fixed location, to detect, track and alert operators to potential security concerns.

Affordable, Precision Moving Target Kill

Current approaches to engaging surface moving targets include area-of-effect munitions and man-in-the-loop targeting. These approaches suffer from large, very expensive weapons, the potential for large collateral damage, and the requirement to put the warfighter in harm's way. Today's developmental efforts are focused on putting the entire weapon system burden on the weapon, calling for brilliant weapons that include seekers, automatic target recognition, and the ability to search large areas. The affordability of such an approach remains to be seen. DARPA is responding by sponsoring programs to investigate the feasibility of networking existing targeting assets to provide fire control solutions; develop and demonstrate a new, space-based targeting capability; improve radar capabilities; and develop offensive and defensive weapons.

The **Affordable Moving Surface Target Engagement** (AMSTE) program is exploring the feasibility of putting the weapon system burden on the fire control portion of the kill chain. We believe that distributed, netted fire control can provide a more robust targeting solution against moving surface vehicles, so that these targets can be effectively engaged with less expensive, "dumb" weapons. DoD already has a large investment in existing and planned ground moving target indication radar sensing systems that, if networked together, may enable very precise targeting. In this way, existing and planned weapons can be employed with only minor modifications to accept in-flight updates. There are numerous technical challenges to be overcome. Major concerns include maintaining a robust, high-quality target-track long enough for the weapon to engage and solving battle management and command, control and communications issues. In FY 1999, the moving target exploitation program initiated weapon system trade studies to address critical system feasibility questions and design subsequent fire control experiments. Additionally, the program is initiating work on precision fire control tracking algorithms. In FY 2000, we will complete the trade studies, conduct real-time laboratory experiments with the fire control algorithms to assess their accuracy and robustness, and collect data to enable fire control performance evaluation and iteration.

The **Discoverer II** Joint Program is a joint U.S. Air Force, Defense Advanced Research Projects Agency (DARPA) and National Reconnaissance Office (NRO) technology demonstration program. Discoverer II will establish the technical feasibility and affordability of a space-based system offering high-range-resolution ground moving target indication (HRR-GMTI), synthetic aperture radar (SAR) imaging, and high-resolution digital terrain mapping data directly taskable by theater or joint task force commanders and directly downlinked to theater tactical ground stations. Such a global reconnaissance and surveillance capability is required to ensure U.S. forces attain the dominant battlefield awareness envisioned in Joint Vision 2010. The Discoverer II program will design, fabricate and launch two research and development prototype HRR-GMTI/SAR satellites and will conduct a one-year, on-orbit demonstration with the satellites in FY 2004. Most significantly, the Discoverer II program will demonstrate for the first time the feasibility of fielding these capabilities at a cost that will make deploying a large operational constellation of Discoverer II follow-on satellites an affordable reality. The program leverages heavily on past and on-going DARPA investments in sensor and information technologies and capitalizes on the considerable systems engineering and space program experience and talents of the Air Force and NRO. The Discoverer II program recently awarded three firm-fixed-price phase one concept development contracts, valued at approximately $10 million each, to contractor teams headed by Lockheed Martin, Spectrum Astro, and TRW.

The goal of the **Counter Camouflage, Concealment, and Deception** program is to mature and demonstrate the technologies required to provide the warfighter with the ability to detect targets hiding in foliage. To do this, the program is developing 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. The program will integrate the FOPEN synthetic aperture radar with moving target indication and radio frequency intercept technologies, and develop and demonstrate a multi-sensor exploitation testbed. The testbed is a software-based algorithm integration and testing environment that enables integrated exploitation of data derived from both existing and advanced sensors. Last year, the program completed the critical design review of the FOPEN radar, defined the integrated, multi-sensor system testbed, continued the development of exploitation and FOPEN signal processing algorithms and gathered data for algorithm evaluation. This year, the FOPEN radar will be installed in a RC-12 aircraft, and various algorithms will be integrated into the multi-sensor exploitation testbed. In FY 2000, the program will conduct extensive flight tests to evaluate, for the first time, the FOPEN performance of a simultaneous VHF/UHF imaging radar.

The **Organic Ground Moving Target Indication Radar** program will develop and demonstrate a portable, lightweight radar system that will provide a force protection capability to lower echelon units by tracking approaching personnel and vehicles while 10 to 20 kilometers away and hidden in foliage. Today, units must set up perimeters of land mines or emplaced sensors. Land mines are no longer a viable option, and planting perimeter sensors entails risk to unit personnel. DARPA envisions a system that can be carried on a HMMWV and deployed easily in about 15 minutes. In FY 2000, we will conduct critical phenomenological experiments to verify propagation and wavefront distortion models and begin the development of the lightweight receiver array. The program will conduct system demonstrations in FY 2001.

The **Affordable Rapid Response Missile Demonstrator** (ARRMD) program is building and demonstrating an affordable hypersonic (Mach six to eight) missile to execute rapid-response, long-range missions against time-critical targets or hard or deeply buried targets. The program has as a goal a $200,000 average unit flyaway cost. With the capability envisioned by ARRMD, an aircraft would be able to be up to 600 miles away and launch a hypersonic missile that would hit its target just as quickly as a missile launched from 150 miles away. ARRMD's 600-mile range would allow a single aircraft outside Iraqi airspace, for example, to hit a target anywhere in Iraq. For the Navy, an ARRMD capability can be launched far from shore, out of range of shore-based anti-ship missiles; launching an ARRMD-type of missile from carrier-based aircraft effectively gives the aircraft carrier a 900-mile footprint. We are pursuing two competing design concepts, and are conducting manufacturing demonstrations and testing components in preparation for a preliminary design review this year. In FY 2000, we will finalize the design of the winning concept, and start wind-tunnel testing and full-scale manufacturing demonstrations.

The goal of the **Affordable Multi-Missile Manufacturing** (AM3) program is to develop and demonstrate innovative design, manufacturing, business practices and systems concepts that can substantially reduce the cost of DoD's missiles and smart munitions. Through these technologies and techniques, DoD can reduce missile acquisition costs, reduce the time necessary for the development cycle and allow smaller numbers of missiles to be acquired without increased unit cost. The program has had substantial accomplishments. For example, the program was able to reduce the mid-body of the Joint Standoff Weapon from 256 parts to a single large component part, reducing the per-missile cost by $2,500. Work to improve the manufacturability of the seeker used in the Standard 2 missile will lead to a projected 16-percent reduction in unit cost. In the case of the Joint Air-to-Surface Stand-off Missile, for example, the company participating in the AM3 program was able to offer a unit price that was $125,000 lower than a competing company because of the techniques learned through AM3. Lastly, the program has developed a number of components such as seekers, integrated measurement units, and safing and arming devices that can be used on multiple missile types, thus lowering costs through volume production.

The **Reconfigurable Aperture** program will demonstrate the feasibility of an electronically configurable antenna. While today's array antennas are tuned to a particular frequency range, which is usually rather narrow, reconfigurable aperture technologies would allow the cost-effective design and fabrication of array antennas that can operate efficiently over a large range of frequencies. Reconfigurable aperture technologies would permit increased performance in communications, surveillance and electronic warfare applications, and also allow multiple functionality within a single antenna aperture. This program is just starting this year as we select the contractor team, although some first results have shown excellent high frequency performance of microfabricated interconnects. In FY 2000, the program will develop critical technologies necessary for reconfigurable antennas, including low-loss switches and integrated groundplanes with zero phase shift to improve overall efficiency.

The **Low Cost Cruise Missile Defense** (LCCMD) program will use emerging sensor, propulsion, and guidance and control technologies to provide cost-effective approaches to counter proliferated cruise missile threats. DARPA is concerned that adversaries wishing to challenge the high technology arsenal of the U.S. might deploy a large number of unsophisticated weapons to overwhelm and penetrate our defenses. Our program is focused on technologies that afford the greatest leverage – low cost guidance and control sections for weapons (70 percent of the cost of typical air defense missiles is in the guidance section). The LCCMD program is pursuing a number of low-cost seeker technologies, each with unique cost and performance advantages, to be employed on an interceptor nominally based on a Miniature Air Launch Decoy (MALD) design. The two main thrusts are a noise correlation radar and a MEMS-based, electronically steered radar array. In addition, four other novel seeker technologies are being explored in low-level technical demonstrations. The noise correlation radar system is being fabricated this year. Also this year, we will select another seeker for fabrication from among the other seekers. In FY 2000, the program will initiate captive flight tests of the noise correlation radar, finalize the design of the other selected seeker, and initiate work to design an interceptor (nominally a MALD derivative) for this new mission.

Mobile, Distributed Command, Control and Communications

In Desert Storm, we saw the difficulty of maintaining communications over a vast territory with forces continually on the move. Under the Joint Vision concept of dominant maneuver, future warfighters are likely to be operating as joint or coalition forces while even more widely dispersed across the battlespace. At the same time, the information-rich environment necessary to achieve information superiority will demand even more connectivity with these mobile, dispersed forces. DARPA is pursuing a number of programs to address the technical challenges of this operational concept.

Current Internet technologies do not work well in the mobile wireless environment – particularly when all members of the network may be mobile, as would be true in a battlefield situation. The high rates of network topology change, coupled with the vagaries of radio communications, result in much lower network reliability, lower data rates, and rapidly changing/widely varying quality of service. DARPA's **Global Mobile Networking** program is developing mechanisms that will: (1) allow mobile nodes to adjust parameters, such as transmission power, spreading gain, forward error correction and packet length to maintain network connectivity whenever possible; (2) enable mobile wireless internets to reorganize themselves when network connectivity does change; and (3) harden application services such as file systems to tolerate the sporadic connectivity they are likely to experience in battlefield environments. In FY 2000, the program will begin a demonstration phase, testing its ability to effectively communicate voice and video among 25 moving nodes, both handheld and vehicular. Through simulation, we plan also to demonstrate that the technologies can be scaled to larger networks.

The **Small Unit Operations Situational Awareness System** (SUO SAS) is designed to develop and integrate key communications, navigation, and situational awareness technologies for use by light, early-entry forces in restrictive terrain where they cannot currently communicate. The system is designed to satisfy key information needs for the dismounted warfighter: "Where am I?" "Where are my buddies?" "Where is the enemy?" "What are my options?" Specifically, technologies are being developed that will allow warfighters to communicate clandestinely in buildings, tunnels, jungles and mountainous terrain using self-forming, computer-controlled networks that continuously monitor the environment, mission needs and tactical situation, and optimize themselves to ensure that communications are always maintained. Recent developments in low-power application-specific microcircuits and digital signal processors have enabled this capability and can be packaged in a small, lightweight form that can be easily worn by warfighters. The SUO SAS also includes technologies that provide very accurate location fixes where GPS is not reliable (such as inside buildings or in a city where there is not sufficient line-of-sight for the GPS satellites). These capabilities will greatly increase the effectiveness of small, dismounted forces. Last year, the program developed advanced communications waveforms and developed designs for the accurate, non-GPS geolocation system. This year, field and laboratory tests are underway to measure the performance of the waveforms and the critical technologies that SUO SAS has developed to perform accurate, non-GPS geolocation, enable adaptive self-forming communications networks and perform warrior situation awareness functions. In FY 2000, the program will complete the detailed hardware and software designs and fabricate the major system components.

Current battlefield communications nodes are large, require a lot of power, and can only be carried by JSTARS-sized aircraft. In addition, current nodes support only a limited number of narrowband channels (approximately four) and cannot support dissimilar radio interoperability. The **Airborne Communications Node** program is developing a multi-function, modular, scaleable communications payload for airborne platforms. The payload will augment the existing military communications infrastructure by extending communications beyond the line-of-sight and maintaining communications with mobile warfighters, providing a new, higher data-rate service, interconnecting disparate legacy communications systems, and providing additional communications capacity. The critical technical challenge for the Airborne Communications Node is the electromagnetic interference cancellation required to package many channels (up to 20 at low frequencies) into a small form-factor with a minimum number of antennas. Three competing contractor teams continue to design and develop their proof-of-concept payloads, and this year will conduct technology experiments and tests of high-risk subcomponents. In FY 2000, following proof-of-concept testing of the competitive designs on a manned aircraft, the program will select a single team to design and build a full-capability payload.

While the ongoing revolution in information technology has fundamentally changed the conduct of military operations at the highest echelons, the lowest echelons do not yet have access to advanced information tools. The **Warfighter Visualization** program is developing technology to extend this revolution to the lowest levels by putting such tools in the hands and on the bodies of individual warfighters. These tools may include see-through, helmet-mounted displays that give the warfighter real-time information about his immediate environment, without hampering his natural senses, or systems to provide an "over the hill" or "behind the building" awareness. In FY 1998, the program demonstrated a prototype system that used video taken by a small unmanned aerial vehicle, processed it to put it in the perspective of a ground soldier, and delivered it to a handheld viewer. In FY 1999, the system will be improved to operate in real-time with a helmet-mounted display. In FY 2000, we plan to integrate further sensory enhancements (such as tactile alerts) into the system.

I indicated earlier that, as part of our work to enable “operational dominance,” DARPA is focusing on technologies to enable future air, land and maritime warfare concepts such as combined manned and unmanned warfare. Some of our activities in these arenas are described below:

Advanced Airborne Concepts

DARPA has a long history of innovative research in advanced airborne systems, and this tradition continues today. Our programs range from unmanned combat air vehicles – that take the unmanned air vehicle to the next plateau by going beyond today's autonomous systems to tomorrow's dynamically adaptable systems – to micro air vehicles that have no dimension greater than six inches. We are also pursuing improved rotary wing concepts that offer higher speeds or longer ranges than current systems.

The goal of the joint DARPA and Air Force **Unmanned Combat Air Vehicle** (UCAV) Advanced Technology Demonstration program is to demonstrate the technical feasibility for a "man-in-the-loop" UCAV system to effectively and affordably prosecute 21st century Suppression of Enemy Air Defenses (SEAD)/Strike missions within the emerging global command and control architecture. The program was divided into two phases. During the first phase, which just ended, industry teams designed a system-of-systems based on anticipated threats. Starting from a clean sheet of paper, each team conducted an exhaustive set of engineering trades to define an operational vision for a UCAV weapon system. These operational concepts indicated that air vehicles one-half of the size of today's counterparts displayed compelling mission effectiveness and affordability potential. The results fully validated the program's hypothesis that, in the 2010 timeframe, the acquisition cost of the UCAV would be one-third of today's Joint Strike Fighter acquisition cost, and that operational and support costs, compared to a current manned fighter squadron, would be reduced by 75 percent. The second phase of the program is just starting, with a single contractor selected to conduct a comprehensive series of simulations, ground tests, and flight tests using a surrogate aircraft, two full-scale air vehicle demonstrators, and a reconfigurable mission control station. In this phase, the UCAV program will demonstrate: compatibility of the unmanned system with the envisioned 2010 battlespace; robustness and security of communications with the air vehicle; feasibility of adaptive, autonomous control of the air vehicle, with advanced cognitive decision aids for the "man-in-the-loop" system operators; feasibility of coordinated, multi-vehicle flight; affordability of operations and support costs; and deployability of the system.

The **Micro Air Vehicle** (MAV) program will demonstrate fully functional, working air vehicles that are less than six inches in any one dimension. In addition, the program is supporting the development of more advanced flight-enabling technologies for improved propulsion and power. The program is currently exploring two system concepts: one that is fixed wing, and one that is rotary-wing. The rotary-wing concept will have imaging sensors for both day and night operations and will be useful for reconnaissance and surveillance missions for urban operations. The fixed-wing concept, on the other hand, is particularly well-suited for longer-range, over-the-hill reconnaissance missions. Both concepts' designs were completed last year, and the systems are now being fabricated. In addition, we plan to flight-test a shorter-range (one kilometer), teleoperated MAV with a visible imager this year, and, if successful, to demonstrate the capability at the Military Operations in Urban Terrain site at Fort Benning, Georgia. In FY 2000, flight-tests of both the longer-range (five kilometer) fixed-wing design and the rotary-wing MAV will be conducted. The development of the advanced flight-enabling technologies (propulsion based on flapping wings, tiny fuel cells, thermoelectric technologies, shirt-button-sized turbojet engines, and an autopilot) will continue in FY 2000. We plan to "bench demonstrate" a hydrogen-fueled, silicon, micro-turbojet engine in FY 2000, and we intend to complete and demonstrate an 80-watt diesel engine. We also expect to complete the fabrication and testing of the world's smallest aircraft autopilot and guidance package (50 grams, complete with inertial navigation system and GPS) in FY 2000.

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. The MALD program is currently in the midst of a very successful developmental flight test program. In recent flight tests, all test objectives were met, validating the MALD vehicle's air-worthiness, navigation, and flight control systems. In upcoming months we will demonstrate the electronic Signature Augmentation System payload, which is the heart of the decoy system. When developmental testing is complete, operational testing will be conducted by the Air Force to determine the operational effectiveness of the system and ultimately confirm the operational requirement for the system.

The **Micro Adaptive Flow Control** (MAFC) program is developing strategies to control large-scale flow characteristics using small-scale actuators that include synthetic jets and smart materials. We believe this approach will offer revolutionary performance improvements for aerospace and maritime applications. We are exploring increased thrust-to-weight ratios for aircraft engines by controlling flow separation on compressor blades to reduce the number of blade rows required. MAFC technologies hold promise for improved payload capacity for tiltrotor aircraft, enhanced aircraft maneuverability, extended range for munitions, and suppression of submarine mast wakes. Last year, the program selected a number of concepts for preliminary investigations and started development of MAFC actuators and controllers. In FY 2000, the program will initiate work on promising concepts for systems level integration and demonstration. One possible application is the hot engine exhaust of the C-17, which must be diverted or cooled for safe loading operations. Micro adaptive flow control of jet mixing may be a lightweight way to lower the engine exhaust temperature instead of the current practice of diverting the hot exhaust with heavy thrust-reversers.

The **Advanced Air Vehicle** program is pursuing the development of two different concepts offering improvements in performance, affordability and military utility. The Canard Rotor Wing concept offers high speeds and increased survivability. Because the rotor does not rotate during high-speed cruise flight, the vehicle's radar signature is lower than most rotary-wing vehicles. The Canard Rotor Wing program will have its critical design review this year and then start fabrication of two sub-scale demonstrator vehicles. Rollout is scheduled for FY 2000. Following flight test, the program will transition to the Navy for further evaluations. The A160 Hummingbird concept is using a unique low-disk-loading, hingeless ridged rotor design that offers long endurance and long-range performance in a rotary-wing vehicle. This year, the A160 contractor is conducting ground-testing of the full rotor system and fabricating the first of three unmanned test vehicles. In FY 2000, the first vehicle will start flight-tests.

Advanced Robotics Concepts

DARPA has a heavy emphasis in advanced robotics concepts, with a focus on those applications or technologies that are particularly stressing. One effort involves the development of very small robots that can work cooperatively. The challenge in this effort is to pack useful capability into a very small package, and to develop the software to allow these robots to work together. Another important effort will bring useful robotics technology to the work of dismounted operations in an effort to save soldiers' lives.

The **Distributed Robotics** program is developing microrobots that work together in groups in dynamically changing environments. These small robots will be five centimeters (two inches) or smaller in any single dimension. They will work cooperatively together in groups, be capable of different modes of locomotion (land, water, vertical climbing, etc.) and will adapt their behavior based on remote user inputs or onboard sensors. The program, which started last year, currently has 13 contractor teams investigating different approaches, such as crawlers, jumpers, vertical climbers, and airborne systems, as well as robots that can dynamically change their shape and locomotion mode. This summer, all contractors will demonstrate a single robot accomplishing a specific task. In FY 2000, contractors will start work on multiple robots working together.

The **Tactical Mobile Robotics** program is developing robotic technologies and platforms designed to revolutionize dismounted operations by projecting operational influence and situational awareness into previously denied areas. These portable robots will be robust and able to adapt to complex environments while employing specially designed payloads and devices. In FY 1998, the program selected three platform development concepts, demonstrated key component technologies for robust urban mobility (climbing up stairs, over rubble, etc.), and established a robotic technology experiment site at Fort Sam Houston, Texas. In FY 1999, basic mobility platforms will be outfitted with revolutionary perception aids such as Omni-cameras and laser scanners in conjunction with development of semi-autonomous navigation capabilities for non-GPS conditions (indoors, underground, deep jungle, etc.). In FY 2000, the program will integrate enabling technologies and specialized payloads into functional platforms.

Advanced Battlefield Concepts

The Joint Vision 2010 concept for operational dominance envisions forces that are highly maneuverable and can conduct sustained and synchronized operations from dispersed locations. DARPA programs will support the advanced battlefield by developing enhanced capabilities for early-entry forces, hybrid electric propulsion to provide mobility and stealth, and alternatives to antipersonnel landmines for the future.

The Army After Next and the U.S. Marine Corps' concept for Operational Maneuver from the Sea both envision the use of forces rapidly deployed by air and sea. These units need the capability to rapidly deploy precision, responsive firepower in combination with protection from hostile aircraft and missiles and beyond-the-horizon targeting. The **Advanced Fire Support System** program is a concept for a family of small, container-launched missiles to provide massive, responsive precision firepower early in a conflict. Because the program is addressing cost, military effectiveness, logistics and survivability, we believe the program will compare favorably with alternative approaches in each area. The container-launcher can easily be transported, and, because the shipping container is also the launcher, missiles can be fired immediately after delivery to the desired location. The container-launcher does not require a unique platform – it can be fired remotely from trucks, HMMWVs or a variety of other platforms. Using the same general missile design, the program will develop a family of missiles with different capabilities. To date, the program has started design work for the seeker, missile, and launcher, and, in conjunction with the Navy, tested a full-scale, concentric launcher. This year, we will test a variable thrust motor, complete detailed designs, and conduct several risk reduction demonstrations. Beginning in FY 2000, the program will build and test both launchers and missiles, with initial flight testing planned for FY 2001 and 2002.

In FY 1998, DARPA initiated a joint program with the Marine Corps to develop a lightweight, highly maneuverable **Reconnaissance, Surveillance and Targeting Vehicle** (RST-V) that will use hybrid electric propulsion, have integrated 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. Operational goals include 20 miles-per-gallon fuel economy and 27 miles silent movement capability. The program recently awarded the Phase II contract. The winning concept presented a superior technical approach in automotive technology, integration, mobility and operational suitability. The Automotive Fabrication Readiness Review will occur later this year. In FY 2000, the RSTV will undertake rolling chassis and advanced mobility demonstrations.

DARPA is participating in the Department's effort to develop **Alternatives to Antipersonnel Landmines**. While we coordinate with the efforts ongoing for near-term solutions, our program is oriented toward longer-term solutions. When enemy forces encounter an antitank minefield, they must clear a lane through the minefield. The U.S. uses antipersonnel landmines to protect the antitank minefield from breaching and lane clearance by dismounted troops. DARPA envisions a dynamic, self-healing antitank minefield that would not require the addition of antipersonnel landmines. The antitank mines would detect a breaching attempt through mine-to-mine communication, and individual antitank mines would move to fill-in the breaching attempt. Early studies validate the utility of this approach. Another approach envisions tagging dismounted enemy soldiers with burr-like radio-frequency transmitters that will guide short-range indirect fire. In this scenario, when the tag activates upon attachment to a moving solder, munitions with minimal guidance and homing capabilities (to reduce cost) would be fired towards the enemy soldier using position information determined by the tag. The program will investigate system design issues for both alternative solutions and will identify the technologies needed and demonstrate the ability of surrogate antitank mines to move and communicate. A laboratory demonstration of the tagging concept will also be conducted.

Advanced Maritime Concepts

DARPA has a continuing commitment to pursue high-risk, leading-edge technologies and systems that promise revolutionary improvements for future maritime operations. The Undersea Littoral Warfare program focuses on the unique challenges of antisubmarine and countermine warfare in the littorals, whereas the Buoyant Cable Antenna Array will provide capabilities that support the Navy's concept of Network Centric Warfare by improving the connectivity of submarines. Other important maritime programs include the Sonoelectronics program, which will provide advanced underwater imaging capabilities, and the Submarine Payload and Sensors Study, which will investigate new concepts for submarine payloads.

The **Undersea Littoral Warfare** (ULW) program consists of a variety of techniques and technologies specifically applicable to the unique problems associated with the littoral region. In one effort, the program developed an active acoustic system with greatly improved detection, classification, and targeting performance against low-observable submarines. The acoustic system, known as Distant Thunder, has been successfully demonstrated at sea and transitioned to Navy management last year. As an outgrowth of Distant Thunder, the program is now developing the Netted Search, Acquisition, and Targeting (NetSAT) System. NetSAT uses a bi-directional fiber-optic link to allow a torpedo to be networked with a supporting sonobuoy field during its attack on an opposing submarine. Integration of the sonobuoy and torpedo data on the helicopter launch platform permits the operator to rapidly discern the submarine from countermeasures deployed to confuse the torpedo, ensuring that the weapon ultimately destroys the true target. In FY 2000, NetSAT will conduct its final proof-of-concept demonstration. Another technical challenge associated with naval warfare in the littoral region is finding and avoiding mines. The ULW program is determining whether advanced synthetic aperture sonar processing techniques can classify and identify underwater mines at greater search rates than is possible with current systems. Lastly, finding quiet submarines in the littoral can be a daunting problem, especially in the vicinity of shipping channels, where noise from surface shipping often masks the returns associated with submarines. The ULW program is investigating the use of innovative, multi-dimensional receiver arrays and advanced signal processing, plus overhead surveillance reports of surface ship locations, to improve the resolution and rejection of surface ship interference in shallow water.

The **Buoyant Cable Array Antenna** program will develop a floating antenna to allow submarines to transfer data and communicate at high data rates while operating at speed and depth. Following last year's initial feasibility testing of critical system issues, the program is conducting side-by-side comparative testing of the DARPA multi-element system concept and a Navy-generated single-element system concept. In FY 2000, the program will start design and development of a full duplex (transmit/receive) prototype antenna.

The **Sonoelectronics** program is marrying acoustic, microelectromechanical technologies with signal processing to create compact systems that will "see" and "hear" through acoustics (sound) in harsh environments, the same way that a sonogram uses sound waves to create a picture of an unborn baby. Sonoelectronics will improve the image quality, render it in three dimensions, and will work without touching the object being imaged – something that is not possible today. The military can use such systems for man-portable, near-real-time imaging of objects in shallow turbid waters, with no need for a light source, improving performance for mine imaging, ship self-protection and surveillance, and search and rescue. In addition, such technology can detect and isolate voices or specific sounds in extremely noisy environments. In FY1998, the program completed the initial demonstration of wideband micromechanical structures for acoustic transduction and amplification. This year, the program will demonstrate acoustic array concepts, and finalize designs for other subcomponents. In FY 2000, the program will demonstrate integrated systems for underwater imaging, and initiate work on the technology for isolating sounds in noisy environments.

The present design of submarine payloads and sensors is constrained by the size, loading, storage, and launching approaches for existing weapon systems; in turn, these limitations increasingly constrain the view of the future operational utility of the submarine platform. The purpose of the **Submarine Payloads and Sensors** program, which begins in FY 1999, is to explore the possibilities that emerge when a unified set of payload and sensor concepts (together with their operational implications) and supporting platform concepts are formulated in a balanced manner. Taking its cue from a recently completed high-level study on the future submarine, the program takes into consideration future submarine missions and concepts of operation that may be derived from the application of advanced technologies as well as investigating the technologies themselves. The program will develop flexible platform concepts to support multiple payload/sensor concepts across the areas of advanced ordnance, advanced sensors, and adjuvant vehicles. Our emphasis is on those aspects of platform design not associated with the propulsion train and reactor. This year, we will select multiple teams to start an 18-month concept development phase.

DARPA’s Core Technology Development

DARPA continues its emphasis on developing the core technologies that reflect our traditional strengths: information technology, microsystems technologies, and materials technologies.

Advanced Information Technologies

DARPA’s historical strength has always been in the information technology field. We pioneered the technology that under-girds today’s Internet, the easy-to-use graphical interface approach to computing that is familiar to all Windows users, and massively parallel processors. We certainly do not intend to rest on these laurels, however. Our information technology programs today are even more exciting, as they presage the next information revolution in the world of embedded computing.

DARPA’s key information technology initiative falls under auspices of IT^2, the inter-agency initiative, “Information Technology for the 21^{st} Century.” IT^2 was put in place in response to the report of the President’s Information Technology Advisory Committee, which warned that “the Nation is gravely under-investing” in fundamental information technology research, especially in the areas of software and networking. In response to this finding, DARPA has worked closely with the Advisory Committee and with other agencies to develop a balanced investment strategy consistent with our mission to be the technical enabler for innovation for national security. We adjusted our efforts within the High Performance and Global Scale Systems area and are initiating three new programs in FY 2000: Software for Embedded Systems, Deeply Networked Systems; and Software for Autonomous Systems. The fundamental information technology research planned in these new programs is crucial to attain the information superiority envisioned by Joint Vision 2010.

Most information technology research to-date has focused on computers in direct contact with humans – the servers, workstations, and laptops that are used in office environments and in our military command and control systems. However, these "interactive" computers only constitute about two percent of the total computer population. In contrast to the laptops and desktop processors that users interact with directly, think of the large number of embedded processors silently guarding and improving various aspects of our lives – for example, in car safety systems, environmental control systems, elevators, and all manner of domestic appliances. In 1997, the total production of "personal computer class" microprocessors was just over 100 million parts, while over four billion embedded devices were produced.

The role of embedded computing, and its accompanying software, is growing even faster in the military, where almost every weapons system includes numerous embedded processors that intelligently bridge the gaps between the platform's sensors and its electro-mechanical actuators. Furthermore, these embedded processors can now be networked, enabling new modes of system operation. Accordingly, a key aspect of DARPA's participation in IT^2 will be to reposition a portion of the information technology research community to directly address this crucial area, which presently lacks the type of scientific leadership now devoted to issues associated with computers in direct contact with humans. In particular, our **Software for Embedded Systems** program will investigate new software composition paradigms that are expressly suited to embedded environments. For example, using sensor networks as a representative application, we will develop reusable software components that support the automated aggregation, processing and distribution of sensor-derived information, as well as the tasking and querying of large collections of embedded processors.

Today, about 98 percent of the nation's computers are stranded within platforms with sensors and actuators in direct contact with the outside world, but with processors that are disconnected from the network. Bringing these intelligent nodes on-line, by extending the "depth" of the network to reach them, could close the gap between the presently disembodied world of command and control systems and the physical world the DoD strives to monitor, shape and control. However, the large-scale networking of these devices creates new requirements for: network interface technologies to achieve drastic reductions in cost; real-time networking that can satisfy stringent sensor-to-shooter timing constraints; and automated approaches to network naming, addressing, configuration and administration to make the deployment and operation of a hundred-billion-node infrastructure feasible. DARPA's **Deeply Networked Systems** program will undertake the necessary research to surmount these challenges.

The final component of our response to the Advisory Committee's challenge concerning software is the initiation of a new program in **Software for Autonomous Systems**. If we are to gain a "force multiplier" from our information technology, we must take steps to greatly increase the degree of autonomy with which our software-based systems operate. In the domain of unmanned vehicles, for example, we must leverage information technology to move from one or more operators per vehicle to harnessing tens, hundreds, or even thousands of vehicles per operator. Similarly, in the case of software agents that roam the network, sometimes referred to as "knowbots," millions of agents per user may be a viable target – provided that we can enhance the degree of autonomy with which these vehicles and/or agents operate. Our strategy in this domain has four components: (1) improve the capabilities of individual entities by reinventing their low-level control systems in ways that leverage recent advances in information technology; (2) improve the degree of autonomy of individual entities so that they can deal with unanticipated inputs that are typical of real world interactions; (3) create new capabilities by allowing large numbers of entities, both robots and knowbots, to negotiate with each other and to coordinate their actions without human intervention; and (4) reinvent the interfaces through which human "commanders" can task and interact with the resulting systems.

Although the Advisory Committee's highest-level finding concerned the state of software research, it also expressed serious concerns regarding the state of high-end computing and recommended that the Administration "fund research into innovative computing technologies." Accordingly, DARPA has renewed its commitment to the High Performance and Global Scale Systems area and has placed additional emphasis on its Adaptive Computing Systems and Data Intensive Computing activities.

The **Adaptive Computing Systems** (ACS) program is developing new computer processing components that are able to reconfigure themselves to suit the immediate task at hand. Ultimately, programs will be able to "rewire" their processors while they are running, eventually on an instruction-by-instruction basis.

While ACS is reinventing our processor technology, the **Data Intensive Computing** effort is redefining our memory subsystems to allow data to be fetched from memories more quickly and, in some cases, to allow operations to be performed within the memory chips themselves so that the data does not have to be fetched at all. This type of technology is particularly important for synthetic aperture radar, automatic target recognition, large-scale dynamic databases, and space-time adaptive processing applications, all of which require high-speed manipulation of large sets of data. In many systems, the speed of the processor outstrips the capacity to access memory, creating a bottleneck that can be overcome using the technologies DARPA-funded researchers are creating. During FY 1999, the program will develop a benchmark suite specifically geared to measure the efficacy of this new technology. In FY 2000, the program will provide simulators that can be used to explore architectural options and to test early compiler and operating system approaches.

In addition to IT^2, DARPA continues to develop very aggressive network technologies under the auspices of its **Next Generation Internet** (NGI) program. The DoD's networking requirements are extremely demanding, both in terms of bandwidth and dynamic variability. DoD needs to be able to transmit high-resolution imagery, surveillance digital video, and large data files quickly and to have access to ultra-high capacities on short notice – especially in times of crisis. While commercial endeavors have successfully demonstrated that large numbers of low-speed data streams can be aggregated onto high-bandwidth backbones for long-haul transmission purposes, today's technology does not allow individual users to transmit multi-gigabit streams on an end-to-end basis – let alone allow users to initiate such streams with little or no notice to the service provider. DARPA's program is focusing on a new generation of optical multiplexing and switching technologies that will allow the military's high-end, demanding applications to coexist on a national infrastructure that is shared with hundreds of millions of less demanding users. Some examples of new technologies that are under development within NGI include: optical labeling to allow traffic to be differentially processed by optical components within the network; burst switching to enable the dynamic creation of multi-gigabit paths through the network; and internet tomography tools to enable monitoring of tens of thousands of nodes in the global Internet.

Advanced Microsystems Technologies

To fully transform today's military into the force of the future, DoD must increase the capabilities of current systems and those under development through advanced microsystems technologies such as electronics, photonics and microelectromechanical systems. As Defense resources decline, it becomes less and less likely that the military will be able to afford new military platforms at historical purchase rates. Microsystems technologies, however, can allow the development of more capable, smaller, lower power and affordable components and subcomponents to update and improve these legacy platforms. We have supported, and continue to support, developments in microelectromechanical systems (MEMS), high definition systems, and advanced lithography. In addition, we are moving into newer areas such as optical data networking, advanced photonics, molecular-level large-area printing, and heterogeneous materials on silicon.

DARPA investments have catalyzed the creation of **Microelectromechanical Systems** (MEMS) technologies. The MEMS program is currently focused on developing integrated, micro-assembled, multi-component systems for applications such as aerodynamic control; signal processing using electromechanical computation; inertial measurement and guidance; and microfluidic chip-technologies to be used for biological detection, toxin identification, DNA analysis, cellular analysis, drug preparation and drug delivery. In addition, another program focus is to use a greater variety of materials for the MEMS devices and subsequently to integrate the MEMS devices with electronics. More and more MEMS devices are being inserted into a variety of larger systems. Some examples of systems insertions of MEMS technology to date include use of low-power, wireless integrated microsensors to provide maintenance information on a fire suppression pump onboard the USS RUSHMORE; MEMS pressure sensors in the booster rocket for the F-14 ejection seat; and MEMS tire-pressure sensors embedded in the tires of Army tank carriers. This year, the program plans additional demonstrations: MEMS accelerometers with telemetry to monitor the readiness of the Patriot missile and a MEMS fuze/safing and arming device in a submarine torpedo counter-weapon. In addition, a Navy satellite with MEMS components will be launched, allowing the demonstration of the capabilities of MEMS devices to withstand the rigorous space environment. In FY 2000, the program will focus on developing micro-power sources and micro-communications components and start demonstrations of micro-airborne sensor/communications devices. These new microsystem chips will provide the warfighter and unmanned reconnaissance vehicles with geolocation, communications and extended awareness capabilities.

DARPA continues its investment in **High Definition Systems**, with particular emphasis in organic electroluminescent displays, flexible substrate displays, and displays that fulfill uniquely military needs (i.e., can be read in full sunlight or with night-vision goggles; minimum power usage; rugged; and, lightweight). DARPA is working with the Army to develop a high-brightness display for use in the Comanche helicopter head-mounted display system. The two technologies under consideration are an active matrix liquid crystal display and an active matrix electroluminescent display. Another display technology of interest to the Army and the special operations community is the cholesteric display, which requires very low power and can be seen in full sunlight or while wearing night-vision goggles. Flexible emissive displays are useful for large-area, high-resolution display applications requiring ruggedness, low weight and cost, and flexibility. During FY 1999, an active matrix liquid crystal display meeting the requirements for the Comanche head-mounted system will be demonstrated. Head-mounted active matrix electroluminescent displays will be evaluated by the Land Warrior program, and a thin-film electroluminescent display will be evaluated for the M1A2 SEP upgrade. In FY 2000, the program will demonstrate an untethered cholesteric display that will use a radio-frequency-link to a body-worn computer. Because the display is reflective (visible in full sunlight as well as while wearing night-vision goggles), and because it only needs to be updated when new information is required, the system will be very low power (two AA batteries will last one year). In addition, the program will start to investigate new bistable pixel displays. A bistable pixel display has the advantage that the pixel only needs to be updated when the information in that pixel changes. This greatly reduces the update data rate, because in most images only a few pixels actually change during a single frame. It also reduces the power consumption. Bistable pixels are especially important for very high pixel count displays and for very low-power applications, both of which are important to DoD. We will also continue the work on flexible emissive displays, which will be accelerated in FY 1999.

Although there is much uncertainty about the exact timing of future lithography generations, there is general agreement that certain critical technological hurdles must be overcome to enable the realization of critical dimensions at 100 nanometers and below. After consultation with the lithography tool industry and the semiconductor manufacturers, DoD has developed a plan to co-fund, with industry, the research and development to understand and overcome specific technological obstacles to the realization of lithography for 100 nanometer critical dimensions and smaller and the supporting technologies relevant to more than one lithography technology option. The DoD plan gives DARPA the lead for all but a small basic research program.

The DARPA **Advanced Lithography** program gives preference to lithography approaches that extend to the smallest critical dimensions and to supporting technologies that are applicable to the largest number of lithography technologies. Examples of support and crosscutting technologies of interest include mask technology, resists, metrology, and other such technologies applicable to more than one lithography technology. For 100 nanometer-and-below lithography, DoD is interested in innovative technologies, especially high payoff approaches and proof of concept developments emphasizing a few key components. Technologies of interest include maskless lithography (electron-beam, ion-beam), projection electron-beam, extreme ultraviolet, x-ray, and optical lithographic technologies extended for 100 nanometers and below. Because prototyping of lithography tools for the target lithography generations is premature, the DARPA program will include component prototyping, as opposed to integrated machine prototyping, thus focusing on solving critical problems to enable prototyping at a future time.

The **Optical Micro-Networks** (OMNET) program will demonstrate high-speed, affordable optical data networks for use on-board military platforms such as aircraft and ships. The use of optical networking will enhance the operational effectiveness of these platforms by reducing the size and weight of electronics equipment, while increasing the ability of on-board smart weapons to share targeting information. The optical data networks will also improve weapon system survivability by distributing critical electronics equipment throughout the platform. Some of the most advanced commercial aircraft are currently using optical networks to transfer data, but these networks transfer data at lower speed than that required by the military. In FY 2000, the program will conduct in-flight tests of OMNET hardware onboard an AV-8 during live-fire, tactical operations. This will be the first-ever in-flight testing of a 10-gigabit per second optical network in a combat-type environment.

Electronic interconnects using wires lead to information processing systems that are bulky, heavy and power hungry. The communication bandwidth and speed possible with these electronic interconnects is lower than that of the processor itself, leading to bottlenecks. Recent advances in optoelectronics allow optical elements to be used instead of wires at the chip-to-chip levels and between boards. The **VLSI Photonics** program will develop photonics technology (for optical links instead of electronic links) for chip-to-chip communications and between boards to provide greater than a terabit per second aggregate data transfer rates between circuit boards. These speeds are crucial for high-speed processing applications such as synthetic aperture radar and automatic target recognition. In addition, VLSI Photonics will enable a 100- to 1000-times reduction in power and size for these systems. In 1998, the program demonstrated the integration of vertical-cavity lasers on top of driving electronics, together with the necessary micro-optics. These are being scaled to 16-by-16 smart-pixel arrays of optical communication blocks for the chip-to-chip interconnects. In 1999, the smart-pixel arrays will be connected to actual electronic chips to demonstrate optical link communication between chips at a rate of over 250 gigabits per second. The 16-by-16 smart-pixel arrays will be scaled to 100-by-100 arrays in FY 2000 for a demonstration that involves data processing in a synthetic aperture radar in FY 2001.

The weight and complexity of imaging systems can be significantly reduced if a curved focal surface can be used rather than a focal plane. For example, the field-of-view would increase, the cost should decrease, gimbals will be eliminated, and the ability to zoom electronically would be provided. The **Molecular-level, Large-area Printing** program will develop a high-speed, flexible and inexpensive set of techniques to generate thin film structures, especially curved structures, for sensors, storage devices, signal processing circuitry, and displays. This program started last year. Contractors are characterizing and evaluating a variety of first-generation printing processes, and will next start to look at the second-generation process, which should show improved robustness and capabilities.

A variety of radar, electronic warfare and communications systems receive sensor input in the forms of analog signals. These signals must be converted to digital signals for further processing. The process of conversion is usually accomplished electronically, but the use of photonics technologies will provide enhanced performance to suppress jamming, increased detection of targets in clutter and enhanced target identification. The **Photonic Analog to Digital Converter Technology** will use photonics technologies to achieve a breakthrough in high-speed analog to digital conversion. This program is starting this year, and will develop and evaluate the initial design for critical photonic and electronic subcomponents next year.

The **Heterogeneous Materials on Silicon** program will demonstrate the feasibility of integrating very high-speed digital logic and high-power amplifiers with silicon Complimentary Metal Oxide Semiconductors (CMOS) on a single substrate to provide new functionality not possible with silicon alone. The success of this integration will enable modular drive electronics for systems such as the Navy's Advanced Multifunctional Radio Frequency System and low-power electronically steered antenna arrays for tracking low-earth orbit satellites. The long-term goal of the program is to develop the technology required to integrate 100-gigahertz digital logic and/or 100-watt power amplifiers on the same substrate as silicon CMOS. If successful, a single integrated circuit could replace a high-performance digital signal processor, an active delay line circuit, a digital synthesizer, and a traveling-wave-tube power amplifier, thereby reducing the size and weight, and increasing the reliability of military systems. In FY 2000 and FY 2001 we will develop the individual pieces of technology required to integrate high-speed digital logic (50 gigahertz) and moderate power amplifiers (15 watts) on a silicon substrate. This program is starting in FY 2000, with demonstrations of various integrated devices planned for FY 2001.

Advanced Materials Technologies

Advanced materials technologies are the last of DARPA's historical core investment areas. Past achievements have tended to be in the area of structural materials such as advanced composites and ceramics. Both were instrumental in achieving the performance possible with today's aircraft and aircraft engines. Work continues in structural materials, focusing on ultra lightweight, high-strength materials for specific military applications, including body armor. In addition, we are investigating new materials that are termed "functional" in that they contribute to system operations or capabilities beyond simply forming the system structure. In this area, we are looking at magnetic materials, smart materials (which sense and respond to their surroundings), electroactive polymers, and frequency-agile materials. We continue to support the development of high-temperature superconducting components, as well as a variety of advanced energy technologies and an effort to develop a new high energy explosive material.

The **Ultra Lightweight Materials** program is pursuing metals that have the light weight of a composite material but without the traditional worries of corrosion and delamination. The metal is fabricated with a variety of internal microstructures, giving it strength with minimum weight. This will lead to substantial weight and cost savings in a number of military applications. In addition, the internal microstructures allow the metal normally used as part of a structure to also perform a useful function such as blast mitigation or thermal control. In FY 1999, these new materials will be demonstrated for antenna masts for the E-2C and for skins and doors on the F-18E/F. In FY 2000, the program will investigate and demonstrate additional possible military applications such as bullet-resistant fuel tanks.

The goal of the ultra lightweight **personnel body armor** program 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. The current approach for body armor is to use a thick layer of ceramic material with a flexible backing. The DARPA program is aimed at developing a fundamental understanding of the mechanisms for defeating the armor piercing bullets and exploiting these in new designs. For example, tests last year showed that because ceramic is brittle, the flexible backing decreases the strength and stopping power of the ceramic. Simply adding a stiffer backing material seems to increase the strength of the ceramic layer. This year, we will pursue this unexpected conclusion and other concepts with tests of different materials and layering concepts. In FY 2000, we will field-test resulting concepts against 7.62-millimeter armor-piercing munitions.

The **Smart Materials and Actuators** program is developing new classes of materials and structures that use integrated sensors and actuators to respond and adapt to mission needs and the environment. This technology is being developed to suppress vibration and actively tune structures to reduce noise in systems like machine tools and torpedoes. Shape-changing, or morphing, structures are being investigated for fixed-wing aircraft, rotary-wing aircraft, aircraft engine-inlets, and marine systems to increase speed, range, maneuverability and reliability while decreasing noise, vibration and signature. New relaxor ferroelectric single crystal compositions have been developed with a strain capability of 1.7 percent demonstrated under laboratory conditions. By way of comparison, commercially available electroceramic actuators are limited to approximately 0.1 percent strain. Work to-date has developed active materials and has tested their ability to adaptively respond. The program is now moving to demonstrate the benefits of smart materials in systems of military interest. In FY 1999, we plan to conduct full-scale demonstrations of an active engine air inlet nozzle for a fighter aircraft and helicopter blades with active control to reduce vibration and noise. In FY 2000, the program will test the ability of smart materials to control aircraft wings in wind-tunnel tests and will develop a "smart skin" for use on torpedoes.

As part of the Functional Materials effort, the **Electroactive Polymers** project is developing polymers that can conduct and respond to an electrical current. The polymers can take the form of a thin film or a fiber and move or change shape when an electric current is applied. Such materials can be used as artificial muscles for small robots or as artificial "retinas" to process images quickly and efficiently. This year, different electroactive polymer materials will be tested, and, in FY 2000, we will demonstrate electroactive polymers as artificial muscles and for other uses.

A variety of other efforts in the **Frequency Agile Materials for Electronics** program are investigating new materials that can be modified by the application of either an electric or a magnetic field. In these new materials, the application of this field changes the property of the material in some way. The materials can be used as communications systems filters and antennas – the magnetic or electric field "tunes" the filter or the antenna to be more responsive to a particular frequency. Antennas constructed from these frequency agile materials can be smaller and lighter weight, and can be a variety of shapes. Instead having to put UHF SATCOM antennas in large radomes (such as used by the JSTARS and E-2C), they can be installed on fighter aircraft or unmanned air vehicles and can conform to the shape of the aircraft. The materials fabricated and tested to-date in the program have shown promising performance. These antennas will be demonstrated in the UHF SATCOM band in FY 2000 and in the VHF Communications band in FY 2001. The antennas will be tested at the Patuxent River Naval Air Station range soon after they are developed, with flight tests on P-3 aircraft in the future.

Another use of magnetic materials is for radiation-hard memory chips that keep their memory even without power (so-called "non-volatile" memory). The **Spintronics** program has demonstrated a radiation-hard, 16-kilobit memory that is only one square centimeter in size – this chip will be used on Trident submarine systems to upgrade memory capabilities. This year, the program will develop a memory chip slightly larger than one square centimeter holding more than one megabit of information. This chip will be used in satellite and missile applications. Initial versions of the one-megabit chip will be available for testing this year; a fully radiation-hard version will be tested in FY 2000.

In the area of **Advanced Energy Technologies**, DARPA is investing in a variety of technologies to provide high energy-density power sources for military systems. The program is investigating alternatives to traditional batteries for portable power applications through the use of fuel cells and solar cells, as well as methods to harvest energy from the environment for use in unattended ground sensors or for soldier systems. Last year, the program demonstrated robust, multi-kilowatt logistics fuel processing with fuel cell stack integration and transitioned the technology to the Navy's Ship Service Power Program. This year, the program will focus on generating electrical power in the 300- to 500-watt range directly from logistics fuels using compact, low-signature technologies such as thermophotovoltaics and solid oxide fuel cells. The program is also investigating electostrictive polymers and piezoelectric materials for power generation from mechanical motion such as walking, or deep ocean currents. In FY 2000, we will integrate these energy-harvesting technologies and test them with sensors and small devices in order to greatly reduce or eliminate the need for batteries. We also plan to field-test small fuel cells, in the 50- to 150-watt range, operating on methanol and novel hydrogen sources, for soldier applications.

The **Cryo-Systems** program is developing high-temperature superconducting components packaged with other cryogenic devices for use in radar, electronic warfare suites and communications systems. Today's military communications and radar systems must detect increasingly weaker signals within a background of interference and clutter. To do this, most systems rely on software algorithms. High-temperature superconducting filters and amplifiers, however, are very selective, and can screen out unwanted signals to receive only the desired frequencies. This type of performance is particularly useful for signals intelligence collection systems and for improved GPS jamming rejection. Cryogenic systems have been employed at ground-collection sites, and installed in Navy and Air Force reconnaissance aircraft as well as ships. All are showing greatly improved reception of low-power signals within a noisy background. The range enhancement is typically two to three times greater than previously possible. A signals intelligence collection system for multiple cellular bands, using cryogenic components, will be demonstrated later this year. In FY 2000, the program will focus on developing tunable superconducting filters, while maintaining their superior selectivity, enabling reductions in size and weight while increasing the coverage in detection of low-level signals.

Today, electronics systems are assembled in a straightforward manner – there are printed circuit boards inside square boxes. DARPA's **Mesoscopic Integrated Conformal Electronics** program is aimed at revolutionizing that aspect of electronics by directly "writing" discrete components such as resistors, capacitors, inductors, antennae, and batteries – not on a flat circuit board – but on any curved surface. These discrete components dominate in wireless communication devices such as GPS receivers, mobile radios, cellular telephones, and pagers. To-date, the program has demonstrated the ability to make reasonable quality electronic features on a flexible, plastic substrate instead of the heavy, rigid printed circuit board. This year the program will focus on being able to directly write higher quality electronic materials, as well as being able to fabricate high energy-density battery cells on low-temperature plastic substrates, so that our electronic modules will, indeed, come with "batteries included." Next year, the direct-write tools will be developed with an eye towards rapid manufacturing for DoD and commercial end-users.

Today's explosives (HMX and RDX) have approximately 50 percent more explosive energy than dynamite. The **High Energy Density Materials** program is investigating the synthesis of new molecules that will have 200 percent to 500 percent more explosive and/or propulsive energy per unit weight than does dynamite, and have between two and six times as much propulsive or explosive energy as current state-of-the-art operational materials. In addition, because we are looking at molecules made solely or mostly of nitrogen, production and use should be environmentally friendly. If the program succeeds, the capabilities of the new materials could provide increased range and maneuverability and/or increased kill-effectiveness for missiles through improvements in both the propellant's thrust and the warhead's lethality (per weight and volume). One research team recently proved the existence of a new nitrogen ion, a key step in synthesizing the new high energy-density form of nitrogen sought by the program. In FY 1999, two or three performers will be downselected to continue the synthesis task, leading to synthesis of gram-quantities of the material in FY 2000.

Conclusion

I appreciate being given the time to tell you a little about the important new technologies we are pursuing. DARPA takes its role as the technical enabler for innovation for national security very seriously. It is a role that is key to the success of the warfighter of the 21st century. DARPA's staff and contractors innovate on behalf of a future warfighter, who may someday come before your successors and testify that his (or her) new weapon system provided the winning edge in some future military operation.

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