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# Statement by


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Mr. Chairman, Subcommittee Members and staff: I am very pleased to appear before you today to discuss DARPA's strategic plan, and to highlight a selection of DARPA's FY 2002 programs.

# Introduction

Let me refresh your memory concerning DARPA's strategic plan. DARPA's mission continues to be to act as the technical enabler for radical innovation for national security. We are pursuing three main mission areas that have endured since DARPA's founding in 1958, even as individual technologies change. DARPA's enduring mission areas are:

- To find technical solutions to *National-Level Problems*. The Agency's priority is on problems that may impact our national survival.
- To be the technical enabler for the innovation required for our warfighters to achieve dominance across the range of military operations – *Operational Dominance*.
- To develop and exploit high-risk *Core Technologies* for our Nation's defense.

In the area of *National-Level Problems*, DARPA's programs are focused on biological warfare defense and information assurance and survivability. The biological warfare defense effort is developing therapeutics countermeasures, advanced sensors, advanced diagnostics, air and water purification devices, and genetic sequencing codes for potential biological threat agents. In the area of information assurance and survivability, DARPA is developing technologies to raise strong barriers against cyber attack and provide commanders with mechanisms to see, counter, tolerate and survive sophisticated cyber attacks. DARPA invests approximately 15 percent of its annual budget in this mission area.

In the area of enabling *Operational Dominance*, DARPA is investing in technologies and systems for affordable, precision moving target kill for both offensive and defensive missions and dynamic command and control capabilities for mobile networks and near-real-time logistics planning and replanning. Other programs include technologies and systems that will enable future warfare concepts for air, space, land and sea.

We believe that one key to Operational Dominance will be combined manned and unmanned operations – this will give the future U.S. military an overwhelming edge. Our investments in advanced, high-speed networks, complex system design and operation, wireless communications, microcircuits that combine information technologies and biological systems, and other areas, will enable the U.S. to conduct successful combined manned and unmanned military operations. Providing this technical edge is the key to our involvement with the Army in developing Future Combat Systems (FCS). Our vision for FCS is revolutionary – a network-centric land warfare system of systems composed of manned and unmanned nodes. It will give the U.S. a capability that no other nation possesses.

Our Unmanned Combat Air Vehicle (UCAV) programs are another example of our Operational Dominance investments. We are working jointly with the Air Force and the Navy to develop autonomous unmanned systems that will be able to work with manned aircraft to effectively and affordably suppress enemy air defenses, and for the Navy, also conduct surveillance missions. With these systems, the U.S. will be able to use an unmanned aircraft for dangerous operations rather than put pilots at risk. The unmanned system will operate autonomously within the rules of engagement, in association with manned aircraft, to prosecute its mission. It will not be fire and forget – humans will maintain command and control throughout the mission, and the vehicle will return to base to be used again. This will truly be a revolutionary capability.

The U.S. also must have Operational Dominance in space. The Orbital Express program is developing technologies to allow the autonomous rendezvous, refueling and repairing of satellites on-orbit. This will give us unprecedented abilities to upgrade our space-based assets.

Approximately 40 percent of our annual budget is invested in the Operational Dominance mission area.

DARPA's *Core Technology* investments include information technology, microsystems technologies, materials technologies, micro-electromechanical systems, beyond silicon complementary metal oxide semiconductor (CMOS) technologies, and investments that combine biology with DoD's traditional strengths in information technologies, electronics, optoelectronics, sensors, and actuators. It is the results of all of these investments that will allow DoD to build systems and capabilities for future operational dominance. In addition, investments in these core areas provide DARPA with a unique outreach into commercial and dual-use technology.

DARPA's investments in information technologies will provide information superiority to the DoD through revolutionary advances in embedded and autonomous systems software; high performance computing components; advanced networking; seamless computer interfaces for the warfighter; ubiquitous computing and communications; and agent-based systems.

In addition, DARPA is investigating chip-scale microsystem technologies that integrate the core technologies of electronics, photonics (light) and micro-electromechanical systems (MEMS). This chip-scale integration offers substantial new opportunities to revolutionize and miniaturize communications, targeting and analytical systems, as well as sensors.

DARPA invests approximately 40 percent of its annual budget in the Core Technology mission area.

I will now go into more detail about DARPA's investments in currently ongoing and planned programs. The Department is in the middle of a strategy review and a Quadrennial Defense Review. As these reviews complete, we may propose changes to some of the details of these efforts. So, with that understanding, I'll launch into an overview of our programs.

# Technical Solutions to National-Level Problems

DARPA's charter is to solve national-level technology problems, foster high-risk, high-payoff military technologies to enable operational dominance, and avoid technological surprise. In today's world of emerging asymmetric and transnational threats, our concern focuses on two principal national security issues: protection from biological warfare attack and protection from information attack.

## PROTECTION FROM BIOLOGICAL WARFARE ATTACK

A clear and growing national security need is protection of our military forces from biological warfare attack by both military and terrorist organizations. DARPA's goal is to deter or thwart such attacks with a Biological Warfare Defense thrust focused on sensors, medical diagnostics and countermeasures, air and water purification, pathogen genetic sequencing, building protection, and consequence management.

> "We will work to defend our people and our allies against growing threats: the threats of missiles; information warfare; the threats of biological, chemical and nuclear weapons . . . . We will be creating the military of the future, one that takes full advantage of revolutionary new technologies . . . ."
> *--President Bush, January 26, 2001*

### *Sensors*

To detect the presence of a threat agent, DARPA is investing in the development of advanced **Bio Sensors** that are robust, autonomous, fast, and sensitive to multiple biological warfare agents. DARPA's mass spectrometer holds the promise of extraordinarily fast and robust identification of all known biological warfare pathogens. The first-generation prototype was evaluated in field trials last year against simulants; based on these trials as well as other technology development, we are now making design and engineering modifications to develop a robust and automated identification and detection capability using time-of-flight mass spectrometry. The program is also developing a nucleic-acid-based microarray sensor to integrate and automate DNA/RNA isolation, labeling, and hybridization procedures into a single platform. The program has already developed a first-generation sensor designed to determine whether anthrax is present, to enable fast separation of hoaxes from real threats. We are evaluating the sensor's performance this year for possible transition to a number of partners, and we are developing an improved, hierarchical sensor in FY 2002.

Another part of the sensor program is investigating whether it is possible to build sensors around cells or pieces of tissue to alert us to the presence of a toxic environment. These **Tissue Based Biological Sensor** (TBBS) systems use the physiological response of biological cells and tissues to detect biological or chemical threats. The TBBS program is fabricating new devices based on high-density microarrays to detect the presence of engineered agents (or as-yet unidentified threats) for which there are no antibodies or genetic sequences. We constructed laboratory prototypes in FY 2000, including an integrated chip microarray that incorporates liver tissue and measures liver response following exposure to biological agents and chemical toxins. We then took hand-held systems that incorporate electrically active cells into the field at the U.S. Marine Corps base at Twentynine Palms, CA, and tested portable life support systems to provide on-site support for these systems. In FY 2001, we are continuing development of these systems to screen them against a wider list of chemical and biological threats and to determine the limits of sensitivity, false alarm rates, and the effects of interferrants. The **Metabolic Engineering for Cellular Stasis** (MECS) program complements TBBS efforts. It is investigating biological practices that allow organisms to adapt to environmental extremes and is using those practices to engineer new cellular systems such as platelets and red blood cells. In FY 2000, MECS researchers demonstrated dramatic improvements in the stability of cells by genetically engineering them to increase their resistance to drying for storage. In FY 2001, the program is designing and testing cell and tissue systems that reliably report on viral and bacterial exposures and investigating key sensor features to minimize false positives and maximize signal strength.

### *Medical Diagnostics and Countermeasures*

In the event of a biological attack, the U.S. will need to identify those who have been exposed to a biological warfare agent and to distinguish them from the "worried well," as well as from those with natural diseases that might require different treatment. Therefore, identifying disease markers that can serve as rapid indicators of exposure is one of the focus areas of the **Advanced Medical Diagnostics** program. One group at Stanford University is looking for genetic markers by testing human cell cultures exposed to a variety of infectious disease agents and other stimuli. In FY 2000, the researchers identified a number of human genes that are selectively turned on or off in response to infection, and in FY 2001, they are testing for these markers in clinical settings such as hospitals. Another activity in this program is identifying markers in breath that may be used to determine who has been exposed to a potential pathogen. In FY 2001, the program identified specific biochemical markers using non-invasive mass spectroscopy that can provide critical information from breath samples. Future studies will look for these markers in breath in models of pathogen exposure (in model systems). In FY 2001, we made significant progress in establishing diagnostic detection equipment based on antibody detection of pathogens. The program transitioned this time-resolved fluorescence technology to the Centers for Disease Control, and it is now being validated for use in public health facilities; the system has been tested against a number of biological pathogens. Rapid sequencing techniques also progressed significantly in FY 2001, and the program is transitioning results to the private sector for further development.

The **Unconventional Pathogen Countermeasures** (UPC) program is developing broad-spectrum countermeasures for threat pathogens. This includes anti-viral and antibiotic drug discovery and development as well as vaccinations. Three UPC projects, plant-based vaccine production, optimized vaccine development using gene-shuffling, and optimization of novel antimicrobial therapeutics, have succeeded in initial DARPA experiments, and we are transitioning them to the U.S. Army Medical Research Institute for Infectious Diseases (USAMRIID) for further development. In addition, the U.S. Army Institute for Surgical Research, Fort Sam Houston, is evaluating skin decontamination by nanoemulsion technology. In FY 2001, we anticipate transitioning other successes to USAMRIID, including novel antibiotic therapeutics, antibiotic target methodologies, and novel DNA vaccines and platforms. A novel vaccine enhancer developed under the UPC program is likely to transition to the Centers for Disease Control or USAMRIID later this year. By FY 2002, we expect to have additional programs ready for transition including vaccine candidates, novel enzyme antibacterial therapeutics, and new approaches to using computers to accelerate the process of discovering therapeutics.

### *Building Protection*

In addition to the component technologies, DARPA is developing complete systems solutions to counter the biological warfare threat. The goal of the **Immune Building** program, which is just getting underway in FY 2001, is to make military buildings far less attractive targets for attack by chemical or biological warfare agents by reducing the effectiveness of such attacks via active and passive response of heating, ventilation and air conditioning systems and other building infrastructure (neutralization, filtration, etc.). This ambitious goal can only be achieved through a combination of technology development and systems-level experimentation. The program is leveraging earlier efforts in these technologies – for example, decontaminating foams and novel materials that can be used for both chemical and biological filtration – and extending them for use in this application. The program is also developing new component technologies specifically for this application, such as new gaseous decontamination techniques that can follow the contaminant into the small, inaccessible spaces within buildings, specialized low-pressure-drop filtration for use at return vents, and high-efficiency/long-lifetime sources of ultraviolet radiation for on-the-fly neutralization of agents. In addition, several industry teams are evaluating candidate architectures for building protection systems. In FY 2002, the program will test successful technologies and prototypes as parts of complete protection systems, and we will evaluate the most promising architectures experimentally at full scale, as a first step in the design of "optimal" protection systems.

### *Air And Water Purification*

Clean air and water are crucial to the sustained operation of our Military Services in the event of a biological and chemical warfare attack. To-date, our program in **Air and Water Purification** has demonstrated encouraging results. Warfighters must be able to obtain potable water quickly – their water purification devices and beverage containers must be integrated in order to work and pack away together. One project, the New Generation Hydration System**,** will produce microbiologically safe drinking water and beverages from sources of unknown quality and will provide an efficient storage and delivery system for hands-free, on-the-move hydration.

One of the program's key design objectives is to be able to purify all available water sources in the field, including desalinating seawater. We plan to meet this requirement by developing a forward osmosis membrane. The program has completed proof-of-principle experiments showing technical feasibility. During the remainder of this year, the program is optimizing the components of the system, e.g., increasing the water flux through the membrane and demonstrating removal of volatile organic compounds and other harmful contaminants from the water. In FY 2002, the program will make the system more rugged and will integrate the forward osmosis component with a standard military hydration bag (such as a Camelback). The Marine Corps plans to transition DARPA's New Generation Hydration System as an official enhancement program.

The Air and Water Purification program is also developing pioneering approaches for advanced gas mask filters. Today's masks have higher-than-desirable breathing resistance, and their capacity (the period of time they effectively filter) is limited. Recently, we have demonstrated the proof-of-principle that microfibrous carriers make better use of carbon to adsorb chemical agents and that they accomplish this with an inherent particulate filtration capability. For the next two years, our work is aimed at reducing the pressure drop by at least a factor of two over current C2A1 canisters, while maintaining the equivalent period of time the filters operate effectively.

## PROTECTION FROM INFORMATION ATTACK

The United States possesses limited capabilities to protect against sophisticated cyber attacks. Defending against distributed, coordinated attacks requires technology and infrastructure that commercial industry is not developing. To address this challenge, DARPA initiated the **Third Generation Security** (3GS) suite of programs to defend the Defense Department's advanced information systems. The goals of these programs are to raise strong barriers to cyber attack and provide commanders with technology to see, counter, tolerate, and survive sophisticated cyber attacks.

In FY 2000, the 3GS suite of DARPA programs made significant progress toward these goals. These programs:

- Developed and demonstrated techniques to detect malicious code and confine damage caused by mobile malicious code;
- Identified survivability principles to allow continued operations through a wide class of cyber attacks;
- Developed distributed security technologies to overcome the limitations of perimeter defense strategies (i.e., firewalls);

- Developed intrusion detection and correlation techniques to enable detection of certain kinds of stealthy network-based attacks and to reduce the overwhelming numbers of security alerts that operators face by recognizing actions that are part of significant multi-step attack scenarios; and
- Developed modeling techniques to determine how the effects of attacks or defensive responses might impact the system's continued ability to perform mission-critical functions.

In FY 2001, the 3GS programs are integrating evolving security technologies to achieve automatic defense, assess correlated attacks, achieve preliminary situation understanding, improve tolerance against intrusion, obtain better assessments of damage and containment, and develop a hardened core. DARPA is using experimentation and technology transition partnerships with operational commanders to evaluate these advanced defensive technologies and transition them to warfighters. Also this year, conceptual system definition studies will begin to apply the results of the 3GS programs to make the DoD's Global Information Grid (GIG) more survivable in the face of cyber attacks. In FY 2002, the suite of programs will use previous system concept studies to design both a survivable prototype of an exemplar GIG system and a Cyber Panel for monitor and control. Next year, the program will:

- Demonstrate the ability of mission-critical systems to operate through cyber attacks;
- Develop a new family of protocols resilient to both service denial and traffic analysis;
- Develop techniques for detecting and correlating disturbances across large networks to allow response to widespread attacks in real time; and
- Develop and demonstrate tools for selecting and carrying out collective defensive actions in response to correlated cyber attacks.

# Enabling Operational Dominance

DARPA is the technical enabler for the revolutionary innovation required for our warfighters to achieve Operational Dominance – dominance across the range of military operations. DARPA is emphasizing development of technologies and systems to enable affordable, precision, moving target kill for both offensive and defensive missions. We are also developing technologies and systems to provide dynamic command and control capabilities to our commanders, including the advanced communications and mobile networking technologies necessary for assured communications and information superiority. Other programs focus on technologies to allow planning and replanning in near-real-time. Lastly, DARPA is investing heavily in technologies and systems that will enable future warfare concepts for combined manned and unmanned operations, and operations in space, on land, at sea and in the air.

## Affordable, Precision, Moving Target Kill

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

The **Affordable Moving Surface Target Engagement** (AMSTE) program is developing technologies to make it feasible and practical for the warfighter to precisely, rapidly, and affordably engage individual moving surface vehicles. The program will demonstrate that, without expensive modifications to existing and planned systems, networked sensors and weapons can be integrated to provide robust, precise standoff engagement of moving surface targets. In FY 2000, the AMSTE program completed a series of weapon system trade studies that evaluated AMSTE component architectures, developed and performed real-time laboratory experiments to assess the accuracy and robustness of fire control algorithms using radar data collected from multiple airborne sensors, and completed detailed system designs of an experimental AMSTE system. These studies demonstrated the feasibility of the AMSTE concept and identified critical supporting technologies requiring further development and maturation. In

FY 2001, the AMSTE program awarded two contracts, to Northrop Grumman Corp. Integrated Systems Sector (Melbourne, FL) and to Raytheon System Co. (El Segundo, CA), to develop and assemble prototype AMSTE experimental systems (representative radar sensors, data links, and weapons) for live flight experimentation. At the end of this year, a series of developmental flight experiments will culminate in the delivery of GPS-guided precision weapons against moving vehicles, targeted by standoff networked sensors using AMSTE precision fire control techniques. Further experimentation with the AMSTE system is planned for FY 2002, and the program will develop and incorporate critical enhancements to address high-confidence track maintenance in highly cluttered environments.

The **Advanced Tactical Targeting Technology** (AT3) program is developing and demonstrating technologies that will radically improve today's capability to target surface-to-air missile (SAM) threats through the use of networked, next-generation electronic support measures systems. AT3 enables the rapid and accurate targeting of precision-guided weapons to counter the modern, more capable enemy SAM systems, which are using increasingly sophisticated tactics such as early emitter shutdown, making them particularly challenging targets. In FY 2000, the program successfully completed initial software algorithm development, non-real-time flight tests, test data analysis, and a critical design review. The data collections focused on a few critical issues: platform-to-platform decorrelation from electronically or mechanically scanned systems, multipath, and geolocation performance. Using realistic emitters, we conducted these tests with a combination of legacy hardware, new AT3 hardware, and off-the-shelf navigation solutions, and all technical objectives were achieved. The successful conclusion of the tests laid the foundation for our continuing development work in AT3. DARPA has selected Raytheon Defense Systems Company (Tucson, AZ) to conduct the program's second phase. This year, the program is fabricating AT3 test hardware, conducting hardware-in-the-loop and ground tests, and continuing software algorithm development. In FY 2002, the program will complete real-time flight tests of the AT3 packages against real threats, analyze the test data, and continue software algorithm development based on the collected flight-test data.

A new generation of collection systems will provide dramatically increased volumes of high-fidelity data to the operational decision-maker. The challenge will be to manage and synchronize these advanced collection systems with tasking, processing, exploitation, and dissemination capabilities to provide critical information in a constantly changing operational situation. The **Advanced ISR (Intelligence, Surveillance, and Reconnaissance) Management (AIM)** program is providing the technical foundation for ISR support through the development of an automated system to optimize the tasking of ISR assets to meet users' needs. The AIM program is developing and advancing technologies in areas of multi-node collaboration, semi-automated reasoning, and mathematical programming. The resulting AIM capabilities will transition to DoD automated planning and command, control, communications, computers and ISR (C4ISR) migration systems as appropriate. In FY 2001, the AIM program is installing the Multi-Asset Synchronizer at the U.S. Southern Command to participate in Exercise *Unified Endeavor*. AIM is providing enhanced coordination and visualization of multiple diverse collection assets, enabling collection managers to assess the utility of the technology and to provide valuable feedback to guide further development. In FY 2002, AIM capabilities will be further extended to provide near-real-time re-tasking of assets to respond to contingencies and to maximize exploitation system product value.

The goal of the DARPA **Counter Camouflage, Concealment, and Deception** (Counter CC&D) program is to mature and demonstrate a foliage penetration (FOPEN) synthetic aperture radar (SAR) to provide the warfighter with all-weather, day/night capability to detect targets hidden by foliage and camouflage. In FY 2000, the FOPEN SAR was installed on an Army RC-12 aircraft, and the program conducted preliminary flight tests to validate the real-time image formation software and verify that the system could provide the required image resolution and sensitivity. This year, the FOPEN SAR has demonstrated excellent image quality in the VHF and UHF bands and will complete the preliminary RC-12 flight tests by imaging vehicles hidden under foliage at Camp Navajo, AZ, to establish the capabilities of single-pass and change-detection algorithms. In FY 2002, the RC-12 FOPEN SAR will fly an extensive series of flights to collect the data necessary to train, test, refine and validate algorithms in different foliage environments. The program will also conduct experiments to determine the ability of FOPEN SAR to perform terrain mapping and terrain characterization.

The **Symbiotic Communications** program will develop a passive, all-weather airborne system that can produce real-time high-resolution synthetic aperture radar images, and very accurate (National Imagery and Mapping Agency level four) terrain height maps, categorize terrain (for example trees versus roads), and detect and locate slowly moving ground vehicles. This system is a passive, bistatic receiver, making it difficult for adversaries to detect and counter the system. This approach will allow our warfighters to gather the battlespace data they need without putting themselves at risk. In FY 2001, an expert Government team and two contractor teams will develop system concepts and ground-based experiments to validate technical feasibility and to refine performance predictions. In FY 2002, the two contractor teams will conduct early flight tests, achieve radar processing of signals of interest, and demonstrate bistatic synthetic aperture radar processing.

DARPA is concerned about the threat of attack by large numbers of low-cost air vehicles – from unsophisticated cruise missiles to small fixed-wing aircraft. This asymmetric threat can emerge very quickly, and there are many ways an adversary can acquire such a threat, e.g., manufacturing them indigenously, importing them from other countries, or converting existing assets. Initiated in 1996, the goal of the **Low Cost Cruise Missile Defense** (LCCMD) program is to develop a viable, affordable option for countering such an attack without resorting to our current inventory of interceptors (designed for far more sophisticated threats) and running the risk of being overwhelmed by sheer numbers of attacking platforms. The LCCMD program is developing and demonstrating affordable seekers for use on a low-cost interceptor system. Seekers represent approximately two-thirds the cost of a typical interceptor system. Last year, the program conducted laboratory testing of a laser radar seeker and a novel microwave-frequency noise radar seeker. In FY 2001, the program is conducting field-testing of the noise radar seeker and initiating development of an affordable micro-electromechanically switched electronically scanned array (MEMS ESA) seeker. In FY 2002, the program will complete a preliminary design of the MEMS ESA seeker and fabricate subassemblies of its antenna system. The U.S. Army Space and Missile Defense Command has expressed great interest in this program, and has funded an effort this year to evaluate low cost cruise missile defense options.

The **Real Time Battle Damage Assessment** (RT-BDA) program is developing and demonstrating new techniques to automate the assessment of target battle damage. The program will use tactical and theater synthetic aperture radars coordinated with weapons delivery to image the targets before, during, and following the strike to enable immediate assessment of the strike effectiveness. This year the program is conducting instrumented data collections of real battle damage on realistic targets to produce a database to support further research in signature exploitation techniques. The program is also investigating imaging radar BDA phenomenology and developing prototype RT-BDA detection algorithms and assessing their effectiveness. In FY 2002, we will further mature these initial algorithms to provide damage localization and assessment, and they will be implemented and evaluated in a real-time laboratory system.

The **Global Positioning Experiments** program addresses the problem of enemy jamming of the Global Positioning System (GPS). The program will demonstrate the use of airborne pseudolites, which are high-power, GPS-like transmitters on aircraft, to broadcast a powerful replacement GPS signal that "burns through" jammers and restores GPS navigation over a theater of operations. Two field demonstrations last year showed that signals broadcast from airborne pseudolites can be used in place of satellite broadcasts to provide good quality navigation to military GPS receivers with only software modifications to the receivers. In FY 2001, the program is conducting laboratory and field tests to demonstrate that beamformer antennas can protect the airborne pseudolite from jamming. In FY 2002, the program will combine these two key pieces of the concept by flying an aircraft in the presence of powerful jamming and demonstrating the ability of a beamforming antenna to allow the aircraft to acquire a satellite signal and rebroadcast it as a pseudolite. Preparations will also begin for a multiple, airborne psuedolite demonstration.

## DYNAMIC COMMAND AND CONTROL

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

### *Near-Real-Time Planning and Replannning*

Many recent studies agree that future U.S. adversaries are unlikely to challenge the U.S. directly. Rather, it is more likely that they will present an asymmetrical threat, developing and using approaches that avoid U.S. strengths and exploit potential vulnerabilities using significantly different methods of operation. Adversaries will attempt to create conditions that effectively delay, deter, or counter the application of U.S. military capabilities. DARPA is undertaking high-risk research to help our military and intelligence agencies identify threats before attacks happen. This will allow deterrence or deflection of unconventional but potentially devastating attacks against our military forces and infrastructure. The DARPA **Asymmetric Threat** initiative will develop a suite of new technological capabilities to better detect, correlate, and understand these asymmetric threats.

The **Human Identification at a Distance** program began in August 2000. In FY 2001, the Human Identification at a Distance program is developing automated multi-modal surveillance technology for identifying humans at a distance using different biometrics techniques such as face and body parts identification, infrared and hyper-spectral imagery, gait and temporal human dynamics, non-imaging physiological based-biometrics, and remote iris scan. In FY 2002, the program will assess the capabilities of each biometric to identify people at a distance. Based on the assessment, the program will further develop the most promising biometrics and investigate fusion methods.

The **Wargaming the Asymmetric Environment** (WAE) program will develop and demonstrate specific predictive tools to better anticipate and act against terrorists. WAE is a revolutionary approach to identify predictive indicators of terrorist-specific attacks and behaviors by examining their past behavior in the broad context of their political, cultural and ideological environment. Initial results demonstrate the feasibility of developing automated and adaptive behavior prediction models tuned to specific terrorist groups or individuals. It uses their past behaviors and the consequences of their deeds, as well as the antecedent activities that led up to the act, to predict what, when, where, how and why they will strike next. Over the past year, WAE developed a model able to predict an active terrorist group's next tactic (assault, bombing, assassination, hijacking, or no attack). The model was validated against archival data covering 66 attacks over 17 years. In FY 2001, WAE is expanding its predictive model and validation process to increase the level of detail for predictions of target characteristics, timeframes, geographical location, and motivating factors. In FY 2002, WAE will extend its predictive model development and validation to include other groups and individuals; these models will then be used to develop an intervention-testing environment.

The **Evidence Extraction and Link Discovery** (EELD) program will develop automated discovery, extraction and linking of sparse evidence in large amounts of classified and unclassified data sources. EELD is developing detection capabilities to extract relevant data and relationships about people, organizations, and activities from message traffic and open source data. It will then link together related items that comprise potential terrorist groups or scenarios, and learn patterns of different groups or scenarios to identify new organizations or emerging threats. EELD's initial activities demonstrated the feasibility of extracting relationships from text and validated the detectability of patterns representing terrorist groups and scenarios. EELD also developed two promising techniques for learning patterns of activity, and developed functional system concepts to guide technology developments. In FY 2001, EELD will develop techniques for evidence extraction, link discovery and pattern learning, validate the detectability of patterns in classified data, and initiate collection and characterization of documents for technology evaluations. In FY 2002, EELD will develop and demonstrate technology to extract relationships, and detect and learn single-link type patterns.

**Project Genoa**, in the process of concluding, provides the structured argumentation, decision-making and corporate memory to rapidly deal with and adjust to dynamic crisis management. Project Genoa is developing information technology for the intelligence community to rapidly and systematically accumulate evidence, facilitate collaboration while protecting critical information and test hypotheses that support decision-making at the national level. In FY 2000, Project Genoa matured and transitioned a new "thematic" search engine to users on Intelink. Based on successful technology demonstrations, the Defense Intelligence Agency has agreed to be a transition partner for Project Genoa technology. In FY 2001, Genoa evidence-accumulation components are being delivered to the Office of the Secretary of Defense and Joint Staff Directorate for Intelligence (J2), the Joint Counter-intelligence Analysis Group, and U.S. Pacific Command. In FY 2002, these transition activities will be completed.

The **Command Post of the Future** (CPOF) program is developing tools that enable commanders to rapidly acquire a deep understand of any military situation, leading to faster and better decision making and more effective employment of military forces. In the past year, CPOF has developed several prototypes of the BattleBoard, a mobile command interface that provides the commander with a visual interface to subordinates, superiors, peers, and staff that significantly improves situation awareness and has demonstrated an order of magnitude reduction in time to plan while at the same time improving the robustness of plans. In FY 2001, CPOF is extending research into team collaboration tools and augmenting the collaboration and visualization tools in the BattleBoard with reasoning tools that will provide the commander with the ability to attach intelligent monitors to places, objects, and times in the battlespace, effectively using the BattleBoard as an extension of his memory and expertise. In FY 2002, CPOF will add a dialog system to the BattleBoard providing the commander with richer, more natural ways to query information in the command and control system. Additionally, CPOF will integrate the BattleBoard into existing Army and Marine Corps command and control systems.

The **Active Templates** program is developing and delivering critical command and control software tools for special operations forces (SOF). These tools enable commanders to plan four times faster, coordinate decisions immediately, synchronize combined-arms operations, and control resources that dictate the outcome of the fight. In FY 2000, the temporal plan editor and execution checklist tool were tested successfully in three SOF exercises and subsequently adopted by a number of SOF organizations. In FY 2001, DARPA is developing a geo-spatial editor for planning and tracking SOF missions on a map or an image. In FY 2002, the program will use default reasoning to develop a networked spreadsheet that allows users to coordinate information, get intelligent assistance for decision-making, and reuse solutions to similar problems solved in the past.

Advanced information technologies are being actively applied to warfighter logistics support, making that support secure, scalable, and robust, and to collaborative logistic and operational planning and execution capabilities for the Global Combat Support System.

The objective of the **Advanced Logistics Project** (ALP) is to demonstrate the feasibility of using advanced agent-based technology to make a revolutionary improvement in how the DoD provides logistics support to the warfighter. The Advanced Logistics Project is a joint DARPA/Defense Logistics Agency effort, in partnership with the U.S. Transportation Command and the Joint Staff Director for Logistics. The project has developed a distributed systems technology that will revolutionize dynamic planning, execution, and overall information management of the DoD logistics enterprise. In FY 2000, the project dramatically enhanced the architecture to provide the capability to develop and manage multiple concurrent logistics plans. The program worked with the Defense Agencies and Military Services to identify high-payoff pilot projects and developed several applications. One is operational today at U.S. Transportation Command, and another is operating at the Defense Supply Center Columbus, a component of the Defense Logistics Agency, and is scheduled to go into full operation by late June. The program concludes this year having demonstrated a systems architecture that has the capability to: generate an item-level logistics plan in under an hour; totally control the transportation pipeline; continuously generate time-phased support and sustainment demands; monitor the execution details down to the individual items against real-time information from the real world; and dynamically repair the plan when necessary. If this technology were fully fielded in the military, it would allow the military logistics enterprise to: gain control of the logistics pipeline; enable the warfighter to project and sustain overwhelming combat power sooner; permit forces and materiel to be deployed, tracked, sustained, and redeployed more effectively and efficiently with reduced reliance on large DoD inventories; provide users at any level the ability to effectively interact during planning and execution; and, link operations with logistics staff elements at all echelons. As an infrastructure for global logistics, an operational ALP capability would truly enable Focused Logistics as envisioned in *Joint Vision 2020*.

The **Ultra*Log** program is developing information technologies to enhance the survivability of large-scale, distributed, agent-based logistics systems operating under very chaotic wartime conditions. This program will build upon – and extend – the revolutionary technologies developed under the Advanced Logistics Project in the areas of security, scalability and robustness to ensure reliable logistics support to the warfighter under the most extreme kinetic and information warfare conditions. If successful, this would serve as a template for creating agent-based distributed command and control systems operating at all echelons that could dynamically recover from information attacks, infrastructure loss, and other real-world problems that plague effective planning and control in complex wartime environments. In FY 2000, the program identified several critical survivability technology extensions such as adaptive communications protocols, layered certificate and encryption-based data security, and techniques for recovery from catastrophic information loss, as well as the processes for measuring and experimentally evaluating them. In FY 2001, the program is concentrating first on building the foundation for survivability in the core architecture to include secure information management, increased fault-tolerance, and system scalability. The program will perform its first large-scale evaluation and assessment in late 2001, to include a Red Team attack of the logistics information system during a representative Major Regional Contingency (MRC) scenario. In FY 2002, the program will focus on expanding the logistics information system's capability to detect threats and change system-state dynamically in response to those threats. The military concept of "ThreatCon" will be incorporated into the software agent architecture to support dynamic reconfiguration for enhanced survivability in increasingly chaotic conditions. In the program's second major assessment in the late 2002, the prototype system will attempt to detect various threats and failures and deploy appropriate countermeasures during the representative MRC scenario.

The primary theme of the **Joint Theater Logistics** Advanced Concept Technology Demonstration (ACTD) is logistic command and control. The ACTD will leverage current and emerging technology to produce, and rapidly transition, advanced collaborative logistic and operational planning and execution capabilities for the Global Combat Support System (GCSS). It will build a series of web-based Joint Theater Logistics Decision Support Tools that will encourage operations and logistic collaboration during planning and requirements determination and execution tracking, and while realigning resources to meet changing operational situations. The Joint Theater Logistics ACTD will correct existing logistic deficiencies and provide the capabilities necessary to ensure the future coordinated sustainability for logistic operations. This ACTD builds upon the success of the Joint Decision Support Tools and technical architecture developed under the earlier Joint Logistics ACTD, and incorporates technologies from DARPA's Advanced Logistics Project, the Command Post of the Future, and other ACTDs targeted for Joint Task Force operations. The target user for Joint Theater Logistics ACTD is at the operational level: the Joint Task Force, its Service components, and major Service logistics organizations.

In FY 2000, the Joint Theater Logistics ACTD conducted an initial demonstration of collaborative products, allowing operations and logistic users, in real-time via the web, to coordinate shared concepts for planning and execution. This effort included selection of combat and combat support forces, missions, locations, and time phasing. In FY 2001, the Joint Theater Logistics ACTD is demonstrating the ability to collaboratively develop operational courses of action and the corresponding logistic supportability assessments for fuel, engineer, and other commodities in a Joint Task Force environment. In FY 2002, the ACTD will provide a logistic watchboard capability to monitor and replan ongoing logistic operations in real-time, with flexible visualizations to provide rapid drilldown for assessment details. The Joint Theater Logistics ACTD products will transition through the Defense Information Systems Agency in FY 2003 as a Pilot Service Program, with expected fielding to GCSS in FY 2005.

### *Mobile Networking Technologies*

The **Airborne Communications Node** (ACN) program is developing a multi-mission payload that will simultaneously provide, in a single package, assured communications and radio frequency exploitation (signals intelligence, electronic warfare and information operations) for joint and multinational forces on maneuver. The payload will be scalable for application on a wide range of platforms. It will enable high-bandwidth, beyond-line-of-sight connectivity and will allow the tactical commander to dynamically reconfigure his available assets to satisfy changing mission priorities. In FY 2000, the three competing Phase I contractor teams demonstrated their architecture and proof-of-concept designs for ACN. The program selected two teams to incorporate multi-mission functionality (e.g., assured communications and radio frequency exploitation) into their architecture and begin development of the technologies necessary to implement the multi-mission design. In FY 2001, the program is demonstrating subsystem performance through detailed laboratory testing and simulation. In FY 2002, the program will validate multi-mission functionality in an end-to-end system demonstration in a laboratory environment.

The **Small Unit Operations Situation Awareness System** (SUO SAS) program is developing and integrating key communications, navigation, and situational awareness technologies for use by light, early-entry forces in restrictive terrain where they currently cannot communicate. The program is developing technologies to enable warfighters to communicate clandestinely in buildings, tunnels, jungles and mountainous terrain using self-forming, computer-controlled networks that continuously monitor the environment, mission needs and the tactical situation, and optimize themselves to ensure that communications are always maintained. These capabilities will greatly increase the effectiveness and survivability of small, dismounted forces. Last year, a series of contractor laboratory and field tests were highly successful in demonstrating SUO SAS' clandestine communications waveform and its non-GPS method for precisely locating soldiers inside buildings. In FY 2001, the program is completing the detailed hardware and software designs, fabricating the major prototype components, and integrating and measuring system-level performance. In FY 2002, the program will complete prototype-level field performance testing and analysis, providing important measures of the technological advances for implementation by the Services in their communications and situation awareness systems. Transition details are currently being discussed with the Army.

The **WolfPack** program is developing new electronic warfare technologies that can hold enemy emitters (communications and radar) at risk throughout the tactical battlespace while avoiding disruption of friendly military and protected commercial radio communications. The WolfPack concept emphasizes an air-deployable, ground-based, close proximity, distributed, networked architecture to obtain radio frequency spectrum dominance. The WolfPack concept is to use a network of nodes to sense the radio frequency environment, ascertain the type and configuration of the threat, and carry out a precise, coordinated response. That response can either be to disable communications and radar reception, or to relay the geolocation information of the threat transmitter. In FY 2000, a team made up of representatives from government, academia, and industry validated the WolfPack concept and highlighted the critical areas of technology development through analytical assessments of critical technology and performance tradeoffs. This year, the program is starting development of high-risk, high-payoff technologies such as wideband antennas, precision geolocation techniques for urban terrain, spectrum denial techniques for dense threat environments, and extremely small micro-jammers. The program is selecting competing contractor teams to design the system architecture and develop critical component technologies. In FY 2002, the WolfPack program will finalize the system designs and conduct laboratory and limited filed demonstrations of component technologies for network management and emitter node and network identification, classification and geolocation.

## FUTURE WARFARE CONCEPTS

DARPA is investing in a number of diverse technologies and prototype demonstrations that will enable future operational concepts for a wide variety of critical military missions combining manned and unmanned systems and in space, in the sea, on land, and in the air. The investments for combined manned and unmanned warfare are significant. The autonomous robotics technologies being developed today will allow future warfighters to accomplish their missions more effectively with less risk of casualties, thus preserving the U.S. military's most important resource, its people. In space, we are pursuing revolutionary methods to extend the life of spacecraft while they are on-orbit. We have programs to reduce the frictional drag on ships, analyze future missions for attack submarines, and improve the performance of towed sonar arrays. For land warfare, we are developing a hybrid-electric drive reconnaissance, surveillance and targeting vehicle, covert optical tags for precisely locating objects at kilometer-ranges, and alternatives to antipersonnel landmines. In the air, we are developing active control of flows using a variety of very small-scale actuators, and, based on our success with the Miniature Air Launched Decoy program, we are fabricating a low-cost interceptor to engage enemy cruise missiles.

> "On land, our heavy forces will be lighter, our light forces will be more lethal. All will be easier to deploy and to sustain. In the air, we will be able to strike across the world with pinpoint accuracy, using both aircraft and unmanned systems. On the oceans, we will connect information and weapons in new ways, maximizing our ability to project power over land. In space, we'll protect our network of satellites essential to the flow of our commerce and the defense of our common interests."
>
> *--President Bush, February 13, 2001*

### *Combined Manned and Unmanned Operations*

Flying manned aircraft into hostile territory to strike targets or to suppress enemy air defenses places the aircrews at great risk. The DARPA/Air Force **Unmanned Combat Air Vehicle** (UCAV) Advanced Technology Demonstration will prove that some of the most hazardous missions can be performed effectively by an unmanned vehicle and made operational by 2010, while, at the same time, reducing costs and risk to human life. DARPA firmly believes that the unit recurring fly-away cost of the UCAV weapon system will be one-third that of the Joint Strike Fighter and that operations and support costs, compared to a current manned fighter squadron, will be reduced by 75 percent. The program began its second phase in 1999, selecting a single contractor to conduct a comprehensive series of simulations, ground tests, and flight tests using a surrogate aircraft, two full-scale air vehicle demonstrators, and a reconfigurable mission control station. The first UCAV demonstrator air vehicle was previewed last year, and the test flight program started this year. The X-45A air vehicle is currently completing engine runs and will systematically move through a series of taxi tests toward a first flight late this Summer. In parallel, a series of simulations will demonstrate the ability of an operator to manage a UCAV in a realistic battle environment. The remainder of the current phase of the UCAV program, extending through FY 2003, will demonstrate: compatibility of the unmanned system with the envisioned 2010 battlespace; robustness and security of communications with the air vehicle; the 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 potential of the unmanned approach to hazardous air missions has also resulted in a joint DARPA/Navy Naval UCAV (**UCAV-N**) program. The Navy has a need for sea-based, highly survivable, effective and affordable air power to conduct deep strike, suppression of enemy air defenses, and surveillance missions as part of an integrated air campaign. A Naval Unmanned Combat Air Vehicle can prosecute the enemy integrated air defense system and high-value targets with relative impunity without placing a pilot in harm's way. In addition, a UCAV-N capability that can maintain continuous vigilance will enable advanced surveillance, suppression of enemy air defenses, and immediate lethal strike for attacking time-critical targets. DARPA and the Department of the Navy have agreed to a joint program to validate the critical technologies, processes and system attributes and demonstrate the technical feasibility of a UCAV-N system. The UCAV-N Advanced Technology Demonstration program is structured in two phases: first, analysis and preliminary design, and second, development and demonstration. In July 2000, DARPA awarded two Section 845 agreements to Boeing and Northrop Grumman for analysis and preliminary design of a UCAV-N air system, and those studies were completed in March 2001. In April of 2001, the Phase I contracts were modified to permit more complete system preliminary design and to begin risk reduction of critical technologies, processes and system attributes. A successful conclusion to Phase I would lead to a seamless transition into Phase II in January 2002. Phase II will continue through December 2004.

The jointly funded, collaborative DARPA/Army **Future Combat Systems** (FCS) demonstration program will define the concept design for a new generation of deployable, agile, versatile, lethal, survivable, sustainable and dominant combat systems. The program will develop innovative technologies to get more firepower to the battlefield quickly, establish dominance once there, and reduce the risks to U.S. soldiers. A collaborative system of manned and unmanned platforms is the key FCS enabler. DARPA and the Army are developing the technologies to achieve this new way of fighting, managing the development risks carefully in order to field a highly successful combat system.

The program will develop a preliminary design and fabricate and test an FCS concept demonstrator that will show how the collaboration of manned and unmanned vehicles can establish dominance on the battlefield. At the same time, the program is developing radically innovative enabling technologies for insertion in the demonstrator. These jointly funded enabling technologies will provide mobile, networked command, control, and communications capabilities; autonomous robotic systems; precision indirect fires; airborne and ground organic sensor platforms; and precision, three-dimensional, adverse-weather reconnaissance, surveillance, targeting and acquisition. In FY 2001, the FCS program entered a competitive concept development phase and is conducting a series of government-run experiments to evaluate the potentially revolutionary impact of various technologies on land warfare. In addition to this design and demonstration effort, DARPA is supporting eight programs to provide supporting technologies:

- The **Unmanned Ground Combat Vehicle** program, to provide increased mobility, access and flexibility for ground combat units;
- The **Perception for Off-Road Robotics** program, which will solve problems in autonomous ground vehicle mobility;
- The **Organic Air Vehicle** program to provide small ground combat units with their own air vehicle for close-in surveillance, reconnaissance and targeting;
- The **A160** program, developing a long-endurance, high-altitude rotorcraft for wide-area reconnaissance and surveillance and for use as a communications relay;
- The **JIGSAW** program, using laser imaging to facilitate the identification of targets hidden under foliage;
- The **Command and Control** program, which will develop the necessary architecture for a combat system such as FCS with distributed capabilities;

- The **FCS Communications** program, for the robust, secure links between mutually supporting vehicles needed on the battlefield; and
- The **NetFires** program, a continuation of the Advanced Fire Support System, to provide precision, vertically launched missiles.

The **Unmanned Ground Combat Vehicle** program is determining the performance benefits associated with design of ground combat vehicles unrestrained by the need to accommodate a crew. The resulting vehicles are expected to show radical improvements over their crewed counterparts in deployability, endurance, and obstacle negotiation. This program began in FY 2001 and will generate seven preliminary unmanned vehicle system designs for payloads of approximately 330 pounds and 3300 pounds by year-end. These payloads are notionally associated with sensor missions and sensor plus weapons missions. In FY 2002, the program will select at least four designs to conduct critical subsystem testing (power systems, suspensions, structural dynamics, and controls) in conjunction with design refinement in preparation for prototype fabrication, which should begin in the Summer of 2002.

The **Perception for Off-Road Robotics** program is determining the extent of autonomous ground navigation that can be achieved in the near-term to support tactical assumptions being made for robots in FCS. This program is structured around unscripted field testing of multiple perception approaches using state-of-the-art sensors, algorithms, and processing capability in a wide variety of environmental conditions. Example multiple perception approaches include dual perspective sensing with a small unmanned air vehicle assisting the ground vehicle, or combined active and passive sensing with radar and infrared sensors. Some approaches also use strong adaptive learning algorithms to place sensor data in the context of the local terrain and simplify the identification of hazards. The field tests will incorporate on-the-fly learning by the robots and operation in coordinated teams (including unmanned air vehicles). This program began in FY 2001 and will involve four competing perception system teams, each preparing two surrogate vehicles for autonomous mobility and perception testing in FY 2002. In FY 2002, three of these approaches to participate in field testing in forest, desert, mountainous, and outdoor urban terrain under both day and night conditions. These tests will be used to refine the algorithms and assess the performance (and potential performance) of each approach under these widely varying conditions. The results will provide validated data for FCS simulation models.

The purpose of the **Organic Air Vehicle** (OAV) program is to provide ground combat units, including Future Combat Systems units, with a capability to detect adversary troops concealed in forests or behind buildings or hills – anywhere that U.S. forces do not have a direct line-of-sight to the hostile force. Today the military must send out human scouts to locate and identify enemy troops, a slow and dangerous process. The air vehicle will be small, lightweight, and inexpensive enough to be carried, launched, and operated by lower-echelon ground units. The goal is that the OAV design be less than one foot in any dimension, weigh less than two kilograms, and cost approximately $1,000 each in quantities of 100,000 or more (cost for the air vehicle without payloads). The air vehicle will carry a variety of sensors, such as LIDAR, infrared, or electro-optic devices to detect vehicles or individual soldiers. Initial testing of an OAV candidate, the Lift Augmented Ducted Fan vehicle, was completed satisfactorily last year. In FY 2001, we will conduct flight tests of promising vehicles and develop flight control software. The program will finalize integration of complete, scalable vehicles and sensor packages in FY 2003.

The **Hummingbird A160** program is developing a revolutionary advancement in the capabilities of helicopters. The program began in 1998 to satisfy a military need of the Army and the Marine Corps for an affordable, vertical take-off and landing unmanned air vehicle with a long ferry-range (greater than 2500 nautical miles) and high-endurance (greater than 24 to 48 hours) capability with substantial payloads. The A160 is also being developed as a sensor and communications platform for U.S. Special Operations Command and the DARPA/Army Future Combat Systems program. Automated flight controls and an automated ground station will allow operation of the aircraft with minimal operator training. The flight control system and ground station were demonstrated successfully last year with a surrogate unmanned helicopter. The rotor system was also demonstrated on a ground-based rotor test stand in the past year, and the first A160 air vehicle is expected to begin flight-testing this year. In FY 2002 and 2003, the A160 program will integrate and demonstrate several surveillance payloads.

The **JIGSAW** program is developing LADAR sensors to enable combat identification by humans. Unlike video data, LADAR sensors will provide three-dimensional information that can penetrate holes in foliage and assemble information from multiple viewpoints as the sensor moves around the potential target. This program, which started in FY 2001, is collecting experimental data mimicking FCS environments and is developing software to perform the assembly and visualization of three-dimensional information. In FY 2002, the program will build prototype LADAR sensors with integrated software to perform experiments in realistic scenarios.

The objective of the **FCS Command and Control** program is to develop an integrated command and control system for the Future Combat System Unit Cell that enables two to six people to command all organic assets, both manned and unmanned, in combat. Since the proposed area of influence, operational reach, and lethality of the cell's organic assets are comparable to that of a current operational battalion, this program is attempting to reduce the command and control staff by a factor of 10. The current battle command approach is stovepiped in nature and is not integrated. The operational constructs of FCS dictate the need for a responsive, integrated command and control system to support this new approach to distributed networked battle. The program began in October 2000, and has mapped information flows, tasks, operational constructs and technical build requirements for the integrated command and control architecture. This year, the program continues research in integrated battle command and modeling and conducts an initial pilot test simulation of a unit cell in combat. We begin a series of four experiments in integrated battle command in October 2001, with the final experiment planned for April 2003.

The objective of the **FCS Communications** program is to create a real-time, mobile, ad hoc network capable of operating with the extremely low probability of detection and robustness to jamming necessary for positive robotic and fire control requirements. In FY 2001, the program selected contractors to develop critical enabling technologies: high band technology for dynamically exploiting millimeter-wave frequencies; low bandwidth (e.g., future Joint Tactical Radio System) technology for dynamically exploiting complex radio frequency environments; mobile ad hoc network technology for smoothly blending the high bandwidth and low bandwidth technologies into an assured single network; and network modeling and simulation. In FY 2002, the program will down-select to a single team for system integration and demonstration.

The Future Combat Systems 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 that need to be able to call upon precision, responsive firepower guided by beyond-the-horizon targeting. The **NetFires** program is developing a family of small, container-launched missiles to provide massive, responsive, precision firepower early in a conflict and is a key element supporting beyond-line-of-sight engagements for the DARPA/Army Future Combat Systems program. NetFires is designed for low logistics burden and low life-cycle cost: a single C-130 could deliver a shipping container with 150 NetFires missiles capable of engaging 150 separate targets up to 200 kilometers away. The system is shipped in its launching container, requires no additional launch support equipment, and can be fired remotely from trucks, HMMWVs, or a variety of other platforms. NetFires' rounds are ready to fire immediately, resulting in a much higher potential rate of fire than is possible with current howitzers or missile launchers. Last year, the program tested both a variable thrust motor, a key enabling technology, and a launcher. This year we are continuing to verify the operation of the variable thrust motor, having successfully demonstrated maximum-flight-duration motor burn-times. Both missile contractors have successfully conducted their first boost test vehicle launches, and we are conducting seeker captive flight tests and extensive wind tunnel tests; air drop tests of the loitering attack missile will take place this summer. Initial unguided air vehicle flight-testing begins this year, and extensive, fully integrated missile flight-testing will be conducted in FY 2002 and 2003.

One key to developing intelligent, autonomous, unmanned platforms is advanced software. The **Software for Distributed Robotics** (SDR) program is developing robot software technologies to allow a single soldier to interact naturally with and intuitively control a large swarm of very small micro-robots performing a collective task. In FY 2000, SDR demonstrated statistically grounded, probabilistic control algorithms suitable for directing the actions of a dozen micro-robots. In FY 2001, the program is demonstrating the ability of a single soldier to control the behavior of a swarm of 100 simulated micro-robots. In FY 2002, SDR will demonstrate these ensemble behaviors on a swarm of 100 physical micro-robots and will transfer the software to physical robot platforms.

### *Space Operations*

The **Orbital Express** program is designed to create a revolution in space operations. It will demonstrate the feasibility of refueling, upgrading, and extending the life of on-orbit spacecraft. Automated spacecraft will perform all of this space work, lowering the cost of doing business in space and providing radical new capabilities for military spacecraft such as high maneuverability, autonomous orbital operations, and satellites that can be reconfigured as missions change or as technology advances. Giving military satellites the capability to maneuver on-orbit would provide them with dramatic advantages: they would be able to evade attacking spacecraft and could escape observation by making their orbits less predictable to adversaries. Last year, the program selected multiple contractor teams to recommend the optimum architecture for an on-orbit servicing infrastructure. The teams reported to DARPA on the space missions they determined would benefit the most from being serviced, e.g., surveillance satellites that could be maneuvered to coordinate overhead coverage with air strikes to provide timely battle damage assessment if they could be refueled, or space based radars that could be upgraded with faster processors instead of waiting for new satellites to be launched. In FY 2001, the teams are designing a pair of spacecraft for an on-orbit demonstration of the enabling technologies needed to make on-orbit servicing feasible – autonomous guidance, navigation, and control software to control satellite rendezvous and proximity operations, sensors to measure and match relative satellite motions, wide capture-range grapple and soft docking mechanisms, and open satellite bus architectures that can accept plug-in upgrade components. The program will select one team to build components necessary for the on-orbit demonstration and continue development of key technologies. Fabrication and ground-test of the two space vehicles will continue through FY 2004, with launch of the space experiment anticipated for late 2004.

The **Coherent Communications, Imaging and Targeting** (CCIT) program could lead to more efficient systems for tracking satellites and transmitting communications to them from mobile platforms. Current systems, which use adaptive optics (flexible mirrors whose surface can be changed to compensate for atmospheric aberrations or distortions), are too heavy to use in mobile platforms. The CCIT program will demonstrate aberration-free communications, imaging, and tracking using the coherent properties of laser light and aberration correction devices that employ micro-electromechanical (MEMS) technology. FY 2001 is the first year of the program, and we are designing and modeling the CCIT system and developing aberration correction. The program is developing three device types, and we will assemble the most promising into a laboratory CCIT system in FY 2002. All three Military Services are potential customers as CCIT provides capabilities for secure communications.

### *Maritime Operations*

The goal of the **Robust Passive Sonar** (RPS) program is to significantly increase the performance of tactical towed sonar systems by canceling out surface shipping noise, the primary cause of interference. The RPS program accomplishes this cancellation by innovative and optimal processing techniques coupled with multi-dimensional receive arrays and other external information. The expected net system performance gain is 10 to 20 decibels, and the system is expected to dictate future array and acoustic sensor field designs. Last year, the program began development of the space-time processing algorithms to reject interference. In FY 2001, the program is beginning development of a processing system that will integrate the various algorithms and is also planning an initial data collection exercise. In FY 2002, the program will conduct data collection exercises with the Navy and carry out a preliminary performance assessment of the integrated system.

The **Submarine Payloads and Sensors Program** was a joint DARPA/Navy program to investigate missions for attack submarines in the future, the payloads and sensors needed to conduct these missions, and the impact of these changes on the overall submarine design. Two consortia, formed in 1999, provided final reports to DARPA and Navy last year, and program management of this effort has transferred to the Navy this year. Concepts generated under the study will enable the Navy to investigate new payload and sensor technologies for its Virginia Class submarines. In FY 2002, DARPA is evaluating the results of the study in consideration of other DARPA investments in maritime technologies. Several innovative technologies in underwater propulsion concepts, underwater littoral warfare concepts and antisubmarine research can be combined to enable new warfighting capabilities. One such idea is a very fast, highly agile underwater fighting vehicle employing vortex combustor technology for propulsion and advanced sensor technologies for targeting surface ships and submarines in the littoral regions.

The **Buoyant Cable Array Antenna** (BCAA) program is developing a submarine phased array antenna in a towed buoyant cable format, which will provide high bandwidth, full duplex communication capabilities while a submarine is operating at speed and at depth. Over the next decade, increased emphasis on joint littoral operations, network centric operations, and advanced threat sensor systems will overwhelm the submarine’s operational connectivity. In FY 2000, the program developed and tested antenna and transmit algorithms in controlled environments, i.e., laboratory and in-water conditions. In FY 2001, DARPA is conducting open-ocean testing of the antenna system to demonstrate critical performance milestones. FY 2002, the integrated system will be fabricated, deployed from both a surface ship and a submarine, and tested at sea to demonstrate high bandwidth connectivity from a submarine.

The **Friction Drag Reduction** (FDR) technology program is developing a multi-scale modeling capability for turbulent flow to allow ship designers to decrease friction drag by at least 30 percent with a commensurate increase in endurance and/or payload fraction and possibly significantly increasing speed. Using recent advances in computational technology, FDR will examine whether injecting polymers and microbubbles will achieve these goals. In FY 2001, DARPA is modeling different drag-reduction mechanisms. In FY 2002, DARPA will continue modeling activities, and begin system optimization and design of near full-scale laboratory experiments.

### *Ground Operations*

The **Antipersonnel Landmine Alternatives** (APLA) program is focused on long-term alternatives to antipersonnel landmines that would prevent adversaries from maneuvering at-will. The Self-Healing Minefield is developing an antitank minefield that completely eliminates the need for antipersonnel landmines. The military uses antipersonnel landmines within an antitank minefield to prevent dismounted soldiers from finding and disabling the antitank mines. In the Self-Healing Minefield, no antipersonnel landmines are used. Instead, antitank mines detect a breach attempt via mine-to-mine communication and the minefield responds by self-repositioning a fraction of the mines remaining in the minefield to fill in the breach. In FY 2000, the program began designing and testing three concepts for the antitank mine mobility system and communication system, investigated behavioral responses to breaching, and completed preliminary field-testing of a liquid fuel-based hopping mobility system. During FY 2001, the program is testing and refining the three system concepts, culminating with the construction of at least 10 prototype inert mines for each concept. During FY 2002, the program will complete final testing of the first generation prototype mines at Fort Leonard Wood, MO.

The **Reconnaissance, Surveillance and Targeting Vehicle** (RST-V) program will develop, demonstrate and transition to the Services four hybrid-electric drive, lightweight, highly maneuverable advanced technology demonstrator vehicles that can be transported inside a V-22. The RST-V’s compact, V-22 airlift-requirements-driven design also makes it attractive for transport in a wide variety of aircraft, including the CH-47 and CH-53 helicopters and the C-17 and C-130 fixed-wing aircraft. The vehicle will incorporate advanced integrated survivability techniques and an advanced suspension. It will carry integrated precision geolocation, communication and reconnaissance, surveillance and targeting sensor subsystems. The RST-V platform will provide small-unit tactical reconnaissance teams, fire support coordinators, and special reconnaissance forces with quick deployment and deep insertion of a multi-sensor vehicle to provide battlespace awareness. Last year, the first two vehicles rolled out and the program demonstrated the ability to transmit digital video and to operate using battery-only mode, diesel-engine-only mode, and diesel-electric hybrid mode. In FY 2001, the program is participating in the U.S. Navy *Extending the Littoral Battlespace* Advanced Concept Technology Demonstration and U.S. Marine Corps *Capable Warrior* Advanced Warfighting Experiment to demonstrate the silent watch/silent movement capability of a hybrid-electric vehicle. During the experiment, Force Reconnaissance Marines will conduct a reconnaissance, surveillance, and targeting mission using the RST-V’s integrated command, control, communications, computer and intelligence/reconnaissance, surveillance, target acquisition communication and sensor suite digitally linked into the *Extending the Littoral Battlespace* wide-area network architecture. The third and fourth vehicles will also be rolled out this year. During FY 2002, the vehicles will undergo survivability, automotive, and active suspension performance testing.

The **Optical Tags** program is investigating optical technologies and innovative design and fabrication techniques for covert, kilometer-range, optical tags systems for downed pilot extraction, covert tracking, and precision targeting. Specific applications will be selected based on their operational significance and user input, and then demonstrated in meaningful warfighter experiments. During FY 2001, appliqué-based tags are being fabricated and demonstrated at kilometer ranges. A live technical demonstration for early-entry and special operation forces is planned for late-Summer 2001, when we will demonstrate specific vehicle identification within a convoy, individual soldier identification and location marking applications. During FY 2002, the program will begin investigating precision strike applications and conduct engineering tests of improved tags in a more stressing, operationally realistic situation.

The **Tactical Sensors** program is developing the architecture, sensors, and other technologies to incorporate unattended ground sensors into the suite of tools useful to the warfighter for detecting and classifying time critical targets. The system will consist of miniature, low-power internetted unattended ground sensors, deployed in clusters and fused with longer-range space and airborne systems. In FY 2001, the emphasis is on quantifying system performance, developing target classification algorithms, and initiating planning tools. In FY 2002, the program will finalize the system design and build a number of systems for demonstration and validation in the field.

### *Air Operations*

The **Small Scale Propulsion Systems** program is developing a new class of propulsion systems that will be smaller than any existing engines, i.e., less than seven centimeters diameter and generating thrusts of less than 10 kilograms. The new engines will enable development of very small missiles to use against small targets, small unmanned vehicles for close-in surveillance, and new space-launch vehicles. Engines being developed include a shirt-button-sized turbo-jet engine, a rocket engine only 12 millimeters wide by five millimeters thick, an efficient and high-thrust seven-centimeter diameter turbo-jet, and a pulse detonation engine. During FY 2000, the program began detailed design of the engines. During FY 2001, the program is completing detailed designs, finishing the fabrication of the button-sized turbo-jet engine, and testing the pulse detonation engine prototype and the turbo-pumps for the 12-millimeter rocket. The program will finish fabrication and testing in FY 2002.

The performance of any system that travels through air or water is dominated by the ability to control the flow over its surfaces. To-date we have been limited to passive control methods such as surface shaping. Recent advances in very small-scale actuators are being used in the **Micro-Adaptive Flow Control** (MAFC) program to enable active control of flows using a variety of very small-scale actuators. The MAFC program combines adaptive control, distributed sensor arrays, and advanced miniature actuators to provide a closed-loop control system for a particular application. The program is beginning to demonstrate revolutionary performance improvements for aerospace and marine applications. Performance improvements as large as 30 percent have been achieved, with momentum inputs 10 to 50 times smaller than those used in conventional systems. MAFC technologies are being explored for a wide range of applications, including: adaptive lift-on-demand for agile weapons and uninhabited aircraft; lightweight gas-turbine engines; control of cargo aircraft jet engine exhaust on the ground for safe loading operations; and steering projectiles for extended range and precision. In addition, MAFC technologies hold promise for improved payload capacity for rotorcraft, enhanced aircraft maneuverability, extended vehicle range, and decreased fuel burn at lower total system cost. The applications are guided by system-level performance benefits and cost assessments. In FY 2001, several promising control devices are testing protocols and demonstrating open-loop flow control. We tested a prototype full-scale flow control system on a C-17 engine and established that it would not adversely affect engine performance. An active hover download alleviation system for the V-22 performed better than expected at one-tenth scale, with a 20 percent increase in overall vehicle lifting capacity; testing will progress to one-quarter scale in FY 2002. The program will demonstrate fully integrated MAFC subsystems in FY 2002 and FY 2003.

# Developing and Exploiting High-Risk, High-Payoff Technologies

DARPA continues its traditional investments in information technology, microsystems technologies, advanced materials, and micro-electromechanical systems (MEMS). It is the results of these investments that allow us to build the systems and capabilities for operational dominance of the future. In an exciting new initiative, BioFutures, we have begun to invest in programs that lie at the intersection of biology, information technology, and the physical sciences, having realized that the biological sciences, when coupled with DARPA’s traditional strengths in materials, information, and microelectronics, could provide powerful approaches for addressing many of the most difficult challenges facing DoD in the next 15 to 20 years. And in the Beyond Silicon Complementary Metal Oxide Semiconductors (CMOS) thrust, we are pursuing a radically different approach to the fabrication of logic and memories, enabling enormous gains in computational power in smaller and smaller devices.

## INFORMATION TECHNOLOGIES

DARPA’s investments in information technologies will provide information superiority to the U.S. military through revolutionary advances in:

- Design methodologies for embedded and autonomous systems software;
- High performance computing components;
- Networking;
- Seamless computer interfaces for the warfighter;
- Ubiquitous computing and communication resources; and
- Agent-based systems.

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

### *Embedded and Autonomous Systems Software*

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

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

As DoD systems increasingly transition from platform-centric to network-centric weapons systems, developing a new generation of technologies that can greatly enhance the adaptivity, assurance, and affordability of embedded software is essential for U.S. national security. To address this need, the **Program Composition for Embedded Systems** (PCES) program is creating new technology for programming embedded systems that will substantially reduce development and validation effort and improve the flexibility and confidence of the resulting software. The technology produced by the PCES program in FY 2000 has been used to refactor complex monolithic operating systems into modular components that can be reassembled rapidly to build custom embedded control systems. In FY 2001, the program is developing and applying static analysis techniques for real-time embedded systems' properties and demonstrating these techniques to enhance the performance and robustness of operational avionics mission computing systems. In FY 2002, the PCES program will develop and apply intermediate representations and mechanisms for code composition and transformation that will synthesize adaptive software to control and enhance the quality of service properties of data-streaming missions performed by advanced unmanned air vehicles.

The **Mobile Code Software** program develops software technology to resolve time-critical constraints in logistics and mission-planning, including integrated maintenance and mission planning to support the operation of Marine Attack Squadrons, real-time mission planning and dynamic replanning experiments for unmanned combat air vehicle operation, and adaptive scan-scheduling for electronic warfare platforms. Demonstrations of Mobile Code Software in real-time, distributed, resource management of radar sensors for tracking moving objects showed that negotiation-based approaches can meet the time requirements of electronic warfare applications. The Mobile Code Software program solves the resource management problem through the interaction of lightweight, mobile software components. We use a bottom-up organization approach and negotiation as techniques for resolving ambiguities and conflicts to get logistics and mission-planning solutions that are both "good enough," and "soon enough." In FY 2000, Mobile Code Software successfully demonstrated real-time negotiation technology in mission planning with users at Marine Aircraft Group 13, Yuma, AZ. In FY 2001, the program is scaling-up the technology to demonstrate integrated mission planning and maintenance planning using real-time negotiation. In FY 2002, Mobile Code Software will demonstrate rapid, dynamic, negotiation-based re-planning in highly decentralized environments and in electronic warfare applications.

The **Mobile Autonomous Robot Software** (MARS) program is developing software technologies that can enable machine-learning strategies to automatically generate sophisticated robot behaviors such as autonomous navigation and real-time obstacle avoidance. These sensor-mediated behaviors will reduce the requirement for remote operator control for robots employed in tactically realistic environments including complex, dynamic environments such as urban combat battlespaces. In FY 2000, MARS demonstrated a suite of off-line learning technologies that can rapidly generate desired robot behaviors with minimal hand coding of the control software. In FY 2001, the program is demonstrating on-line learning techniques that can automatically generate desirable, adaptive behaviors without human intervention. The ultimate goal is to allow the warfighter to task a robot in the same terms as he or she might task a human. In FY 2002, MARS will demonstrate a trainable, perception-based autonomous indoor navigation capability.

The goal of the **Software-Enabled Control** (SEC) program is to leverage increased processor and memory capacity to achieve higher performance and more reliable software control systems for mission system platforms. Military applications include integrated avionics design and vehicle control for high-performance unmanned air vehicles (UAVs) and unmanned combat air vehicles (UCAVs), as well as upgrade potential for existing airframes such as the F-15E, F-18, and AV-8B. This research will yield control technology that is robust enough to withstand extreme environments and to enable highly autonomous, cooperating mission systems. In FY 2000, the SEC program designed an open software architecture for hybrid discrete and continuous control that supports better integration of control mode logic with continuous control laws, including synchronized switching and new software scheduling mechanisms. In FY 2001, a prototype implementation of the hybrid multi-mode control software is being completed for single-vehicle uses, including predictive modeling of environmental effects (e.g., wind gusts, turbulence) and safely controlling mode transitions under such effects. This technology will provide enhanced maneuverability/evasive capability for UAV/UCAV systems and enhanced robustness under extreme conditions for piloted systems, increasing the warfighter’s survivability and decreasing his workload. Multi-modal control technology will provide better-controlled transitions between complex operational flight modes (inherent in vertical takeoff and landing UAVs and high performance/transonic manned aircraft), thereby reducing safety risks to the warfighter and vehicle. In FY 2002, the program will develop adaptive hybrid control services to ensure stable operation and extend the control software design to support highly coordinated control of multiple platforms. Coordinated multi-modal control technology will simplify the task of controlling groups of unmanned vehicles, increasing the capacity of a single warfighter to safely control large numbers of air and ground vehicles. This technology will directly support management of authority within groups, supporting the ultimate goal of enabling safe combined manned and unmanned operations.

From avionics systems to smart weapons, embedded information processing is the primary source for superiority in weapon systems. The new wave of inexpensive MEMS-based sensors and actuators and the continued progress in computing and communication technology will further accelerate this trend. Weapon systems will become increasingly “information rich,” where embedded monitoring, control and diagnostic functions penetrate deeper and with smaller granularity in physical component structures. Virtually all new and planned weapon systems illustrate this trend: proposed future functionally integrated but physically distributed “open flat avionics architectures,” inherently distributed architectures for National Missile Defense and Future Combat Systems, mission control software architecture for UCAV, and many others. These systems all require solutions that the **Networked Embedded and Autonomous Software Technology** (NEST) program is developing: application-independent, customizable, and adaptable services for the real-time “fine-grain” distributed control of physical systems. The quantitative target is to build MEMS-based, dependable, real-time, embedded applications comprising 100 to 100,000 computing nodes. In FY 2001, NEST is designing Open Experimental Platforms (including a “smart structure” and a distributed vehicle application), challenge problems, and NEST integration frameworks. The smart structure application provides active, acoustical/structural mode damping and adaptive damage identification in payload fairings. The distributed vehicle application implements closed-loop coordination among large number of sensors and micro-vehicles in pursuer-evader simulations. In FY 2002, the program will demonstrate the scalability and fault resilience of basic coordination service components in 100-node, simple network embedded software technology applications using lightweight, wireless communication networks.

## *High Performance Computing*

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

Many defense applications such as dynamic, sensor-based processing, battlefield data-processing integration, and high-speed cryptographic analysis are data-starved – that is, the processor is so fast that it has to wait for memory to be accessed from random access memory between operations, thus slowing down the computation. Prior analysis showed that memory access was growing at the rate of seven percent annually, while Moore's Law predicted the doubling of processor speed every 18 months. This program is aimed at reducing this imbalance.

The **Data Intensive Systems** program is developing innovative data access techniques to solve this problem and enable new military capabilities. For example, if the processing portions of the computer architecture are physically closer to the memory location, data can be retrieved more quickly. In FY 2000, the program designed and simulated intelligent memory controllers, adaptive caches, and memory systems. In FY 2001, we are completing the concept development and testing of the early prototypes and demonstrating a 16-fold improvement in the speed at which memory is made available to the processor for data intensive applications.

Energy and power management has now become a critical factor for future embedded and large scientific computing applications. The **Power Aware Computing/Communication** program is developing an integrated software/hardware power management technology suite comprised of novel techniques that may be applied at all levels of a system – from the chip to the full system. This will enable embedded computing systems to reduce energy requirements by a hundred- to a thousand-fold in military applications ranging from hand-held computing devices to unmanned air vehicles. In FY 2000, we began power aware computing and communications research, metrics, and mission scenarios. In FY 2001, the program is evaluating and prioritizing individual power aware technologies for components, micro-architectures, compilers, operating systems, and algorithms. In FY 2002, power management technologies will be demonstrated showing a potential 10-fold power/energy savings for multiple candidate DoD platforms and missions, including Land Warrior Dismounted Soldier, distributed sensors, and unmanned combat air vehicles.

## *Networking*

DoD applications are highly bandwidth-intensive, and their demanding requirements cannot be met by the commercially developed networking technologies that are optimized for web browsing and low data-rate data streaming. The **Next Generation Internet** program, ending this year, has developed the key technologies, both in hardware and software, to enable access to extremely high bandwidth. The program has deployed a national-scale SuperNet test bed that ties together several dozen sites at multi-gigabit rates. A number of high-speed, end-to-end networking records were established during our experimentation. These early experiments also revealed the vulnerability of existing networking protocols to bandwidth-intensive flows, and have stimulated a number of efforts to streamline the networking protocol. This year, the new protocols that enable high-speed access at 40 gigabits per second are being integrated into network interface cards and tested along with all-optical burst switches.

The **Gigabyte Applications** program is developing technologies for a highly robust, high-speed networking infrastructure in a heterogeneous environment. By extending high-bandwidth capability to wireless links, it will be possible to deploy high-speed networks with many hundreds-of-megabit- to gigabit-per-second capacity in remote tactical locations with no pre-existing fiber infrastructure. Such links will also enable high-speed reach back to a command post or to the U.S. This can be contrasted to approximately 20 megabits per second connectivity made available to a handful of U.S. installations during the Bosnia conflict – a speed totally inadequate for distributing sensor output, maps, high-resolution imagery and other intelligence data in real-time. The program is also developing key DoD applications that take advantage of a robust capability to stream gigabytes to terabytes of real-time data. In FY 2001, the program is testing multi-antenna wireless networking technology that has the potential for gigabit end-to-end radio frequency connectivity. In FY 2002, the program will demonstrate the sparseband sensor processing technology, where multiple gigabit per second streams from radars operating in different bands or locations are networked and coherently processed to dramatically enhance the sensitivity and resolution that could be attained from independent sensors.

### *Seamless Computer Interfaces*

The **Translingual Information Detection, Extraction, and Summarization** (TIDES) program is creating technology to enable English speakers to locate and use network-accessible information in multiple languages without requiring knowledge of those languages. Last year TIDES started developing key component technologies and cooperated with Third Fleet in a field experiment called *Strong Angel* that applied early versions of the technologies to humanitarian assistance and disaster relief operations in a mock exercise in Hawaii. In FY 2001, TIDES is making the technologies more robust and using them in a more ambitious experiment called Integrated Fleet Experiment-Bio (IFE-Bio), aimed at global infectious disease monitoring, that will be conducted in Bedford, MA, and San Diego, CA. In FY 2002, the program will add cross-document, cross-language summarization and translation capabilities and will conduct experiments in additional languages of defense interest, including Chinese and Arabic.

### *Ubiquitous Computing*

Miniaturized, low cost sensors will become more capable and pervasive in future military systems to detect ground-moving targets and biological and chemical warfare agents, and for military operations in urban terrain. To fully utilize these sensor capabilities, we must develop software that can create an ad-hoc network of deployed sensor devices, and process information collected by the sensors for reconnaissance, surveillance, and tactical uses for the warfighter. The **Information Technology for Sensor Networks** (SensIT) program is producing software that enables flexible and powerful sensing capabilities for networked micro-sensors. During FY 2000, the program developed new algorithms for ad hoc sensor networks, and methods for cooperative sensing. The initial version of the SensIT software with dynamic programming ability was demonstrated at the U.S. Marine Corps base at Twentynine Palms, CA, where extensive data from acoustic, seismic, infrared and other sensors was collected to develop micro-sensor network methods for detecting, classifying, and tracking ground moving targets and communicating this data to (and receive tasking instructions from) a remote site. In FY 2001, the program is developing an integrated software suite and conducting field demonstrations, also at Twentynine Palms, CA. This demonstration will include inter-networking of ground sensors with sensors on mobile platforms such as unmanned air vehicles, predicting target movements, imaging the targets and relaying the image data to a command center for confirmation. In FY 2002, the program plans a field demonstration and two joint experiments with the Marine Corps. These demonstrations will feature fully integrated software that highlights the new operational capabilities of low-latency networks of programmable, multi-modal micro-sensors for rapid tracking of ground moving targets and for detecting and classifying of threats in urban environments.

A grand challenge for information technology is bridging the gap between the physical and digital worlds. Computers should disappear into the background while information becomes ubiquitous. The **Ubiquitous Computing** program focuses on developing the underlying technologies to provide accessible, understandable, relevant information to mobile users, based on an understanding of the user's tasks and informational needs, to provide the user with greater and more timely situational awareness – thereby increasing his survivability, lethality, and effectiveness. In FY 2000, the Ubiquitous Computing program delivered several products, including: a small foot-print operating system, TinyOS, that enables self-organization of small computing devices, such as those in the SensIT distributed sensor network vehicle tracking demonstration; an initial, component-based architecture to provide seamless computing support to mobile ground troops, enabling them to have access to digital information needed for their tasks; and an architecture to support secure, mobile access to "persistent data," i.e., data that must be stored and accessed for some period of time, such as logistics and casualty information. In FY 2001, the program is developing software components to support nomadic data access and representations for task-level computing.

### *Agent-Based Systems*

The **DARPA Agent Markup Language** (DAML) program is creating technologies that enable software agents to identify, communicate with, and understand other software agents dynamically in a web-enabled environment. Agents, which are software programs that run without direct human control or constant supervision to accomplish goals specified by the user, can be used to collect, filter and process information – a crucial need of command, control, intelligence, surveillance, and reconnaissance applications. DAML is developing an extended XML markup language that ties the information on a page to machine-readable semantics, thus creating an environment where software agents can function. This effort will provide new technologies for operational users by integrating information across a wide variety of heterogeneous military sources and systems as the technologies are deployed in both command and control and intelligence applications. Last year, in the first year of the program, DAML developed the first working draft of the software language and coordinated it with the World Wide Web Consortium. In FY 2001, the program is releasing working versions of Briefing Tools, Search Tools, and Ontology Creation Tools, and is defining and testing a toolset for military applications of DAML technologies. In FY 2002, the program will deploy the DAML Search tool on an operational Intelink node and prototype selected DAML tools to enhance search and retrieval tools at the Center for Army Lessons Learned and other military and civilian venues.

Information superiority in the modern battlefield requires that the military be able to rapidly assemble a set of disparate information systems into a coherently interoperating whole. This must be done without system redesign and may include interoperation with non-DoD governmental systems, systems separately designed by coalition partners, or commercial-off-the-shelf and open-source systems not built to a pre-existing government standard. The **Control of Agent Based Systems** (CoABS) program is building on the technology of run-time interoperability of heterogeneous systems to develop new tools for facilitating rapid system integration. Last year, CoABS developed and demonstrated a flexible information infrastructure and an interoperability tool called the Agent Grid, which supports the dynamic deployment of complex applications for military command and control. The Agent Grid was demonstrated to the U.S. Army Communications-Electronics Command Research, Development and Engineering Center (CECOM), Fort Monmouth, NJ, and to the Air Force Research Laboratory (AFRL), Rome, NY. CECOM is now investigating the Agent Grid for use in their battlefield command and control systems, such as the Maneuver Control System, and AFRL is experimenting with the Agent Grid to solve interoperability issues for Air Force missions. In FY 2001, CoABS is using agent technologies and tools in military scenarios to demonstrate the run-time integration and interoperability of heterogeneous systems in applications that address present and future command and control problems. In FY 2002, CoABS will transition run-time integration capabilities to the Military Services by providing the command and control infrastructure for Joint Forces Command's *Millennium Challenge '02*, operating in the Army's Agile Commander Advanced Technology Demonstration, and facilitating new operational capabilities for the Air Mobility Command.

At present, complex military problem-solving tasks are either performed totally by human operations officers and intelligence analysts, or with minimal assistance by small knowledge bases. Computer scientists trained in artificial intelligence technology must formulate these knowledge bases. The **Rapid Knowledge Formulation** (RKF) program is developing methods to conduct rapid database searches, construct knowledge bases, and draw inferences for key information. The RKF program is enabling end-users to directly enter knowledge into knowledge bases and to create massive knowledge bases ($10^6$ axioms) in less than one year. It will allow artificial intelligence novices to directly grasp the contents of a knowledge base and to compose formal theories without formal logic training. As a result, it will enable military and technical subject matter experts to encode the problem-solving expertise required for complex tasks by directly and rapidly developing, extending, and expanding small knowledge bases by a factor of 10. Because these knowledge bases are required for analysis of hardened and deeply buried targets, offensive and defensive information operations, and weapons of mass destruction capability assessments of terrorist organizations, the capabilities enabled by RKF will be extremely useful. The RKF program began in FY 2000 and demonstrated a language and diagram interface, analogic reasoners, and theory explanation capabilities; it also developed 10 to 20 core theories. In FY 2001, RKF is demonstrating direct knowledge entry by a single, novice user at a rate of 2,000 axioms per month entered into a knowledge base that addresses malaria and orthopox (smallpox) biological weapon threats, vaccines and other countermeasures. By the end of FY 2002, RKF will demonstrate knowledge entry of a biological warfare challenge problem at a rate of 50,000 axioms per month from each of 25 subject-matter experts.

## MICROSYSTEMS TECHNOLOGIES

DARPA's pursuits in microsystems technologies are driving a new chip-scale revolution in electronics, photonics, and micro-electromechanical systems (MEMS) while demonstrating revolutionary display technologies and photonics for military information systems.

The objective of the **University Opto-Centers** program is to establish multi-investigator university optoelectronic centers with programs closely coupled to photonic industry researchers to develop and demonstrate chip-scale optoelectronic integration technologies. The development of advanced, chip-scale optoelectronic modules is essential for future, high-performance military sensor and information processing systems. University-based research provides the knowledge base and the highly capable expertise to both innovate and support the development of these capabilities within industry. In FY 2000, the University Opto-Centers established new capabilities for the design, fabrication and demonstration of chip-scale modules that integrate photonic, electronic and micro-electromechanical systems-based technologies. The program also established university technology research goals and identified methods to facilitate industry access to these technologies. In FY 2001, the program is evaluating specific chip-scale integrated module designs and assessing the success of engaging industry commitment to the program. In FY 2002, the program will fabricate and test individual chip-level sub-assemblies for later use in prototype development.

The **Flexible Emissive Display** program was established in FY 1999 and is developing and demonstrating large-area, high-resolution, flexible, emissive, rugged displays for DoD applications. The development of rugged, lightweight, inexpensive, flexible displays will be useful for aircraft, ships, land vehicles, and foot soldiers. In FY 2000, the program conducted demonstrations in all three key technology areas: backplanes, emissive materials, and substrates. In FY 2001, the program is demonstrating a low-cost, high-speed, roll-to-roll assembly process for plastic-film liquid crystal displays and is demonstrating a flexible, lightweight, emissive, color, electroluminescent display based upon plastic material. By the end of this fiscal year, the program will have demonstrated emissive color display video capable of greater than 80 lines per inch on a flexible substrate.

The primary human-machine interface remains the visual display of information. The DoD has a diverse range of needs for display technology, and today most of these needs (approximately 80 percent) can be met by commercial parts, while the remaining require ruggedized or custom design and manufacture to meet performance requirements. DARPA's **High Definition Systems** (HDS) program, ending this year, began 13 years ago and invested over $650 million in display and related technologies. The HDS program has played a significant role in meeting today's DoD display needs. At the start of the program, cathode ray tube technology dominated most applications. Liquid crystal displays (LCDs) were just beginning to emerge as an alternative, primarily for power-efficient, lightweight laptop computer applications. The primary suppliers of these technologies were in Japan and were unwilling to work with DoD contractors. Today, for most of the displays important to the DoD, LCDs continue to dominate, but new technologies are emerging that include MEMS mirror arrays, light emitting diodes (LEDs), and thin film electro-luminescence displays. These latter types of displays are available from both domestic and international sources, but the dominant LCD suppliers are still centered in the Far East (Korea, Taiwan and Japan). However, the market for LCDs is highly competitive, presenting a robust marketplace in which DoD suppliers have ready access to the most advanced technologies.

Specific HDS program successes include: MEMS-based Digital Micromirror Device technology, which is finding application in the Common Large Area Display Set for Airborne Warning and Control System, Joint Surveillance and Target Attack Radar System and E-2C airborne systems and UYQ-70 aboard ship; cholesteric liquid crystal technology that can maintain a static image without consuming power and is finding application for information management systems by the Army Military Police; small (one-inch) active matrix LCD for use in head-mounted displays being transitioned to the Army's new reconnaissance/attack helicopter, the RAH-66 Comanche; and low-voltage thin film electro luminescence displays for the forward looking infrared displays in the Army's Abrams M1A2 System Enhancement Program. A major investment area for the HDS program has been in developing flexible emissive displays, including organic light emitting diodes and flexible substrate technologies. These technologies are becoming available but face considerable manufacturability and long-term reliability challenges. However, they offer the promise of roll-up or "window-shade" displays for compact, portable command and control applications. In addition, the HDS program has supported, on a cost-shared basis, the U.S. Display Consortium (USDC). The USDC is made up of U.S. display industry companies and provides support for the development of display manufacturing equipment, processes and materials. The Consortium has completed more than 40 projects, including 25 that resulted in commercialization of new tools or materials for fabricating LCD, electro-luminescent or organic light emitting diodes.

Relative to defense needs, today's truly global market for high definition displays and the far greater commercial applications of these devices has resulted in an advantageous position for the DoD. The DoD strategy as we go forward is to make use of the global industrial capability where it is available, using existing acquisition guidelines, with contractors buying most display components in a highly competitive, rapidly evolving and increasingly robust market place. In the future, DARPA will limit its research and development investments to focused specific needs where industry is not yet leading the way and a military advantage is foreseen.

The **Photonic Analog-to-Digital Converter Technology** program will apply photonic technologies to improve analog-to-digital converter performance to achieve 12- to 14-bit resolution at sampling rates up to 10 giga-samples per second. Sampling at these very high rates enables use of more complex radar waveforms and improved signal-to-noise performance, providing enhanced resolution and improved target imaging for military radar systems. The ability to directly perform analog-to-digital conversion of multi-gigahertz signals at the source, while preserving their entire spectral content, will have significant impact on the performance of a wide range of radar, electronic warfare and communication systems and create new architectural possibilities for these systems. In FY 2000, the program evaluated alternative designs for the optical clock, optical sampler, and electronic quantizer modules. In FY 2001, the program is completing the initial photonic analog-digital converter evaluation and finalizing the design for the demonstration module. In FY 2002, the program will integrate the photonic clock and sampler modules with electronic quantizers and complete analog-to-digital converters with at least 10 gigasamples per second.

Traditional approaches to electronic interconnects based on wire interconnection lead to information processing systems that are bulky, heavy, and power-hungry. The communication bandwidth and speed possible with these electronic interconnects is lower than that of the processor itself, leading to bottlenecks within the system. The **Very Large Scale Integration (VLSI) Photonics** program is developing photonics technology that uses optical links instead of electronic wire links for chip-to-chip and board-to-board communications. This new technology will allow data transfer rates faster than a terabit per second, which is 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.

The most important accomplishment in the VLSI Photonics program has been the demonstration of the capability to manufacture vertical-cavity surface-emitting lasers with yields of over 99 percent on large-area (three-inch) wafers. Technology for manufacturing conventional lasers will never achieve this low-cost, large-area capability. Surface-emitting lasers have demonstrated the lowest threshold currents of any lasers ever manufactured, with estimated lifetimes of well over 50 years. In FY 2000, the program used optical links to transfer useful data between chips to allow benchmarking performance against traditional electrical approaches. We are planning the two major capstone demonstrations of the program for the third and fourth quarters of FY 2001, the program's final year. The first involves data processing in synthetic aperture radar, and the second in hyperspectral imaging. Both of these applications generate large quantities of data that are currently difficult to process in real-time. The reduced size of the optical components and increased data processing speed will demonstrate the feasibility of achieving more than 100-times reduction in power-volume product for synthetic aperture radar two-dimensional fast Fourier transform computations. This program has successfully captured the interest of systems designers, including commercial high-end workstation designers, and has stimulated the creation of at least two start-up activities to pursue the continued development of the technology.

Thermal imaging remains a cornerstone technology for many military applications, including small unit operations, ground, air and sea target acquisition, missile seekers, and threat warning. Significant strides have been made in converting thermal imaging technology from cryogenically cooled detectors to uncooled thermal detectors, which have the potential to improve detector performance by a factor of 10. The **Uncooled Infrared Integrated Sensors** program has catalyzed a major shift in focal plane array technology. For many years, the standard uncooled array was based upon a pixel size of 50-by-50 micrometers and an array format of 320-by-240 picture elements. This relatively large pixel size limited both the system resolution and target acquisition range, and most importantly, restricted the options available to the system designer. Last year, this program demonstrated for the first time the ability to fabricate uncooled infrared sensors with a pixel size of 25-by-25 micrometers, a 75-percent reduction in area. Although thermal sensitivity should be reduced for smaller pixels, the sensitivity was maintained at 0.050 degrees Kelvin, exceeding current uncooled performance. These efforts will truly revolutionize thermal imaging, providing lower cost sensors for current systems and allowing the integration of imaging micro-sensors into novel platforms such as micro air vehicles and robotics. A 320-by-240 array incorporating this structure demonstrated two times the target acquisition range of the typical uncooled infrared sensor. In FY 2000, the program began the investigation of new concepts for thermally sensitive microstructures. In FY 2001, the program is demonstrating a

100-gram imaging sensor with performance acceptable for micro air vehicles. In FY 2002, the program will incorporate high responsitivity materials into the detector structures and integrate materials and microstructures into imaging arrays. This will establish the viability of high-performance uncooled infrared, providing acceptable thermal imaging performance in a package 10 to 100 times smaller and at one-tenth the cost of current thermal imaging sensors.

The objective of the **Photonic Wavelength and Spatial Signal Processing** program is to develop integrated electronic and optoelectronic device and module technologies that allow the dynamic and reconfigurable manipulation of both the wavelength and spatial attributes of light for adapting, sensing and image pre-processing. The reconfiguration and data pre-processing capabilities of these technologies will allow the design and manufacture of real-time sensing and imaging systems. These systems could be deployed in a wide variety of tactical systems, such as night vision systems, early warning sensors, and autonomous platforms. This will be a significant improvement over the current generation of sensing and imaging systems, most of which are not capable of real-time data collection, analysis, and presentation. The technology will allow hyperspectral imaging in real-time in a single, chip-scale microsystem. The data contained in a given scene will be processed, in terms of spatial and spectral content, on-chip at the sensor/imaging array through the heterogeneous integration of detector arrays, micro-optics, and controlling electronics. This approach will result in greater than an order of magnitude reduction in the amount of data that must be transmitted to a user, thereby reducing demand on constrained bandwidth links. Furthermore, since processing is done at the sensor, faster and more reliable decision making will be enabled, e.g., rapid detection, identification, and classification of chemical and biological agents. The same suite of technologies can also be used in the detection and recognition of targets and objects that are otherwise obscured from view. During FY 2000, the first year of the program, we developed the basic source and detector device technologies that cover spectral bands between 350 nanometers and 14 micrometers. In FY 2001, the program is demonstrating emitters and detectors in the spectral band 350 to 500 nanometers. In FY 2002, the program will develop micro-machined optical elements for the spectral band 300 to 500 nanometers and three to five microns in the infrared band.

The **Advanced Lithography** program is seeking solutions to critical technical barriers in emerging microcircuit fabrication technologies that are essential to improving the computational speed, functionality, size, weight, and power requirements of microelectronics. These performance improvements will benefit essentially all advanced military systems, including computation and signal processing for communications, sensing, and guidance systems. In FY 2000, the program developed key tool components, materials and processing to accelerate the availability of emerging lithography technologies beyond 193 nanometers. In FY 2001, the program is demonstrating key components of a maskless wafer writer and key components for lithography of 0.07-micron features. In FY 2002, the program will develop key tool components, materials and processing for both maskless and projection approaches for lithography at 0.05 microns and will fabricate prototype devices for military applications with features of 0.1 micron in size. The FY 2002 budget level for the Advanced Lithography program will reflect and support the semiconductor industry's decision regarding next generation lithography; they decided to pursue extreme ultraviolet lithography as opposed to optical and x-ray lithography technologies. DARPA's Advanced Lithography program will therefore reduce investments in those areas while concentrating on leading edge technologies critical to military needs – maskless and nanolithography. DARPA will continue to push the leading edge of lithography into the sub-35 nanometer range, while industry provides the engineering developments for next generation lithographies. In addition, DARPA initiated a broad effort to identify and develop the next-generation of microcircuitry components to overcome the traditional limits of current silicon technology. This effort, Beyond Silicon Complementary Metal Oxide Semiconductors, is discussed later.

The objective of the **Three-Dimensional Imaging** program is to develop the ability to rapidly capture a three-dimensional image of a target and determine its detailed target profile. This will significantly enhance the ability to identify targets in cluttered backgrounds and to correctly identify friendly versus unfriendly targets. Imaging from fast-moving platforms and the requirement to rapidly engage multiple targets necessitates the development of an imaging array, which, using a single flash of laser illumination, provides both intensity and target depth information. The Three-Dimensional Imaging program focuses on the materials, detector, and unique electronics technology required to obtain, in a single, very short-duration, eye-safe laser pulse, a target depth profile or three-dimensional image of the target. Key innovations in the technology are the ability to incorporate gain into the detector structure, fabricate focal plane arrays of high-gain detectors sensitive at short-wave infrared wavelengths, and to integrate range-processing circuitry into the unit cells at each detector. In FY 2000, the program evaluated fundamental materials properties necessary to fabricate high-gain detection devices in the short-wave infrared wavelengths, with a focus on material defect reduction and the uniformity enhancement necessary for array development. This year, the program has demonstrated a four-by-four detector array with a gain of 30 at one gigahertz and will complete investigations of novel high-gain detector concepts. In FY 2002, the program will demonstrate a low-power system with a range resolution of one to six inches at one to two kilometers.

The **Steered Agile Beams** (STAB) program is developing small, lightweight laser beam steering technologies for the replacement of large, mechanically steered mirror systems for free-space optical communications and infrared countermeasures systems. New solid-state/micro-component technologies such as optical MEMS, patterned liquid crystals and micro-optics will provide the opportunity to incorporate small, ultra-light, rapidly steered laser beam subsystems into a broader range of military platforms and man-transportable applications. These advanced subsystems will enable laser designators to simultaneously engage multiple targets, increase both smart weapon kill ratio and delivery platform stand-off distance (and, therefore, launcher survivability), allow full 360-degree infrared countermeasures coverage around aircraft and other high-value military assets, and provide a secure, covert means of high-bandwidth transmission programs for special operations forces and scout intelligence preparation of the battlefield. During FY 2000, the program determined the optimum mix of technologies to be developed, and established STAB system architectures and performance objectives for subsystem components to form the basis for managing risk and technical progress. In FY 2001, the program is developing, fabricating and evaluating the beam steering, emitter, and detector components and downselect the most promising approaches. In FY 2002, the program will develop design goals for assembled components and fabricate individual laser beam steering components.

High-performance radio frequency systems are critical to a wide range of advanced military radar, electronic warfare and secure communication applications, but they are currently restricted to deployment on large weapons platforms due to the size, weight and power characteristics of electronics-based radio frequency components. The **Radio Frequency Lightwave Integrated Circuits** program will develop smaller, lighter, yet higher performance photonics-based radio frequency components capable of operating over a much broader range of radio frequencies, while also providing the form factors required by the small and rapidly mobile weapons platforms of the future. This program, which began in FY 2000, is identifying promising approaches to photonic components or enhanced radio frequency applications. The first year was spent developing radio frequency photonic modules that enable links with zero net radio frequency loss from input to output and demonstrating optically integrated modules capable of performing complex radio frequency functions. In FY 2001, the program is identifying key applications for integrated radio frequency photonic modules, producing initial prototypes, and demonstrating methods to evaluate their performance. In FY 2002, the program will integrate recently developed emitters, waveguides, detectors and integrated circuits to produce radio frequency photonic component prototypes.

## ADVANCED MATERIALS

DARPA's **Structural Materials** program is tailoring the properties and performance of structural materials to lower the weight and increase the performance of defense systems. Technologies are being pursued that will lead to ultra-lightweight ground vehicles and spacecraft through the use of structural amorphous metals or multifunctional materials. The program is also developing improved body armor for the individual soldier.

The **Multifunctional Materials** program explores materials that combine the function of structure with another critical system function (power, repair, ballistic protection, etc.). For example, in FY 2001 the program is demonstrating the use of fuel cells whose physical structure also serves as the functional structure for the system or platform, significantly reducing the parasitic weight of power generation in weight-sensitive micro air vehicles. An example is a micro air vehicle with a wing that is the structure, the antenna, and the fuel cell wall (hydrogen inside, air outside). In FY 2002, the program will investigate structures that combine ballistic protection with structure.

The goal of the **Lightweight Body Armor** program is to significantly reduce the weight of soldier body armor designed to stop 30 caliber armor piercing bullets to an aereal density of 3.5 pounds per square foot. Three ultra-lightweight body armor concepts, two of which use active armor techniques, are supported by the U.S. Army Training and Doctrine Command Systems Manager-Soldier. The DARPA program is the first to investigate how active armor systems could be safely and effectively employed for personnel protection. This year, the program is selecting the most viable concept for further development, with subsequent demonstration of an armor system by the Army planned for FY 2002.

The **Structural Amorphous Materials** program exploits the truly unique properties (toughness, strength, ballistic properties) of structural amorphous materials for critical defense applications such as ballistically resistant ship structures and as a replacement for depleted uranium in anti-armor projectiles. In FY 2001, we are developing approaches for processing these advanced materials in bulk at reasonable cost. In FY 2002, we will evaluate the properties of these materials in the context of making significant improvements for defense applications.

The objective of the **Mesoscopic Integrated Conformal Electronics** (MICE) program is to be able to create electronic circuits and materials on any surface, e.g., to print electrical circuits on the frames of eyeglasses or interwoven with clothing. The MICE program will provide a number of benefits to the DoD. The ability to print ruggedized electronics and/or antennas on conformal surfaces such as helmets and other wearable gear will provide new capabilities and functionalities to the future warfighter. MICE technologies will eliminate the need for solder, thereby greatly increasing the robustness of electronic circuitry, and the need for printed wiring boards, enabling significant weight savings for a number of military electronic platforms. To accomplish these objectives, the program is developing manufacturing tools that directly write or print electronic components such as resistors, capacitors, antennas, fuel cells, and batteries on a wide variety of substrates and with write speeds that approach or exceed commercial printing technologies – all at significantly decreased processing complexity and cost. Recent efforts have demonstrated the ability to print metal lines on curved surfaces, feature sizes as small as five microns, and print speeds close to one meter per second. One of the most exciting developments has been the demonstration of printed zinc-air batteries that have four times more volumetric power density than commercial batteries. With these demonstrations in hand, industry is moving forward with plans to use MICE tools for printing batteries, fuel cells, conformal antennas, and circuit interconnects. Plans for upcoming years include printing high-gain antennas on conformal surfaces, printing solar cells and fuel cells for integrating energy sources with the electronics, and making high-quality electronic parts at very low temperatures.

The **Smart Materials and Structures Demonstrations** program has applied existing smart materials in an appropriate device form to reduce noise and vibration and to achieve aerodynamic and hydrodynamic flow control in various structures of military interest. These devices can facilitate a paradigm shift for the design of undersea vehicles, engine inlets, aircraft wings, and helicopter rotor blades. Demonstrations have included small, high-bandwidth devices for acoustic signature reduction of marine turbo-machinery, shape memory alloy (SMA) actuators to control the shape and attitude of fighter inlets to achieve higher aerodynamic efficiencies and performance, flexible skins with embedded SMA wires that permit continuous control surface shape changes for improved aerodynamic performance (Smart Wing), and small, powerful actuators capable of fitting into the confined interior space of a rotating helicopter rotor blade for noise and vibration reduction (Smart Rotor). We are also exploring novel ways to make compact hybrid actuators that will employ smart material driving elements to create a new class of efficient, high energy density actuators in a package that is smaller and lighter than conventional hydraulic and electromagnetic actuators with similar power ratings. These new actuators could lead to considerable weight savings and reduced complexity and maintenance in smaller aircraft and have applications to the control of new types of hypersonic missiles. We concluded the marine and aircraft demonstrations earlier this year, and will conduct the final Smart Wing wind tunnel test of a scale-model unmanned combat air vehicle in the NASA Langley Transonic Dynamics Tunnel later this year. Construction of full-scale helicopter rotor blades in the Smart Rotor effort is currently underway, and wind tunnel and whirl stand tests are planned for late 2001. The overall goal of the Smart Rotor effort is to successfully demonstrate acoustic noise and vibration reductions in a flight test aboard an MD900 Explorer in early 2002.

The **Exoskeletons for Human Performance Augmentation** program is developing technologies to enhance a soldier's physical performance to enable him, for example, to handle more firepower, wear more ballistic protection, carry larger caliber weapons and more ammunition, and carry supplies greater distances. This will provide increased lethality and survivability of ground forces in combat environments, especially for soldiers fighting in urban terrain. Working with significant interest and technical input from the operational military, we are exploring systems with varying degrees of sophistication and complexity, ranging from an unpowered mechanical apparatus to full powered mechanical suits. The program is addressing key technology developments, including energy-efficient actuation schemes and power sources with a relevant operational life, active-control approaches that sense and enhance human motion, biomechanics and human-machine interfaces, and system design and integration. In

FY 2000, the program evaluated innovative actuation concepts using chemical energy sources such as hydrocarbon fuels to provide mechanical motion. In FY 2001, researchers are developing, characterizing and testing integrated technologies, activities that will continue in FY 2002.

Biomimetic technologies look for inspirations from biological systems to create hardware with superior capabilities. One focus of the biomimetics efforts in the **Controlled Biological and Biomimetic Systems** program is to explore the unique mobility offered by legged platforms. The program designed small, legged robotic vehicles (the size of a shoebox) for fault-tolerant mobility over rough terrain where wheeled and tracked vehicles often fail. Field-testing with the Marine Corps has demonstrated that these platforms have significant mobility in operational environments such as urban terrain where large obstacles and unplanned rough terrain impeded mobility. Preliminary assessment of the six-legged platforms called Rhex and Scorpion have shown superior performance in benchmarking tests against wheels and tracks and in operational environments of interest. The program now plans to explore developmental prototypes and define additional military utility for these legged robotic vehicles. We are interested in including additional fundamental principles of legged performance, new biomimetic structural and functional materials and enhanced software. The program will ultimately add sensor payloads for navigation and guidance and to perform specific military applications such as reconnaissance, or identification and removal of unexploded ordinance.

The **Functional Materials** program is developing non-structural materials and devices that enable significant advances in communications, sensing and computation for the military. Examples include: magnetic materials for high sensitivity, magnetic field sensors and non-volatile, radiation-hardened magnetic memories; light-emitting polymers for flexible displays; and frequency-agile materials based on ferrite and ferroelectric oxides for high sensitivity, compact tuned filters, oscillators, and antennas. In FY 2000, the program demonstrated light-emitting polymers for flexible displays with performances almost equivalent with inorganic alternatives. The program demonstrated a frequency-agile, lightweight patch antenna for UHF satellite communications that has 20 times less volume than existing antennas and, thus is suitable for low-profile mounting on the roof of military vehicles. We also developed a very low cost, high performance ferroelectric phase shifter for monolithic thin-film electronically steered antenna applications. In FY 2001, the program is expanding its work in electroactive polymers to include the development of thin-film spatial filters that will improve by a factor of 10 the speed and power requirements for sensors for missile defense. In addition, the program is exploring the development and application of artificially engineered nanocomposites or "meta-materials" for achieving electromagnetic properties unobtainable in nature. In FY 2002, the program will demonstrate actuators that mimic biological muscles for robotic applications and meta-materials concepts for a number of important DoD electromagnetic applications. The program will demonstrate a one-megabit, fully radiation-hard memory by the end of FY 2002. This memory will be competitive with conventional memories and will definitely replace some, if not all, of the existing random access semiconductor memories like Flash, Dynamic Random Access Memory (DRAM) and Static Random Access Memory (SRAM). This memory technology is transitioning to the Defense Threat Reduction Agency and the Navy Trident Program, and it is beginning to generate a significant amount of commercial investment.

The **Totally Agile Sensor Systems** (TASS) program is developing ultra-sensitive radio frequency receivers using high-temperature superconductivity (HTS) filters and low-noise amplifiers. This technology will provide the highest possible sensitivity for communications intelligence and signals intelligence missions pursued by the U.S. military and intelligence communities. The goal is to enable superconducting filters and amplifiers that can achieve up to 10 times the range compared to conventional means for detection of low-level signals. In FY 2000, the program investigated several methods to "tune" the frequency of HTS filters. In FY 2001, the program is working towards tunability of 30 to 50 percent of base frequency demonstrating a system to detect and geolocate sources of unintended radiation for the Rivet Joint aircraft. In FY 2002, the program will push tunability to 100 percent of base frequency, with automatic electronic selection within one millisecond. The program will consider using the technology for non-imaging identification and location of battlefield targets.

Current sensor system architectures sense signals from a physical stimulus, transduce them to electrical signals, convert the electrical signals to digital form for processing by computers, and finally extract critical information from the processed signals for exploitation. **Integrated Sensing and Processing** (ISP) aims to replace this chain of processes, each optimized separately, with new methods for designing sensor systems that treat the entire system as a single end-to-end process that can be optimized globally. The ISP approach is expected to enable order-of-magnitude performance improvement in detection sensitivity and target classification accuracy, with no change in computational cost, across a wide variety of DoD sensor systems and networks, from surveillance to radar, sonar, optical, and other weapon guidance systems. FY 2001 was the first year of funding for this program. In FY 2001, the program is developing new mathematical frameworks for global optimization of sensor system performance. In FY 2002, the program will implement physical and software prototypes of the new methodology in test bed systems such as missile guidance and automatic ground target recognition modules for validation and evaluation, and to support continuing iterative development of new design methods for sensor systems.

The **Virtual Electromagnetic Test Range** (VET) program will develop and demonstrate fast, accurate three-dimensional computational electromagnetic prediction codes enabling practical radar cross-section design of full-size air vehicles with realistic material treatments and details and components such as cavities, thin edges, and embedded antennas. Success will provide the predictive modeling phase of aircraft design with an order of magnitude savings in man-hours; two orders of magnitude reduction in computation expenses may be obtainable. An order of magnitude reduction in range and model costs is also predicted. The biggest impact of these new capabilities is likely to come in the form of cost reductions for modifications and upgrades to existing air vehicles. In FY 2001, the program is developing the capability to predict scattering from deep cavities, gaps, cracks, and thin edges with high fidelity. In FY 2002, it will demonstrate the capability for high fidelity prediction from multi-sensor apertures and arrays.

It has been long recognized that current and future battery technology will not provide sufficient energy to meet the requirements of military missions unless multiple batteries are carried throughout a mission, an incredible expense in logistics and mission effectiveness. This limitation could also significantly degrade the usefulness of emerging systems such as robots and other small unmanned vehicles. To address this issue, DARPA began the **Palm Power** program in FY 2001 with the goal of developing and demonstrating technologies to reduce the logistics burden for the dismounted soldier by developing novel energy conversion devices operating at 20 watts average power with 10 to 20 times the energy density of batteries. The program is examining several approaches that can convert high-energy-content fuels to electricity, with an emphasis on approaches that can use available military fuels. Among the technologies being considered are: direct oxidation solid oxide fuel cells; extremely compact fuel processors for integration with proton exchange membrane fuel cells; novel small engines; new approaches to solid state thermionic emission and thermoelectrics coupled to advanced miniature combustion systems; and advanced materials and materials processing. In FY 2002, the program will evaluate new materials and concepts to meet program goals.

## MEMS

**Micro-electromechanical Systems** (MEMS) technology enables ultra-miniaturization of mechanical components and their integration with microelectronics while improving performance and enabling new capabilities. The MEMS program has been focusing on developing integrated, micro-assembled, multi-component systems for applications such as aerodynamic control; 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. Over the last several years, many significant programs were established within DARPA that leverage MEMS technology. One such new activity is the **Micro Power Generation** program. The development of micro power sources will enable ultra-miniaturization and functionality of new standalone systems. The use of MEMS technology has already demonstrated size reduction, mass reduction, power reduction, performance enhancements, new sensing concepts and new functionality in weapon systems and platforms. Micro power sources will be the key components in ultimate miniaturization and integration of standalone, self-contained, wireless micro- sensors and micro- actuators that can be deployed remotely in clusters to drastically enhance superiority of weapon systems and field awareness. Another new activity is the **Nano Mechanical Array Signal Processors** (NMASP) program. The development of NMASP will enable ultra-miniaturized (the size of a wristwatch or hearing aid) and ultra low-power UHF communicators/GPS receivers, greatly improving the mobility and location identification of individual warfighters. NMASP technologies will deliver these new component level technologies, as well as new methods for production of mass spectrometers, calorimeters, bolometers, and high-resolution infrared imaging devices.

The objective of the **BioFluidic Chips** (BioFlips) program is to demonstrate technologies for self-calibrating, reconfigurable, totally integrated bio-fluidic chips with local feedback control of physical and chemical parameters and on-chip, direct interface to sample collection. In FY 2000, its first year, BioFlips identified promising microfabrication platforms to integrate fluidic chip components and developed several subsystem approaches to achieve system specifications. The program used advanced modeling of microscale fluidics to evaluate these subsystem designs. In FY 2001, BioFlips is developing closed-loop bio-fluidic chips to regulate complex cellular and molecular processing through the integration of individual biomolecular transport components and *in situ* sensors for local feedback control of the fluid parameters. In FY 2002, the program will demonstrate optimization of subsystems and components for integration into prototype systems. Examples of prototype systems include micro flow cytometers that are the size of a wristwatch, a sample preparation microsystem that extracts purified DNA from whole blood samples, and a wristwatch-sized physiological monitor that can acquire body fluids through the skin for measuring blood gas partial pressures, pH, glucose, and hematocrit.

## BIOFUTURES (BIO:INFO:MICRO)

DARPA's investigations at the intersection of biology, information technology and the physical sciences (Bio:Info:Micro) began in FY 2001 with the realization that the biological sciences, when coupled with the traditional strengths of DARPA in materials, information and microelectronics, could provide powerful approaches for addressing many of the most difficult challenges facing DoD in the next 15 to 20 years. Chief among these challenges is preventing human performance from becoming the weakest link on the future battlefield. For example, DoD must be able to maintain the decision-making and fighting capability of the soldier in the face of asymmetric attack (e.g., biological warfare defense), stress and increasingly complex military operations. We will explore and develop new capabilities and methods for performing complex military operations by applying what we learn from the models provided by living systems, which function and survive in a complex environment and adapt, out of necessity, to changes in that environment. In short, the combination of biological science and technology offers an avenue into the understanding – and development for defense applications – of systems that are capable of complex, robust, and adaptive operations using fundamentally unreliable components.

As we proceed with the Bio:Info:Micro initiative, two development themes emerge that have become our organizing principles: critical human factors for future warfighting, and complexity in military operations. The proliferation of technology on the battlefield and the open-market availability of extremely capable weaponry are dramatically shortening the timelines for critical decision-making while increasing the complexity of the battlespace. The tools we develop at the intersection of biology, information technology, and the physical sciences will enable radically new command capabilities to deal with this increased complexity in warfare, while addressing the increasing demands being placed on our warfighters.

*Critical Human Factors for Future Warfighting:* Human physical and cognitive limitations often constrain technological superiority and superior warfighting, especially in a future battlespace that will continue to increase in complexity and tempo. A major thrust for DARPA's **Biological Science and Technology** program is to explore solutions to extending human performance. Solutions include extending physical and cognitive performance during the stress of military operation, and interacting with complex, teleoperated, semi-autonomous, and autonomous systems. The program is exploring biological principles and practices to enable new capabilities to sustain or extend human performance for future warfighting. The program will investigate therapeutics, sensors, materials, neural and mechanical interfaces, biological or biomimetic controllers, and learning, memory and training.

*Complexity in Military Operations:* Military operations and systems are increasing in complexity. DoD must explore new solutions able to maintain superior performance in spite of increased complexity. Living systems demonstrate robust solutions as they operate in a complex world by optimizing performance through adaptive evolution. A major thrust at DARPA will be to explore and develop new capabilities to perform complex military operations based on the principles and practices of biology. Of particular interest to DoD are biological capabilities for: regenerative, cooperative, or redundant processes and materials; information processing; pattern recognition and decision analysis; target identification and acquisition; maneuverability and navigation; stability in wide environmental extremes; and communication of singular or networked systems.

Three programs illustrate DARPA's emphasis on human factors and complexity in military operations:

The **Metabolic Engineering for Cellular Stasis** program is investigating biological practices that allow organisms to adapt to environmental extremes (water, temperature, salt) and using these practices to engineer new cellular systems such as platelets and red blood cells. In FY 2000, this revolutionary effort demonstrated the functional recovery of dry platelets and other cells that could be used in therapeutic or diagnostic applications for

DoD. Future efforts will focus on new engineering methods and practices that result in the enhanced stabilization of cells and tissues.

The **Bio-Computation Program** is exploring and developing computational methods and models at the bio-molecular and cellular levels for a variety of DoD and national security applications. The program is developing powerful, synthetic computations that can be implemented in bio-substrates, and computer-aided analytical and modeling tools that predict and control cellular processes and systems of living cells. The DoD applications of the program include the ability to predict cellular-level effects of chemical and biological agents and the underlying pathogenic processes; the effect of stress on cell functions (such as circadian rhythms) that affect warfighter performance; and mechanisms for controlling these effects. We are selecting performers in FY 2001. In FY 2002, the program will begin to develop scalable, DNA-based computing and storage and computational models that capture the behavior of mechanisms in living cells underlying pathogenesis and rhythms that are common to many organisms.

The **Simulation of Bio-Molecular Microsystems** (SIMBIOSYS) program is developing innovative interfaces between molecular-scale processes in chemistry, biology and engineering (electronics, optics, MEMS) through experimental and theoretical analyses. The program is beginning this year by developing experiments, models, phenomenological relationships and scaling laws for a range of bio-molecular recognition processes (i.e., antigen-antibody, DNA hybridization, enzyme-substrate interactions) and bio-fluidic transport processes in microsystems. In FY 2002, SIMBIOSYS will develop methods to transduce these molecular recognition signals into measurable electrical/optical/mechanical signals through integrated on-chip elements that interface with the biological recognition process. We will characterize and quantify innovative transduction (and signal amplification) methods through experiments and models.

## Beyond Silicon Complementary Metal Oxide Semiconductors

We are approaching the end of a remarkably successful era in computing – the era in which Moore's Law reigned and where processing power per dollar doubled every year. In large part, this success was a result of advances in complementary metal oxide semiconductor (CMOS)-based integrated circuits. Although we have come to expect, and plan for, the exponential increase in processing power in our everyday lives, today Moore's Law faces imminent challenges both from the physics of deep-submicron CMOS devices and from the enormous costs of next-generation fabrication plants. This situation requires DoD to consider a radically different approach to the fabrication of logic and memories – a program we call Beyond Silicon CMOS.

The Beyond Silicon CMOS thrust is starting in FY 2001. The initiative is aimed at maintaining the phenomenal progress in microelectronics innovation that has served military systems designers so well over the last 30 years. Taking advantage of advanced materials deposition and processing techniques that enable increasing control over material and device structures down to nanoscale dimensions, the Beyond Silicon MOS initiative will enable low-cost-to-manufacture, reliable, fast, and secure information systems critical to meet future military needs. Because the transistors can be made so small, we can make chips with a very large number of transistors per chip, which allows greater fault tolerance and high speed (future microprocessors based on these technologies will run at speeds 10 to 100 times faster than today's best gigahertz-level clock rates). And, with the resulting greater computational power, we will be able to run more complex algorithms to improve security. In the case of the ultimate computers that exploit quantum mechanical effects, we will be able to make use of physical phenomena not available in today's electronic devices to achieve computational capabilities unavailable by traditional techniques.

With a goal to develop new device capabilities, DARPA is exploring options such as non-silicon-based semiconducting materials, including organic and amorphous materials. Components and systems leveraging quantum effects, and innovative approaches to computing designs incorporating these components, will allow low-cost, seamless, "pervasive computing" (making generally available the kind of computing power normally associated with large computing facilities); ultra-fast computing; and sensing and actuation devices. Much as today's desktop computers have the power of the super-computers of a decade or so ago, these chip-scale computers will enable super-computer-like capabilities in portable machines. The military impact could be, for example, to enable a computationally intense synthetic aperture radar capability on a small unmanned air vehicle.

The Beyond Silicon CMOS thrust is composed of five programs that will develop new capabilities from promising information processing components using both inorganic and organic substrates and components and systems leveraging quantum effects and chaos.

The first of the Beyond Silicon CMOS programs is **Antimonide Based Compound Semiconductors** (ABCS). Its goal is to develop low-power, high-frequency electronics circuits and infrared sources based on the antimonide family of compound semiconductors. Specific goals include circuits with over $10^4$ devices per circuit operating at frequencies above 100 gigahertz and consuming less than one femtowatt ($10^{-12}$ Joules per second) – a two-order-of-magnitude improvement over today's capabilities (i.e., 10 times faster, consuming one-tenth the power). Specific infrared source goals include operating above thermoelectric-cooled temperatures, with much greater efficiency for continuous wave, mid-wave infrared and single-mode operation in the long-wave infrared range. In FY 2001, this program is demonstrating non-silicon-based transistor technologies and nanostructured materials for quantum-based electronic and optoelectronic device applications. In FY 2002, ABCS substrate technology will accelerate recent breakthroughs in lateral epitaxial overgrowth and thin-film delaminating and rebonding to develop a source for ABCS substrates with essentially any desired thermal or electronic property.

Another program is **Integrated Mixed Signal Analog/Digital and Electronic/Photonic Systems** (NeoCAD) with a goal of developing and demonstrating innovative approaches to computer-aided design of mixed signal (analog/digital) and mixed electronic/photonic systems. The objective is to design and prototype the ultra-complex microsystems having the high degree of integration and complexity needed for military and commercial applications. In FY 2001, NeoCAD is developing fast algorithms for non-linear analysis of mixed signal systems (analog and photonic devices), and the program is extending algorithm methods to non-linear problems. In FY 2002, NeoCAD will develop model order reduction methods (for analog and photonic devices) to enable the creation of device behavioral models, and will develop and demonstrate top-down design capabilities for analog, mixed signal and mixed electronic/photonic systems that match the efficiency currently achieved with digital-only designs.

The goal of the **Spins In Semiconductors** program is to change the paradigm of electronics from electron charge to electron spin. This can have profound impact on the performance (speed and power dissipation) of memory and logic for computation and for optoelectronics for communications. We can ultimately expect increases in both storage densities and processing speeds of at least 100 to 1000 times. This will give the warfighter the ability to process and assimilate much more data than possible by other means and make him much more situationally aware. Many DoD systems will also benefit from this significantly enhanced performance by enabling much more sophisticated signal processing by allowing our systems to handle significantly more data. For example, if we are successful, we will provide orders of magnitude more flexibility to our remote sensing assets. The program has already demonstrated long-lived electron spin coherence in semiconductors, which translates to very long spin-propagation distances. In FY 2001, we will demonstrate that spin information can propagate across boundaries between different semiconductors in a heterostructure without any loss of spin information. In FY 2002, we intend to demonstrate a very high-speed optical switch using spin precession to control optical polarization.

The **Polymorphous Computing Architectures** program is developing a revolutionary approach to implementing embedded computing systems that support reactive, multi-mission, multi-sensor, and in-flight retargetable missions and reduce the time needed for payload adaptation, optimization, and verification from years to days to minutes. This program breaks the current development approach of "hardware first and software last" by moving beyond conventional computer hardware and software to flexible, polymorphous computing systems. This program is just beginning and is identifying reactive, in-mission computing requirements and potential polymorphous computing concepts in FY 2001. In FY 2002, the program plans to model and evaluate candidate polymorphous computing architectures.

The **Quantum Information Science and Technology** (QuIST) program is developing information technology devices and systems that leverage quantum effects and technologies for scalable, reliable, and secure quantum computing and communication. Quantum computers and communication systems are potentially much more capable and secure than today's systems and can serve DoD's increasing need for secure communication and computational power to meet the stringent requirements of military data and signal processing. The QuIST program begins this year with investigations of components and architectures of quantum information processing systems, along with algorithms and protocols to be implemented on those systems. In FY 2002, the program will demonstrate techniques for fault-tolerant computation and secure communication, and will demonstrate components of quantum photonic communication systems.

In a revolutionary departure from today's painstaking circuit fabrication methods, the **Molecular-scale Electronics** (Moletronics) program is pursuing the construction of circuits using nanoscale components such as molecules and inexpensive chemical self-assembly processes. These chemically assembled systems will have high device density (scaleable to $10^{11}$ devices per square centimeter, about 100 times that of current silicon integrated circuits) and low power. It is now realized that requirements for electrical power drive much of the information-age infrastructure, placing ever greater need to obtain low-power electronic systems. In FY 2001, the program demonstrated both the ability to reversibly switch memory molecules at room temperature, the "tools" of computation ("AND," "OR" and "NOT" gates), and a working 16-bit memory at 10 times the density of silicon Dynamic Random Access Memory (DRAM). In FY 2002 and 2003, we will optimize the performance of the molecular devices, demonstrate a molecular gain device, increase device density, and develop innovative architectures that exploit the unique properties of switching on the molecular scale to demonstrate the advantages of electronics on this scale.

# Conclusion

Both President Bush and Secretary Rumsfeld continue to highlight the need to take advantage of new possibilities offered by the ongoing technological revolution, as well as to develop defenses against modern technological threats. I hope that this short summary of DARPA's investment strategy has outlined how DARPA stands ready to do both – provide technological opportunities for our warfighters, and harness technology to provide advanced defenses. Our proposed program, of course, will have to change as the nature of the threat changes, and as the strategy for coping with those threats evolves. I thank you for the opportunity to speak with you today, and welcome your questions.

# Appendix – Examples of DARPA's Science and Technology Investments in Support of our Warfighters

The **Affordable Multi-Missile Manufacturing** (AM3) program, a five-year, DARPA/Tri-Service initiative, was structured to attack rising missile costs with a combination of process and product changes to reduce the cost and cycle times for tactical missile manufacturing. The results are being felt in over 13 military systems, including: a common inertial measurement unit for the Wind Corrected Munitions Dispenser; commercial parts activities for the Low Cost Autonomous Attack System and Army Tactical Missile System; flexible manufacturing systems for Patriot Advanced Capability-3; electronic procurement for Line-of-Sight Anti-Tank weapons; common test approaches for the Evolved Sea Sparrow Missile (ESSM) and Stinger; multi-missile factory approaches for the AIM-9M Sidewinder, the Rolling Airframe Missile, ESSM, Javelin, and BAT brilliant anti-armor submunition; and improved software tool approaches for BAT and the Advanced Precision Kill Weapon System.

The DARPA **Compact Lasers** program was developed to defend aircraft against heat-seeking missiles. The diode-pumped, mid-infrared, solid-state laser technology developed in the program has been selected to provide the multi-band laser for the Air Force's Phase I Large Aircraft Infrared Countermeasure program. This program's purpose is to protect large aircraft from all currently fielded man-portable heat-seeking missiles. Phase I of the program will outfit large transport aircraft such as the C-17 and the C-130 with defensive systems that use the DARPA-sponsored lasers.

For many airborne systems involving video or infrared sensors, a window protects the sensor from the environment. Flat or gently curved windows can cause drag and other degradations to platform performance. In the **Precision Optics** program, the window is shaped to meet the needs of the aerodynamic environment, rather than forced to fit commonly used optical shapes for aircraft and missiles. This reduces the aerodynamic drag, which will increase the range or velocity of the missile, and maintains low observability. Precision Optics technologies were demonstrated in an advanced variant of the Stinger missile. This variant of Stinger, like all other electro-optic/infrared guided missiles, had an aerodynamically blunt, hemispherically shaped dome. Using Precision Optics technology, the new seeker head incorporated an ellipsoidal-shaped dome for reduced aerodynamic drag and used correctors to compensate for the look-angle-dependent aberrations. The seeker successfully acquired and tracked targets at Redstone Arsenal, AL. The Army and Navy are conducting development efforts to use the DARPA technology in advanced missiles.

The **Moving and Stationary Target Acquisition and Recognition** (MSTAR) program has improved advanced automatic target recognition capabilities using the one-foot resolution synthetic aperture radar imagery that is increasingly available from operational platforms. The MSTAR algorithms were evaluated as a component of the Semi-Automated Imagery Intelligence Processor (SAIP) system by replacing SAIP's original automatic target recognition algorithms with the model-based MSTAR algorithms. The MSTAR algorithms have demonstrated correct detection rates of 90 percent or better, and identification rates of detected targets of 80 percent or better. The MSTAR-enhanced SAIP system assists an analyst in forming reports and identifying target types among a set of more than 30 modeled target types. SAIP has transitioned to a Joint Program Office in the Army Space Program Office, which is integrating SAIP capabilities into the operational Tactical Exploitation System.

The **GPS Guidance Package** (GGP) program has developed a smaller, lower-cost, long-life navigation system based on highly integrated fiber optic gyros, silicon accelerometers, and miniature GPS receivers. The Army is testing the GGP this Spring as an improvement for the Multiple Launch Rocket System firing unit. The adoption of GGP will give the Army the pointing accuracy it needs for its fire support at a fraction of the lifecycle cost of the current Army system.

As U.S. tactical aircraft engage a target, the radars of an adversary's integrated air defense system may track them. DARPA has developed the low-cost **Miniature Air-Launched Decoy** (MALD) to confuse these defenses. This program achieved its affordability objective, an average unit flyaway price of $30,000 (FY 1995 dollars) if 3000 units are produced. This price is many times lower than currently available air-launched decoys, and MALD's deception performance will be very effective in confusing air defense systems. MALD program management has been successfully transferred to the Air Force, with flight-testing continuing this year. The Air Force is planning a "Silver Bullet" procurement of 100 to 150 MALD units beginning in FY 2002.

In the detection and identification of biological warfare agents, antibody-based sensors have traditionally had difficulty distinguishing between the organism that causes anthrax and other naturally occurring, non-pathogenic relatives within the same genus. Under DARPA sponsorship, researchers have developed a set of antibodies that are highly specific to anthrax, but not to its non-pathogenic relatives. Currently, four of these **Anthrax Antibodies** are being evaluated by the U.S. Army Chemical and Biological Defense Command (Edgewood Area, Aberdeen Proving Ground, MD) as a possible replacement for the anthrax antibodies in DoD antibody-based sensors. This will decrease the possibility of false alarms caused by cross-reactivity of the antibodies that identify the bioagent.

Another DARPA development is of new antibody-binding reporting material called **Upconverting Phosphors** (UPT™) for use in sensors for biological warfare agents. Many conventional sensors use fluorescent tags to report the presence of a biological warfare agent as manifested by a binding event taking place (e.g., antibody-to-antigen binding), but the tags have several shortcomings. Fluorescent tags absorb and emit light in similar wavelengths, so signal-to-noise problems limit sensor sensitivity. In addition, only a few separate tags (different fluorescent wavelengths) exist. On the other hand, the UPT™ materials are engineered with a novel arrangement of energy states to allow absorption and emission in widely different wavelengths, allowing much greater sensitivity. Also, 18 separate UPT™ tags have been developed. The UPT™ materials are currently under evaluation by the Joint Program Office-Bio Defense for suitability as a replacement to the fluorescent tags in the currently fielded "Smart Ticket" sensors.

The DARPA **Enhanced Consequence Management Planning and Support System** (ENCOMPASS) has been transitioned to the Crisis Consequence Management Initiative (CCMI) laboratory located at Space and Naval Warfare Systems Center-San Diego, CA (SSC-SD). CCMI is responsible for other DoD projects that involve aerial surveillance and intelligence support. The CCMI laboratory is currently working in cooperation with Joint Forces Command to install the ENCOMPASS components in support of their mission for Homeland Defense. DARPA's ENCOMPASS investment has led to the development of a commercially available software program for overall resources management for crisis response. Key components of the ENCOMPASS program have been tested at *Pacific Warrior* and the Air Force Information Warfare BattleLab in San Antonio, TX. In addition, the Air Force's Lightweight Epidemiology Advanced Detection and Emergency Response System (LEADERS) uses key components of ENCOMPASS and will be installed at Wilford Hall Medical Center and Brooks Air Force Base, San Antonio, TX. The Air Force Surgeon General's office is also in the process of installing LEADERS at Air Combat Command, Langley, VA, and Walter Reed Army Medical Center, Washington, DC.

DARPA has helped in the development of a new Navy transition laboratory, the Concept Exploration Laboratory (CXL), that focuses on technology for military medicine. This facility is located at SSC-SD, with experts in operational planning from the Naval Health Research Center and SSC-SD. The CXL vision is to become the focal point for all advanced medical technology for testing and evaluation before prototypes are transitioned to the Fleet. CXL is working closely with the Pacific Command to support *Cobra Gold* in Thailand and the *Kernel Blitz Experiment* at Camp Pendleton, CA, in June 2001.

The application of fiber-optic technology to high-capacity data-links for electronic warfare, radar and related applications offers a substantial advantage in terms of increased data-handling capability and reduced size and weight over that of existing copper cabling. DARPA's **photonics** programs have developed technologies for efficient, low-cost manufacturing of optoelectronic components that interface electronic subsystems to fiber cabling. These technologies, such as vertical cavity surface emitting lasers, have resulted in a suite of optoelectronic technologies that are being considered for future insertion into platforms. In particular, the Navy's Fiberoptic Roadmap initiative and the Navy's planned upgrade for the EA-6B aircraft are making use of much of the technology developed in these DARPA photonics programs.

Over the past year, DARPA's **Advanced Microelectronics** program has demonstrated an impressive array of results in technologies for ultra-short channel transistors, including the fabrication of silicon switching devices with useful electrical characteristics and having the world's shortest channel length (10 nanometers). In addition, this program also demonstrated a fabrication process that uses only conventional equipment to produce transistors with 25 nanometer features (180 nanometers is current state-of-art in production). These short-channel transistors have unconventional device structures but are compatible with ultra large-scale integration into dense integrated circuits. Electrical measurements show that these new transistors are also very fast, attaining switching speeds in the few picoseconds range, thereby enabling future signal processing chips to operate at speeds on the order of 10s of gigahertz. Several other agencies – the National Reconnaissance Office, National Security Agency, and the Defense Threat Reduction Agency – are now collaborating with the AME program contractors to investigate applications of this nanoscale technology.

The Anti-Torpedo Torpedo (ATT) is a new Navy approach to counter-torpedo attack that has significant volume constraints for control electronics. A **MEMS-based Torpedo Exploder** package offers the required performance in a volume compatible with the ATT design. The exploder incorporates two MEMS devices that have been developed over the past three years, a combination flow sensor/accelerometer and an actuator. The MEMS-based ATT has recently undergone two successful sea trials and the Navy has made the decision to continue development. The availability of DARPA's MEMS exploder was one key enabler for this Navy program.

In the area of smart munitions, over the past several years two complimentary DARPA programs have developed **MEMS Inertial Measurement Units** (IMUs) for use in the guidance package for artillery shells. These MEMS IMUs provide required guidance in a small package capable of withstanding the 50,000 Gs shock experienced when the shell is fired. Following the DARPA demonstration of the capabilities of the MEMS IMU, both the Navy and Army have programmed funds for additional development leading to production.