DARPA FACT FILE

A Compendium of DARPA Programs

April 2002

FORWARD

Purpose: DARPA's charter is to prevent technological surprise from harming U.S. national security by sponsoring revolutionary and innovative high-payoff research. This document provides short summaries of selected DARPA programs in FY 2002 and FY 2003, and it is intended as a ready reference for those interested in DARPA's research portfolio. To better illustrate the goals of the programs, the programs have been grouped into three broad areas, each with various sub-areas:

- **National Level Problems –** Find solutions to urgent, difficult and dangerous threats to U.S. national security, which require an in-depth response beyond that of the Military Services;

- **Operational Dominance –** Develop advanced systems and technologies that leapfrog current capabilities and threats to give U.S. Forces a decisive edge; and

- **High-Risk, High-Payoff Technologies –** Create technological advances that will enable quantum leaps in military capabilities.

There are indexes in the back of the document for finding individual programs and cross-referencing them to Program Elements in the President's FY 2003 budget.

TABLE OF CONTENTS

National-Level Problems

Programs in this area are aimed at finding solutions to urgent, difficult, and dangerous threats to U.S. national security, which require an in-depth response beyond that of the Military Services. In particular, these programs are meant to counter asymmetric and transnational threats, such as terrorist, biological warfare, or information attacks, and maintain unhindered U.S. access to space.

DARPA Support for the Global War on Terrorism

Operation Enduring Freedom

Since September 11, the war on terrorism has been foremost in everyone's minds. Several DARPA technologies are being used to support Operation Enduring Freedom.

Water Purification: Warfighters are testing 6-inch-long pen-sized water purification kits developed by DARPA that consume plain salt tablets and purify up to 300 liters of water on a single camera battery.

Automatic Phrase Translators: In Afghanistan today, warfighters are using hand-held machine phrase translation devices that support direct operations, such as force protection, medical triage, and refugee re-unification; the devices are deployed at our embassy and with forces in the field. These systems support such local native languages as Pashto, Urdu, and Dari. While this one-way technology was militarily hardened and delivered in just 90 days, the follow-on effort, producing a task-constrained two-way speech translation capability, will have its first prototype in the hands of warfighters and embassy staff before the end of this fiscal year, a functional capability that simply does not exist anywhere today.

Rapid Network Tool: In early 2000, DARPA and the Air Force launched a joint experiment to address critical Link 16 network shortfalls demonstrated in Kosovo. This experiment had very rapid payoff with DARPA-developed software tools now being used in Operation Enduring Freedom to reconfigure a theater-wide Link 16 network for military aircraft in a few hours – a task that previously took many weeks.

Rapid Planning: The **Active Templates** program, working in close collaboration with the Joint Special Operations Command, has developed the software tools-of-choice for special operations command and control. These tools allow military planners to sketch out plans against a time-line or with a map or image in the background, merge plans from other teams that are connected to the network, de-conflict and coordinate changes as plans solidify, and then use these same tools to track the progress of the battle during mission execution. Time-and-motion studies show that these tools speed planning by a factor of four, buying time for rehearsal and critical decision-making. These prototype tools were advocated for use following several successful special operations exercises in FY 2001. In October, they were deployed and have been used continually to support combat operations in Operation Enduring Freedom.

Operation Noble Eagle

On the American homefront, DARPA technology has been used in homeland defense, Operation Noble Eagle.

Medical Surveillance: The Air Force's Lightweight Epidemiology Advanced Detection and Emergency Response System (LEADERS) uses key components of DARPA's Enhanced Consequence Management Planning and Support System. A commercialized version of the DARPA bio-surveillance program, LEADERS, provided medical surveillance for signs and symptoms of a biological attack for the state of New York within 24 hours of the attack on the World Trade Center. The Centers for Disease Control also used LEADERS to monitor for specified syndromes from hospitals within in the New York City area and report them back in real-time to the Centers for Disease Control and Prevention in Atlanta via the Internet.

Capitol Hill Remediation: As a result of DARPA's investments in the **Immune Building** program, DARPA was asked to serve as science advisors to the team responsible for the anthrax decontamination on Capitol Hill. DARPA was asked to review decontamination technologies and, in support of this request, we also conducted quick-turnaround testing on three separate candidates to determine efficacy. The chlorine dioxide approach developed under Immune Buildings was selected for the challenging job of remediating the Hart Senate Office Building. In addition, DARPA helped identify and obtain air sampling equipment to support the Environmental Protection Agency and the Centers for Disease Control and Prevention efforts to verify that the buildings were safe for reoccupation. DARPA has also supported Congress by developing, installing, and testing mail-screening equipment to prevent additional contamination from entering the buildings through the mail system.

Advanced Airport Security: Following the September 11 aircraft hijackings, the Secretary of Defense directed DARPA to conduct a study of aviation security aimed at the future needs of our country. DARPA sought information from a wide variety of Government agencies, Defense contractors, commercial vendors, and Federal laboratories, as well as from individuals with no previous aviation security experience. The outcome of the study recognizes that substantial organizational, procedural and technical challenges exist. Proposed solutions range from straightforward engineering tasks that may satisfy near-term security needs, all the way to those that may require scientific breakthroughs in order to assure protection against an evolving threat. DARPA is now working closely with agencies, such as Transportation Security Agency, Federal Aviation Agency, Department of Transportation, Immigration and Naturalization Service, and the Office of Homeland Security as they work to develop and implement more capable security operations.

Information Awareness

The DARPA Information Awareness Office (IAO) is the focal point for DARPA's effort to develop and demonstrate information technologies and components, and prototype closed-loop information systems. These information systems will counter asymmetric threats by achieving total information awareness useful for preemption, national-security warning, and national-security decision-making.

The most serious asymmetric threat facing the U.S. is terrorism. This threat is characterized by collections of people loosely organized in shadowy networks that are difficult to identify and define. These networks must be detected, identified, and tracked. IAO plans to develop technology that will allow understanding of the intent of terrorist networks, their plans, and potentially define opportunities for disrupting or eliminating the threats.

To effectively and efficiently carry this out, technology must be developed that will promote sharing, collaborating, and reasoning to convert nebulous data to knowledge and actionable options. IAO will accomplish this by pursuing the development of technologies, components, and applications to produce a prototype system.

Today's intelligence infrastructure was designed for the Cold War and is well-suited to major military conflicts and strategic threats. However, our information about foreign terrorists is spotty at best – and our efforts to integrate and extend current intelligence systems is unlikely to provide sufficient coverage. Foreign terrorists do not require large numbers to cause great damage, nor must they attack us frequently to influence us: they are low-density, low-intensity combatants. Commercial information technology provides foreign terrorists with cheap, effective communications, planning data, and command and control capabilities – as good as most governments. The availability of biological and chemical weapons, in addition to novel methods of attack, pose a broad and continuing threat to the U.S.

To address today's threat, we need to turn information technology around and use it against foreign terrorists, gathering so much information on them that we can predict and preempt attacks – or, at the very least, strike back with speed, certainty, and finality. The kind of information we need today differs significantly from what we needed during the Cold War. We will need much more information, from both "traditional" intelligence sources and many more sources in addition, and we will need to filter this information to protect the privacy of U.S. citizens and innocents world-wide. We will also need new technology for effectively managing all this information and for reducing the cost of building the many new specific systems required to capture information. Because raw data must be interpreted, we need a collection of automated and semi-automated technologies that amplify the efforts of human analysts to provide greatly improved attack prediction and preemption capabilities. Finally, we need more effective methods for sharing information between Government agencies – capabilities for rapidly assembling teams of people with the right experience and relationships by means of effective tools that support collaboration across organizational boundaries. DARPA's Information Awareness Office was established to create component technologies to address these needs.

Example technologies of interest to IAO are:

- Collaboration and sharing over TCP/IP networks across agency boundaries;
- Large, distributed repositories with dynamic schemas that may be changed interactively by users;
- Foreign language machine translation and speech recognition;
- Biometric signatures of humans;
- Real-time learning, pattern-matching, and anomalous pattern detection;
- Human network analysis and behavior model building engines;
- Event prediction and capability development model building engines;
- Change detection; and
- Biologically inspired algorithms for agent control.

DARPA's information awareness programs will leverage other DARPA investments in information and other relevant technologies. DARPA plans to work closely with the Intelligence Community, other agencies of the national security community, and other relevant agencies of the U.S. Government.

The **Total Information Awareness** (TIA) program will develop and integrate information technologies into a prototype system to detect, classify, and identify potential foreign terrorists so that we may have a better understanding of their plans, thereby increasing the probability that the U.S. can preempt adverse actions.

The TIA program will integrate technologies developed by DARPA (and elsewhere, as appropriate) into a series of increasingly powerful prototype systems that can be stress-tested in operationally relevant environments using real-time feedback to refine concepts of operation and performance requirements down to the component level. The ultimate goal is to create a counter-terrorism information system that: (i) increases the information coverage by an order-of-magnitude and can be easily scaled; (ii) provides focused warnings within an hour after a triggering event occurs or an evidence threshold is passed; (iii) can automatically cue analysts based on partial pattern matches and has patterns that cover 90 percent of all known previous foreign terrorist attacks; and (iv) supports collaboration, analytical reasoning, and information sharing so that analysts can hypothesize, test, and propose theories and mitigating strategies about possible futures so that decision-makers can effectively evaluate the impact of current or future policies.

DARPA will work in close collaboration with one or more U.S. intelligence agencies that will provide operational guidance and evaluation and will act as a technology maturation and transition partner. In the near-term, this collaboration will take place within the U.S. Army Intelligence and Security Command. TIA's focus is on developing usable tools, rather than conducting demonstrations. The program intends to create fully functional, leave-behind prototypes that are reliable, easy to install, and packaged with documentation and source code (though not necessarily complete in terms of desired features) that will enable the Intelligence Community to evaluate new TIA technology through experimentation and rapidly transition it to operational use, as appropriate.

Below, we describe the component programs that contribute to TIA:

Project **Genoa**, which is 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 tool to users on Intelink. The tool, "Athens," complements traditional search engines by allowing users to find nuggets of information in large collections of documents without having to construct a complicated query. A thematic search engine is more efficient for two reasons. First, it allows the user to specify keywords one at a time and exposes the search index by providing all related keywords and the amount of information that would be returned at each step. Users can build search queries incrementally, selecting additional search terms from a list – there is less information to sift through to find the information one needs, and one never gets 10,000 hits on a query, which is the frequent result of using ordinary search engines. Second, a thematic search engine also reduces the information returned by breaking up HTML pages into smaller units, e.g., paragraphs or a few sentences. With a standard search engine, the smallest unit of information is a complete page, even though, most of the time, an analyst's question is very specific. With the standard engine, the analyst has to scan a lot of irrelevant information to find the desired bit.

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 were delivered to the Office of the Secretary of Defense and Joint Staff Directorate for Intelligence, the Joint Information Operations Center, the Joint Forces Command, the U.S. Pacific Command, and the Joint Counter-intelligence Assessment Group (JCAG). JCAG is now actively using Genoa capabilities to support and enhance its own critical mission. Furthermore, JCAG is using these same capabilities to support other Federal agencies involved in the war on terrorism, most notably the Department of Justice's Foreign Terrorist Tracking Task Force. The use of DARPA-developed capabilities to counter and preempt foreign and domestic terrorist threats is an excellent example of how sustained investment in science and technology provides support to the warfighter. In FY 2002, these transition activities will be completed.

Project **Genoa II**, part of DARPA's Total Information Awareness program, will focus on the information technology support needed by teams of intelligence analysts and operations and policy personnel as they attempt to anticipate and preempt asymmetric threats to U.S. interests. The U.S. Government has been slow to change concept of operations and to assimilate new information technologies for this purpose. Needed are faster systems of humans and machines, ways to overcome the biases and limitations of the human cognitive system, "cognitive amplifiers" that help teams of people rapidly and deeply understand complicated and uncertain situations, and a breaking-down of existing stovepiped information repositories. Genoa II will respond with elements aimed at making the teams faster, smarter, and "more joint." The project will apply automation to team processes so that more can be accomplished sooner – more information will be exploited, more hypotheses created and examined, more models built and populated with evidence, and, in the larger sense, more crises situations dealt with simultaneously. It will develop and deploy cognitive aids that allow humans and machines to think together about complicated problems, especially new and deadly asymmetric challenges intended to bypass our existing national security apparatus. Genoa II's products will be deployed to the U.S. Army Intelligence and Security Command.

The **Genisys** program will produce technology for an ultra-large, all-source information repository to help prevent foreign terrorist attacks on the citizens, institutions, and property of the U.S. and its allies. To predict, track, and thwart (or, at least, mitigate) attacks, the U.S. needs a full-coverage database that includes information about all potential foreign terrorists and possible supporters, terrorist material, training/preparation/rehearsal activities, potential targets, specific plans, and the status of our defenses. Current database technology is clearly insufficient to address the need to integrate all relevant existing databases and semi-structured information sources, to automatically populate the new repository with many different and non-traditional data-feeds, and to enable the easy creation of new information systems, which today exist only in manual form. Today's database technology was defined in the 1980s, but current processors, disks, and networks are a thousand times more capable. Genisys will reinvent this technology to meet today's needs and capabilities.

In contrast to today's relational databases, Genisys will: (i) require no *a priori* data modeling and use a simpler query language, making it easier to dramatically increase the information coverage we now know we need to stop foreign terrorists; (ii) support automated restructuring and projection of data, making it easier to declassify and share data between Government organizations and with coalition partners; (iii) store data in context of time and space to help resolve uncertainty that always exists in data, but is not modeled today; (iv) create privacy filters, aliasing methods, and automated data expunging agents to protect the privacy of U.S. citizens and those who have nothing to do with foreign terrorists; and (v) develop a large, distributed system architecture for managing the huge volume of raw data input, analysis results, and feedback – the goal being a simpler, more flexible data store that still performs well and allows us to retain important data forever. The goal of the program is not only to demonstrate technologies, but also to develop a series of increasingly powerful leave-behind prototypes so that the Intelligence Community can get value immediately and provide feedback to focus research. These technologies and components will feed into the Total Information Awareness program.

The **Evidence Extraction and Link Discovery** (EELD) program is developing technologies and tools for automated discovery, extraction, and linking of sparse evidence contained in large amounts of classified and unclassified data sources. EELD is developing detection capabilities to extract relevant data and relationships about people, organizations, locations, 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 has demonstrated the feasibility of extracting organizational relationships in the context of a business domain, and it has validated the existence of detectable patterns representing potential terrorist threat scenarios. EELD also developed two promising techniques for learning patterns of activity that allow for recognition and visualization of relationships as they change over time. In FY 2001, EELD selected techniques the program will develop for evidence extraction, link discovery, pattern learning, and scenarios, and the program initiated the collection and characterization of documents for technology evaluations. In FY 2002, EELD is developing and demonstrating technology to extract relationships, and detect and learn single-link (e.g., financial transactions or communications events between individuals) type patterns. In FY 2003, EELD will extend its capabilities to the extraction of data from multiple sources (e.g., text messages and web pages), with an ability to adapt rapidly to new threat domains. The EELD program will also develop the ability to detect instances of patterns comprising multiple link types (e.g., financial transactions, communications, and travel), and it will develop the ability to learn patterns comprised of multiple types of entities (e.g., persons and organizations) and multiple link types.

The **Wargaming the Asymmetric Environment** (WAE) program will develop and demonstrate specific, predictive technology to better anticipate and act against terrorists. WAE is a revolutionary approach to identifying predictive indicators of terrorist-specific attacks and behaviors by examining their behavior in the broader context of their political, cultural, and ideological environment. Initial test results demonstrate the feasibility of developing automated and adaptive behavior prediction models tuned to specific terrorist groups and individuals. Specifically, WAE has developed, in conjunction with DoD and the Intelligence Community, indication and warning models for select terrorist individuals and organizations. These indication and warning models have been tested historically and, in some cases, operationally, to predict an active terrorist group's next action (attack/no attack, target characteristics, location characteristics, tactical characteristics, timeframes, and motivating factors). The results of these tests are statistically significant, and several models have been transitioned to our DoD and Intelligence Community partners. In FY 2002, WAE is extending its predictive technology research to model a larger set of terrorist groups and individuals, and it will further exploit predictive technologies to increase the level of detail for each predictive model. In FY 2003, WAE will develop terrorist-specific intervention models based upon their respective motivational factors.

The **Translingual Information Detection, Extraction and Summarization** (TIDES) program is creating technology to enable English speakers to locate and interpret critical information in multiple languages without requiring knowledge of those languages. The source data could be unformatted raw audio or text, stationary or streaming; critical information could span one or more sources in one or more languages. TIDES technology includes synergistic components for: (i) finding or discovering needed information; (ii) extracting key information about entities, relations, and events; (iii) substantially reducing the amount that a person must read; and (iv) converting foreign language material to English. TIDES has created two text and audio processing systems (known as OnTAP and MiTAP) and is using them in Integrated Feasibility Experiments involving bio-security and terrorism. The experiments, being conducted at contractor facilities with the assistance of military and intelligence personnel, are designed to assess the utility of the evolving technology, to learn where improvements are needed, to develop effective concepts of operation, and to jump-start the transfer of the most effective technology into operational use. Work on Arabic was substantially accelerated in response to the events of September 11. In FY 2003, TIDES will demonstrate initial machine translation capabilities from Chinese and Arabic to English. These demonstrations will be done for Navy and Intelligence Community partners at various U.S. locations. The goal of TIDES is not simply to increase productivity: it provides commanders and other decision-makers with a great deal of timely, vital information that is currently out of reach.

The **Human Identification at a Distance** (HumanID) program is developing automated biometric identification technologies to detect, recognize, and identify humans at great distances. A biometric technology is a method for identifying an individual from his face, fingerprints, or the way he walks. These technologies will provide critical early warning support for force protection and homeland defense against terrorist, criminal, and other human-based threats. It will prevent or decrease the success rate of such attacks against DoD operational facilities and installations. The program will develop methods for fusing these biometric technologies into advanced human identification systems to enable faster, more accurate, and unconstrained identification at great distances. In FY 2001, HumanID developed a pilot force protection system to identify humans at a distance in outdoor operational DoD settings. It used specific Military Service sites as prototype models for designing demonstrations and experiments. The program also performed preliminary assessments of current and future technologies. In FY 2002, HumanID plans to develop a prototype advanced human identification system and develop methods and algorithms for fusing biometric technologies and deriving biometric signatures. The system will be evaluated and demonstrated at a variety of force protection and homeland defense sites. HumanID will determine the critical factors that affect performance of biometric components and identify the limits of range, accuracy, and reliability. Only the most promising technologies will continue development based upon evaluation of their performance. In FY 2003, HumanID plans to extend the prototype identification system and further develop biometric fusion algorithms for up to five biometric components. The program will also conduct multi-modal fusion experiments and performance evaluations. Advanced human recognition capabilities will be demonstrated in multiple force protection and/or homeland defense environments.

The objective of the **Bio-Surveillance** program is to develop the necessary information technologies and resulting prototype system capable of detecting a large-scale, covert release of a biological pathogen automatically and significantly earlier than with traditional approaches. The key to mitigating a biological attack is early detection. Given the availability of appropriate medications, as many as half the expected casualties could be prevented if an attack were detected only a few days earlier than if detection were delayed until after a significant number of infected individuals entered the health-care system. We are seeking to achieve this increase by monitoring non-traditional data sources, such as animal health, behavioral indicators, and pre-diagnostic medical data. Technical challenges include correlating/integrating information derived from heterogeneous data sources, development of autonomous signal detection algorithms, refinement of disease models for autonomous detection, and ensuring privacy protection. The program will leverage existing disease models and "mine" existing databases to determine the most valuable early indicators for abnormal health conditions. The program will also develop techniques to determine the best way to differentiate "normal" outbreaks of disease from deliberate bio-terrorist releases. The program will develop enhanced automated privacy protection methods to assure the anonymity of records accessed by the data monitoring software. End-to-end prototypes in two cities of military interest will be constructed for evaluation of the data sources and detection techniques. The Bio-Surveillance program will dramatically increase DoD's ability to detect a clandestine biological warfare attack in time to respond effectively and, therefore, avoid potentially thousands of casualties. During FY 2002, the program will identify, characterize, and evaluate non-traditional data sources and detection algorithms. During FY 2003, the program will incorporate disease progression simulations and privacy protection algorithms. Technology developed under this program will be available for transition to military and civilian bio-surveillance systems.

The specific goal of the DARPA **Communicator** program is to develop and demonstrate "dialogue interaction" technology that enables warriors to talk with computers. Information will be accessible on the battlefield or in command centers without the warfighter ever having to touch a keyboard. The Communicator Platform will be wireless and mobile, and will function in a networked environment. Software-enabling dialogue interaction will automatically focus on the context of a dialogue to improve performance. Moreover, the system will adapt to new topics automatically, so that the conversation seems natural and efficient. The technology emphasizes computer-human arbitrated dialogue that uses task knowledge to compensate for natural language effects (e.g., dialects, disfluences, and noisy environments). The majority of the research effort has been on English/computer dialogues in support of command and control operations. Recently, research has begun on foreign language computer interaction in support of coalition operations. Unlike automated translation of news for unlimited vocabulary (speech-to-text, text-to-text) tasks, the effort here is directed toward human-to-machine interactions with task-specific issues that constrain vocabularies. In FY 1999, the program created an open-source architecture for a spoken language dialog system, which is being used by researchers and engineers to experiment with dialogue interaction techniques. In FY 2000, Communicator technology was used for logistic, command and control, and on-the-move information access experiments. DARPA and the sponsoring testers (U.S. Navy and U.S. Marine Corps, through the Small Unit Logistics Advanced Concept Technology Demonstration) evaluated the system and architecture as being highly effective and having potential impact for use in future systems. In FY 2001, hands-on exercises were conducted for small unit logistics operations with the U.S. Marine Corps at Millennium Dragon (using a SINCGARS radio for a field interface) in order to stress-test the technology in extremely noisy and variable environments. In FY 2002, the Communicator system is being stressed in experiments with the Navy on the Sea Shadow and the F/A-18 maintenance mentor at Naval Air Station Patuxent River to support monitoring and alerting of systems, while concurrently improving both information access and distribution. The final Communicator experiment will demonstrate dialogue interaction with a wide array of distributed sensors, heterogeneous databases, and new noisy environments as the U.S. Army evaluates Communicator's ability to automate the combat casualty reporting system. The measure of success will be performance gains for operators using natural dialogue interaction for high-stress and time-critical tasks. Success will validate a new approach for the way 21st century warriors interact with computers, and dialogue interaction will provide for new and effective concepts of operation. A FY 2003 follow-on project focusing Communicator on a command and control problem (e.g., a ship-wide, agent-based dialog network supporting system-wide monitoring and diagnosis aboard the Sea Shadow), as well as a tactical operations task (e.g., fielding the U.S. Army combat casualty system on the Land Warrior platform), may be used to ensure an effective transition mechanism for this revolutionary new interaction technology.

The goal of the **Babylon** program is to develop rapid, two-way, natural language speech translation interfaces and platforms for users in combat and other field environments with constrained military task domains of force protection, refugee processing, and medical triage. The seedling of Babylon, **Rapid Multilingual Support**, is being deployed to Afghanistan in the spring of 2002. Also under consideration is the appropriateness of developing a Babylon module for use at Guantanamo Bay, Cuba, to support prisoner interrogation. Babylon will focus on overcoming the many technical and engineering challenges limiting current multilingual translation technology. Babylon will provide an enabling technology to give language support to the warfighter in deciphering possibly critical language communications during operations in foreign territories. The first year (FY 2002) goal of the Babylon program is to build and rapidly deploy one-way speech translation systems in four target languages – Pashto, Dari, Arabic, and Mandarin – for direct support of overseas field operatives. The systems are delivered in the form of militarized palm-sized PDA devices with 12 hour battery endurance. In FY 2003, each of four Babylon two-way translation teams will develop 10 working-domain-constrained natural language translation prototypes on multiple platforms. Each system will undergo an evaluation process, and the successful teams will advance and continue to refine their systems through technology patches and insertions. In future years, we will expand domains (tasks) supported by our prototypes, and we will improve robustness and enhance the ability of the prototype to meet practical field requirements. This technology is immature and unstable due to the vast complexities of human-to-human communications. Open-domain (multitask), unconstrained dialog translation in multiple environments is still five to 10 years away. DARPA's research is the stimulus to make sure that that capability becomes a reality. Babylon is focusing on low-population, high-terrorist-risk languages that will not be supported by any commercial enterprise.

Protection from Biological Warfare Attack

A clear and growing national security need is homeland defense and protection of our military forces from biological warfare attack by both military and terrorist organizations. The goal of DARPA's Biological Warfare Defense thrust is to deter or thwart such attacks by developing the needed the sensors, medical diagnostics and countermeasures, building protection systems, and air and water purification devices.

Sensors

To detect the presence of a threat agent, DARPA is investing in the development of advanced **Biosensor Defense Systems** that are robust, autonomous, fast, and sensitive to any known bacterial or viral organism, as well as to novel natural or engineered biowarfare agents. Two example systems are the TIGER and BioTOF sensor systems.

TIGER, or **Triangulation for Genetic Evaluation of Risks**, is a novel and potentially universal approach to bio-detection. The TIGER sensor system combines a new triangulation approach for universal genome evaluation with advanced mass spectrometry and rigorous bio-informatic analysis. Triangulation involves integrating data from multiple regions along an organism's genome to derive a unique identifier for that organism. This enables high performance (95 percent probability of detection), detection and classification of known, unknown, and bioengineered threats in complex mixtures. In FY 2001, we developed an end-to-end model that was used to make quantitative performance predictions based on existing sequence databases. During FY 2002, we are developing a "laboratory quality" TIGER system to gather data in real environments. We will use the model and data to design a prototype system in FY 2003.

DARPA's **Biological Time-of-Flight Sensor** (BioTOF) is a Matrix Assisted Laser Desorption Ionization time-of-flight mass spectrometer that will provide fast and accurate identification of biological warfare pathogens. In FY 2002, we will complete a rigorous evaluation of BioTOF brass-boards with completely automated sample collection and processing. Characterization of instrument performance will guide the design of the follow-on prototypes.

DARPA 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 developed a first-generation biochip sensor designed to determine whether anthrax is present and to enable fast discrimination of hoaxes from real threats using universal ribosomal sequences. In FY 2002, we are developing a pox biochip for the detection of the family of pox virus related to smallpox. This pox biochip has been sent to the Centers for Disease Control and Prevention for testing. In FY 2003, we plan to develop a plague and toxin biochip.

We are rigorously characterizing these systems for their detection performance against live agent challenges and realistic clutter, including a detailed evaluation of the detection and false alarm probabilities.

Traditional sensors and detection technologies require previous knowledge about the structure or identity of the threat and only report on whether that known threat is present or not. The goal of the **Tissue Based Biosensors** and **Activity Detection Technologies** programs is to build sensor systems that detect a wide range of threats, including unknown, genetically engineered, or emerging threat agents. The programs are 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 systems use the physiological response of biological cells and tissues to detect biological or chemical threats. We constructed a variety of laboratory prototypes in FY 2001, including an integrated chip microarray that incorporates liver tissue and measures liver response following exposure to biological agents and chemical toxins. We are also building and evaluating systems using lung tissue, neuronal cells, cardiac cells, fish chromatophores, and engineered B-cells. We demonstrated that we could build a shipping module that would allow the neurons to be stored or shipped and still remain stable and viable for up to a couple of months. In FY 2002, we are continuing the development of these systems to screen them against a wider list of chemical and biological threats and to determine the limits of sensitivity and false alarm rates. In FY 2003, we will begin to adapt the systems for testing and evaluation in a number of operational scenarios, including water-quality monitoring and air-quality monitoring

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. Efforts continue to define gene expression profiles following exposure to biological threat agents. In FY 2001, researchers identified unique genes that are only turned on following exposure. These genes can now be used to identify chip-based diagnostic systems, as well as therapeutic targets of action. Another activity in this program is identifying markers in exhaled breath that may be used to determine who has been exposed to a potential pathogen. 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 Prevention, which has successfully validated assays for four threat agents for their emergency response network. Rapid sequencing techniques have also advanced significantly in FY 2001, with demonstrations of rapid sequencing through nanopores at Harvard University. Additional efforts initiated in FY 2002 expand the investment in rapid sequencing, using natural enzymes responsible for reading DNA to sequence DNA in real-time. Further efforts in FY 2003 will be aimed at new mathematical tools to extract information from data-rich diagnostic collection procedures in order to provide early pre-symptomatic diagnostic detection.

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 new approaches to vaccinations. Three UPC projects have shown promise in initial evaluations and are transitioning to the U.S. Army Medical Research Institute for Infectious Diseases (USAMRIID) for further development: a drug designed to attack the DNA of bacteria, viruses and malaria; a family of drugs that target a common and critical enzyme in anthrax and other bacteria; and a protein fragment that blocks the effects of toxins released by bacteria. In addition, the U.S. Army Institute for Surgical Research, Fort Sam Houston, is evaluating skin decontamination by nanoemulsion technology. In FY 2002, we anticipate transitioning other successes to USAMRIID, including novel antibiotic therapeutics, computer-based approaches to shorten the time to develop new antibiotics, and novel vaccines/immune stimulants and platforms. A novel vaccine enhancer developed under the UPC program is likely to transition to the Centers for Disease Control and Prevention or USAMRIID later this year.

By FY 2003, 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.

In DARPA's **Genetic Sequencing of Biological Warfare Agents** program, the validated threat agent organisms whose sequences had not yet been characterized were sequenced and analyzed via modern, high-throughput sequencing technologies. The organisms we sequenced and analyzed are: Coxiella burnetti (Q fever), Rickettsia typhi (typhus), Burkholderia mallei (glanders), Brucella suis (brucellosis), Clostridium perfringens (gas gangrene), and Franciscella tularensis (tularemia). Additionally, several more strains and variants of orthopoxviruses related to smallpox are being sequenced, and an orthopoxvirus database was established in collaboration with the Centers for Disease Control and Prevention and U.S. Army Medical Research Institute for Infectious Diseases. These efforts provide immediate benefit to developers of diagnostic and forensic assays based on nucleic acid sequence. A longer-term impact is that the sequence information provides new molecular targets for developing therapies and vaccines.

DARPA has successfully completed development and transition of the Advanced Consequence Management software program for the management of medical resources and casualties in the event of an attack from weapons of mass destruction. The **Enhanced Consequence Management Planning and Support System** (ENCOMPASS) has been installed at the Crisis Consequence Management Initiative laboratory at Space and Naval Warfare System Center-San Diego for transitioning to Joint Forces Command, National Guard Net, and the Federal Emergency Management Agency. The technology has become one of the pillars for the Advanced Concept Technology Demonstration for Homeland Defense. The DARPA Syndromic Surveillance System, a component of ENCOMPASS, has been used in multiple military and national special events. In addition, the Air Force's Lightweight Epidemiology Advanced Detection and Emergency Response System, which uses key segments of ENCOMPASS, has obtained funding to implement these vital tools at military bases to enhance telemedicine consultation capabilities.

Building Protection

In addition to Biological Warfare Defense component technologies, DARPA is developing complete system solutions to counter the biological warfare threat. The goal of the **Immune Building** program, begun 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 (e.g., neutralization and filtration). 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 (e.g., decontaminating foams and novel materials that can be used for both chemical and biological filtration) and is extending them for use in this application. The program is also developing new component technologies specifically for this application, such as: using chlorine dioxide for the decontamination of 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 airways and ductwork. In FY 2001, we initiated a number of these technology development efforts. In addition, several industry teams evaluated candidate architectures for complete building protection systems. In FY 2002, those technologies and prototypes that successfully passed the evaluation process will be incorporated as components of the complete protection system. We will instrument full-scale test-beds for experimentation with end-to-end systems. Two industry teams are currently refurbishing existing facilities at the old Fort McClellan site (AL) and the Nevada Test Site (NV) for complete system tests scheduled for Government evaluation in FY 2003. The results of these experiments will drive the design of optimal protection systems in FY 2003. In addition, we are developing and validating a modeling capability to enable the application of Immune Building principles to future buildings. To help address the "anthrax letter" problem, DARPA has also initiated efforts to develop portal barrier technologies and to screen and/or neutralize chemical or biological agents in mail and closed containers.

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, and their water purification devices and beverage containers must be integrated in order to work and pack away together. In one project, a pen-sized mixed chemical oxidant unit kills or inactivates microbial pathogens, prevents re-growth of microbial contaminants for days after initial treatment, and provides an order-of-magnitude improvement in disinfection against spores compared with chlorine or iodine. The mixed-oxidant operated water treatment pens are now being selectively field-tested by the U.S. Marines Corps and Special Forces personnel in Afghanistan. The U.S. Marine Corps plans to transition this device into their official enhancement program.

In another project, a 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, into a potable nutrient solution contained in a forward osmosis membrane bag. The program has completed proof-of-principle experiments showing technical feasibility, including preventing chemical and biological challenge agents from penetrating the interior of the bag. During the remainder of FY 2002, the program is optimizing the components of the system, mainly by increasing the water flux through the membrane to produce more potable solution faster. The U.S. Marine Corps also plans to transition this device into their 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. 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. FY 2001 and FY 2002 data have already shown a reduction in the pressure drop by at least a factor of two over current C2A1 canisters, while maintaining a longer period of time for the filters to operate effectively. Future work is planned to employ this unique filter material as the mouthpiece of vastly improved smoke hoods used for emergency escape.

PROTECTION FROM INFORMATION ATTACK

The Department of Defense has a critical and growing dependence on the information systems that are key to the future joint vision of warfare. Moreover, our critical infrastructures – and the economic success of our nation – similarly depend on this technology, and the poor state of security in those networks and systems is a well-recognized national vulnerability. Widely used commercial software is riddled with security holes, and attacks are so common that the DoD and other large organizations require full-time staffs to analyze and respond to serious incidents, while still only seeing a small portion of all attacks. Computers and networks in the private sector are poorly defended and can be compromised and turned to attack DoD networks without the knowledge of the system owner. At the same time, potential nation-state adversaries are known to be preparing cyber attack techniques to undermine U.S. computers and infrastructures in case of a conflict.

To address these challenges, DARPA's **Information Assurance and Survivability** suite of programs was created to raise strong barriers to cyber attack and provide commanders with technology to see, counter, tolerate, and survive sophisticated cyber attacks.

In FY 2001, the Information Assurance and Survivability suite of DARPA programs made significant progress toward these goals. Selected accomplishments from these programs include:

- Developing correlation and analysis algorithms to detect and track complex multi-phase or large-scale cyber attacks (**Cyber Command and Control / Strategic Intrusion Assessment** programs);
- Developing techniques for assessing cyber attack impact at the system functional level from network-level alerts, such as signature, anomaly, and effects-based attack detections (Cyber Command and Control / Strategic Intrusion Assessment programs);
- Developing techniques to isolate corrupted or malicious network entities (**Fault Tolerant Networks** program);
- Developing technology to thwart denial-of-service attacks by constraining an attacker's computing resource consumption capability (Fault Tolerant Networks program); and
- Prototyping protocols for negotiation of policies across coalition members (**Dynamic Coalitions** program).

The following program descriptions provide additional details:

The **Operational Partners in Experimentation** program rapidly puts advanced information assurance technology into the warfighter's hands for accelerated transition to the operational community and improved feedback to the research community. Operational Partners in Experimentation provides a risk-managed process for high-tempo operators to evaluate revolutionary, but experimental, technologies like embedded firewall or anomaly-based intrusion detection systems. The DARPA embedded firewall demonstrated tremendous success in stopping a military red team during the 2001 Fleet Battle Experiment India, where it was identified by the Navy as the most promising technology. The Navy has already begun the process of programming and budgeting to buy these embedded firewalls in bulk, and the specific technical results from the ramp-up to these exercises invariably provides feedback crucial to the effective maturation of these technologies. As a second example, anomaly-based intrusion detection holds the potential of detecting the more sophisticated threats that slip by current sensors, while reducing by a factor of 100 the volume of noise through which analysts must sift to find such threats. Based on early findings, the Department of Defense's Computer Emergency Response Team has already incorporated DARPA anomaly detection into an upgrade of the Joint Intrusion Detection System, fielded worldwide. We are studying possibilities for extending these breakthroughs to coalition operations in FY 2003.

The **Dynamic Coalitions** program is developing technologies for establishing distributed coalitions of joint and/or military users working together for a common mission. These technologies include capabilities for establishing security policies for essential operations, securing the underlying group communication infrastructure, and providing the necessary coalition infrastructure services, such as authentication (ensuring the identity of an individual) and authorization (ensuring the individual has the authority to perform certain functions, which must be present for secure collaboration in coalition environments). Managing security policies is critical for the establishment and maintenance of network-centric coalitions. During the creation of a coalition it is essential to ensure that only those participants that are expected to be part of the coalition are allowed to join, and anyone else is restricted from joining through the group communication and access policies. Lastly, coalitions will require additional infrastructure security services to support operations across multiple domains among varied partners. More frequently than ever, we are joining forces with allies in military exercises and engagements. The technologies being developed by the Dynamic Coalitions program will ensure secure interoperability with our coalition partners. It is essential that we know our coalition partners are trusted as coalition operations are carried out. In FY 2001, the program began development of several technologies: policy language compilers, secure group communication toolkits, and public key infrastructure revocation architectures. In FY 2002, we will perform several experiments consisting of coalition policy negotiation, translation, and enforcement among three to five coalition domains. These experiments are being carried out as part of a joint U.S./Sweden coalition experiment to demonstrate that coalitions can be dynamically created, used, and disbanded in rapid timeframes for various military scenarios. In FY 2003, we plan to perform experiments including coalition formation, dynamic membership changes, dynamic policy updates, revocation and rekeying in response to threats, and coalition dissolution.

The **Fault Tolerant Networks** program is developing technologies to ensure that today's DoD networks – and the networks of the future – can ensure continued availability and graceful infrastructure degradation under partially successful attacks, thereby maximizing the residual capacity available to legitimate users. Current attacks are becoming more sophisticated, and the technologies being developed today are focused on defending against future attacks. Technologies being developed include: (i) ensuring the fault-tolerance and secure survivability of critical network services; (ii) technology to thwart denial-of-service attacks by constraining an attacker's resource consumption, i.e., reducing the amount of network bandwidth or central processing unit cycles available to the attacker; (iii) capabilities to trace and contain attacks as close to the source as possible; (iv) techniques that assist in network recovery from a degraded state to a minimal operational state; and (v) tools that assist in network reconstitution from a minimal operational state to a fully operational state, so that previously successful attacks will have no impact on the new, fully-operational state. In FY 2001, we demonstrated techniques to isolate corrupted and malicious network entities and trace back network attacks, similar to isolated denial-of-service attacks that have been prevalent on the Internet. In FY 2002, we will demonstrate capability to provide detection and defense against distributed denial-of-service attacks. These attacks include tens-of-attacking-hosts against a single victim with traffic loads equivalent to T1 communication channels (1.44 megabytes per second). In addition, technology to establish a secure router infrastructure will begin transition to commercial partners. The transition is occurring through direct communications between the researcher and several router vendors as part of an established routing vendor consortium. In FY 2003, the program will demonstrate algorithms for path classification and selection of protocols for creating resilient network overlays within a modular routing architecture. These network overlays are important to ensure continued operation of the network in the face of an attack, providing alternate communication paths, and ensuring continued network operation. We will also perform an exhibition of secure, graceful degradation of critical network services under large-scale attack, and we will demonstrate tools, techniques, and mechanisms for network recovery and reconstitution in the face of a concentrated network attack. This will be demonstrated on a test network, not an operational network, in order to control the attack traffic and ensure that the attacks are contained.

The **Cyber Panel** program is developing technologies for monitoring the DoD's critical networked information systems for signs of sophisticated and coordinated cyber attacks and responding to avert them or defend against them. Cyber Panel uses and builds upon the capabilities developed in the **Cyber Command and Control/Strategic Intrusion Assessment** programs, completed in FY 2001. Technologies being developed include: (i) detection sensor capabilities that look for unusual behavior by users or system application functions, such as web servers, to discover attacks – even when no known vulnerabilities were observed to be exploited; (ii) correlation techniques that compare observations from different types of detection sensors in different network locations to look for evidence of coordinated attacks; (iii) large-scale attack analysis algorithms that help identify the scope, virulence, and spread-rate of widespread attacks, such as worm software that replicates itself to many computers; (iv) techniques to gauge the potential effects of discovered attacks on militarily-critical tasks being performed by the information system; and (v) techniques to identify and execute effective defensive actions, such as isolating threatened systems, reconfiguring access permissions, or redirecting tasks to alternate computing resources. In FY 2001, Cyber Command and Control/Strategic Intrusion Assessment demonstrated correlation techniques that can: (i) use probability-based algorithms to draw accurate conclusions about distributed attacks, even when specifics of the attack method are not known; (ii) detect slow and stealthy system scans attempting to map a defended network, even when they consist of just a few packets separated by hours and coming from multiple colluding attackers; and (iii) reduce the burden on human analysts by rank-ordering attack alerts based on the criticality and vulnerability of threatened systems, and determining when there are benign explanations for apparent correlated attack behavior. A cyber defense planning tool was also developed and is being examined for potential transition to the Navy's Fleet Information Warfare Center and the Army's Land Information Warfare Activity. In FY 2002, Cyber Panel will demonstrate capabilities to respond in sub-second times to rapidly parry detected attacks on computer systems in a laboratory environment and test correlation capabilities in a live data environment with the Air Force Research Laboratory for potential transition into Air Force operational use. Cyber Panel will also demonstrate the ability for detection systems to communicate across organizational boundaries to trace back routes taken by attacks and take coordinated defensive responses, and it will show the ability to develop response courses of action for human-directed execution. In FY 2003, Cyber Panel will extend fast automatic response execution beyond individual computer systems to defend local networks, develop techniques to slow the spread of virulent attacks, and work to begin transition of response assessment techniques. The Cyber Panel program, building upon the results of Cyber Command and Control/Strategic Intrusion Assessment, provides a combination of: (i) intelligent monitoring to mitigate known and unknown vulnerabilities of DoD systems; (ii) correlation and fusion to identify the most serious attacks from the thousands of alerts human defenders are faced with and assess how military-relevant computerized tasks are affected; (iii) fast automatic responses to buy time for humans to assess the situation; and (iv) deliberative planning and assessment for deciding upon the best defensive course of action. These capabilities provide the core of an ability to perform command and control for defense of the cyber assets upon which the DoD depends for its information superiority.

The **Organically Assured and Survivable Information Systems** (OASIS) program changes the current mind-set of preventing information system intrusions at all costs to a strategy of employing effective safeguards designing the system so that mission critical operations can continue in the event of a system fault. The OASIS program is designing, developing, implementing, demonstrating, and validating architectures, tools and techniques that will allow fielding of organically dependable and robust systems. Critical DoD operational systems will be able to operate through a cyber attack, degrade gracefully if necessary, and allow real-time, controlled trade-offs between system functionality and performance and system security. In FY 2001, OASIS projects demonstrated: (i) effective techniques to protect systems from malicious code attached to emails and transmitted via the Internet; (ii) technology to guarantee the integrity of commercial-off-the-shelf and legacy software; and (iii) a method to prove the legitimacy of code, intrusion-tolerant web servers, and data storage schemes. In FY 2002, OASIS is demonstrating achievements in certificate authority, survivable servers and clients, real-time execution monitors and mobile agent protection, as well as validating redundant architectures using design diversity. In FY 2003, OASIS technologies will be evaluated for their effectiveness in tolerating cyber intrusions and attacks, and their performance will be characterized. In addition to its current transition of specific technologies to the military, the program will culminate in a working prototype of a military mission critical system that will show the feasibility of developing highly dependable systems. The Joint Battlespace Infosphere information systems, responsible for producing Air Tasking Orders, will be fortified with OASIS technologies. The demonstration will consist of continued production, real-time modification, and execution of Air Tasking Orders, even while many of the Joint Battlespace Infosphere information systems are under a sustained cyber attack by a red team. The demonstration is planned for the end of FY 2004.

Maintain Unhindered Access to Space and Protect U.S. Space Capabilities

DARPA is placing an increased emphasis on developing and flying space technologies and spacecraft for new missions. The importance of space to our nation and its security was expressed by the Commission to Assess United States National Security Space Management and Organization, whose final report stated that:

> The security and economic well being of the U.S. and its allies and friends depend on the nation's ability to operate successfully in space. To be able to contribute to peace and stability in a distinctly different but still dangerous and complex global environment, the U.S. needs to remain at the forefront in space, technologically and operationally, as we have in the air, on land and at sea. Specifically, the U.S. must have the capability to use space as an integral part of its ability to manage crises, deter conflicts and, if deterrence fails, to prevail in conflict.

One of the Commission's five conclusions concerned space science and technology:

> [I]nvestment in science and technology—not just facilities, but people—is essential if the U.S. is to remain the world's leading space-faring nation. The U.S. Government needs to play an active, deliberate role in expanding and deepening the pool of military and civilian talent in science, engineering and systems operations that the nation will need. The government also needs to sustain its investment in enabling and breakthrough technologies in order to maintain its leadership in space.

The Secretary of Defense has directed that DARPA, along with the Service laboratories, undertake research and demonstration of innovative space technologies and systems for dedicated military missions. The DARPA investments in space are consistent with our charter to solve national-level technology problems, foster high-risk, high-payoff military technologies to enable operational dominance, and to avoid technological surprise. Two of the strengths DARPA brings to space R&D are the flexibilities provided by Congress in our hiring processes and in our contracting methods for rapid prototype development. These enable DARPA to take advantage of rapidly evolving commercial technologies and emerging scientific breakthroughs to create real innovation in space systems.

The **Orbital Express** program is designed to create a revolution in space operations by demonstrating 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 three Phase I contractor teams completed their operational system concept definitions and demonstration system preliminary designs. The teams prioritized the enabling technologies needed to prove the technical feasibility of on-orbit servicing, developed preliminary designs for a cost constrained initial demonstration, and they developed plans for additional development into an operational system once technical feasibility has been proved. DARPA has selected the Boeing Company team to build a two-satellite, on-orbit servicing demonstration. Initial efforts will concentrate on the autonomous guidance, navigation, and control software for rendezvous and docking, the highest technical risk area in the program. Fabrication and ground test of the two space vehicles will continue through mid- to late FY 2005.

Launch services are being arranged through the DoD Space Test Program, with launch anticipated in mid-FY 2006, based on the Space Test Program's current budget.

The objective of the **Responsive Access, Small Cargo, Affordable Launch** (RASCAL) program is to design and develop a low-cost orbital insertion capability for dedicated micro-size satellite payloads. The concept is to develop a responsive, routine, small payload delivery system capable of providing flexible access to space using a combination of reusable and low-cost expendable vehicle elements. Specifically, the system will comprise a reusable "airplane-like" first stage, with expendable second and third stages integrated to a top stage with avionics and payload. RASCAL demonstration objectives are to place 50 kilogram satellites and commodity payloads into low-earth orbit any time, at any inclination, with a launch efficiency of $20,000 per kilogram or less. The technology, combined with the concept of operations envisioned, will revolutionize the space launch industry by paving the way toward a $10,000 per kilogram efficiency in the operational phase. While the demonstration payload cost goal is commensurate with current large payload launch systems, it will be more than a factor of three less than current capabilities for the dedicated micro-payload size after transition to the Services. This capability will enable cost-effective use of on-orbit replacement/re-supply systems, such as the Orbital Express concept, and provide a means for rapid launch of orbital assets for changing national security needs. With recent advances in design tools and simulations, this program will prudently reduce design margins and trade-off system reliability to maximize cost effectiveness. This program will also leverage advancements in autonomous range safety, first-stage guidance, and predictive vehicle health diagnoses, management, and reporting to lower the recurring costs of space launch. In FY 2002, the first year of the program, DARPA is starting system concept definition, demonstration of aircraft propulsion adaptation to first-stage mission requirements, and system requirements and conceptual design reviews. In FY 2003, DARPA will conduct critical design reviews of the first-stage vehicle and select the teams for the design phase of the program.

The **Satellite Protection and Warning / Space Awareness** (SPAWN) program will demonstrate the technical feasibility of using microsatellites to provide enhanced, near-field space situational awareness for U.S. space assets in geosynchronous orbit to avoid unanticipated gaps in satellite support to military operations. A key goal of SPAWN is to develop a highly capable, modular microsatellite bus architecture with standard payload interfaces to take advantage of launch capabilities provided by RASCAL. This modular bus will also be used to host a variety of other "plug and fly" sensors and scientific instruments. SPAWN will feature a high degree of autonomous operation, anomaly recognition, and reporting to minimize the impact on ground operations. In FY 2002, we are initiating mission analysis, concept definition, and preliminary design studies for a SPAWN system, and we are identifying the objectives of a proof of feasibility prototype demonstration. Based on the results of this Phase I effort, DARPA will, with input from the customer community, make a decision whether to proceed into a Phase II demonstration. In Phase II, detailed designs of the on-orbit demonstration spacecraft will occur, and the spacecraft will be fabricated, ground-tested, and space-qualified. Finally, in FY 2006 the SPAWN demonstration spacecraft will be launched as part of the Orbital Express mission to perform a series of on-orbit demonstrations.

The **Space Surveillance Telescope** program is developing a large-aperture optical telescope with very wide field-of-view using curved focal plane array technology. This will facilitate the detection and tracking of very faint objects in deep space, such as asteroids and debris. Both detection sensitivity and search coverage rate will improve approximately an order-of-magnitude over current capabilities. FY 2002 is the first year of the program, during which an initial design study is being conducted to determine sensor and optics requirements, as well as a system deployment concept of operations. In FY 2003, the first tile of the sensor focal plane will be fabricated, and fabrication of the primary optics will begin.

The **Deep View** program is developing a high-power, high-resolution, ground-based radar to image and characterize small objects in both low-earth orbits and deep space. This will provide the capability to perform a variety of space surveillance missions, including characterizing debris and other objects that are more than an order-of-magnitude smaller than current capabilities allow, and monitoring satellite health. FY 2002 is the first year of the program, during which initial design of the high-power transmitter tubes will be completed. In FY 2003, the program will fabricate and test the first transmitter tube and begin detailed development of the full transmitter and receiver subsystem.

The **Innovative Space-based Radar Antenna Technology** study program will investigate novel technologies and conceptual designs aimed at producing extremely lightweight (approximately five kilograms per square meter), compact (approximately 400 cubic meters, fully-stowed volume), and affordable space-based radar antennas that meet the stressing requirements of continuous tactical-grade tracking of ground moving targets for intelligence, surveillance, and reconnaissance. Such a system will provide wide area surveillance with high revisit rates (approximately 10 seconds), wideband operation, high range-resolution GMTI modes (approximately one foot resolution), and low minimum detectable velocity. This combination of requirements will drive investments in very large-scale antennas, as well as in novel materials and packaging appropriate to launching and deploying such a system. In FY 2002, we are evaluating multiple systems designs, and we are carrying out preliminary labs tests on candidate inflatable technologies. In FY 2003, we will develop detailed system designs, and we will conduct targeted ground-based scale model proof-of-concept demonstrations.

Today's national imaging systems are highly capable and support a wide variety of user needs. However, the "one size fits all" requirement leads to a few massive, highly complex, and expensive spacecraft, the largest launch vehicles, and a vast worldwide distribution network. The **Low Cost Tactical Imager** (LCTI) program is designed to address the unique needs of the tactical warfighter by developing a low-cost, high-resolution, day/night imaging spacecraft with the capability to launch on demand – anywhere, anytime, and into any orbit – to support the tactical warfighter. LCTI will demonstrate novel technologies, such as Fresnel lens, membrane mirrors, and lightweight optics, to reduce the spacecraft mass by a factor of two and the telescope mass by a factor of 10 to enable launch on an air-launched booster. LCTI will provide the first-ever ability to task the spacecraft and downlink the imagery in the same pass to support near-real time imaging and targeting of emitters, perform rapid bomb damage assessment, and defeat denial and deception techniques. LCTI will begin in FY 2003 with systems designs and telescope development.

The **Tactical Optical Sensing** program will develop and demonstrate technology to give the battlefield commander both moving target indications (MTI) over a wide area (200 kilometers-by-200 kilometers) and high-resolution imaging over a small area (approximately five kilometers-by-five kilometers), using the same optical sensor. This combination of capabilities in a single system enables true tactical use of space-based optical sensors, allowing the U.S. to move quickly from a surveillance mode to a target tracking-and-identification mode. This program will develop foveating imaging techniques, which have a large field-of-view with coarse resolution, combined with a narrow field-of-view with fine resolution (the fovea). The program will also develop techniques for doing MTI with optical sensors. In FY 2003, the first year of the program, we will develop robust foveated imaging technology and optical MTI techniques in laboratory devices.

The **Tactical Pointing Determination of Imaging Spacecraft** (TPDIS) program will develop a space surveillance radar to provide the warfighter with near-real-time determination of where an adversary's overhead imaging spacecraft is pointing. Today, commanders are warned when imaging spacecraft overfly the theater so that they may schedule their activities to avoid detection, or camouflage or conceal targets to deny or deceive the adversary. The area accessible to imagers on an overflight is large, and there is currently no theater-based capability to determine what terrain the spacecraft have attempted to image. TPDIS will develop an order-of-magnitude improvement in resolution and accuracy over the current state-of-the-art to provide position and pointing information of space-based imagers. TPDIS will offer warfighters indication and warning of an adversary's attempt to image U.S. and allied forces. In FY 2003, we will complete trade studies and requirements definition to evaluate the feasibility of TPDIS to achieve the required tracking performance. In addition, we will begin risk reduction on the radar hardware, and we will develop an initial system design.

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 surfaces 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 spatial light modulator devices that employ microelectromechanical technology. In FY 2002, we will demonstrate the spatial light modulator devices with scalable architecture. The program is developing three device types, and we will assemble the most promising into a laboratory CCIT system, followed by a demonstration at greater than one kilometer range in FY 2003. All three Military Services are potential customers, as CCIT provides capabilities for secure communications.

Operational Dominance

Programs in this area are aimed at developing the advanced systems and technologies needed to achieve Full Spectrum Dominance, leapfrogging current capabilities and threats to give our warfighters a decisive edge. Sub-areas of particular note here are Affordable, Precision, Moving Target Kill, and Combined Manned and Unmanned Systems.

AFFORDABLE, PRECISION, MOVING TARGET KILL

Current approaches to destroying time-critical moving targets include area-of-effect munitions and man-in-the-loop targeting. These approaches traditionally involve large and very expensive weapons, the potential for large collateral damage, and, often, the requirement to put a warfighter in harm's way. DARPA is responding by developing low-cost, highly capable weapon systems networked to a variety of sensors in order to precisely find and destroy the right land targets in any terrain, in any weather, moving or not, at any time.

Information Exploitation

On October 31, 2001, DARPA established the **Information Exploitation Office** to emphasize development of sensor and information system technology and systems with application to battlespace awareness, targeting, command and control, and the supporting infrastructure required to address land-based threats in a dynamic, closed-loop process. Programs will leverage ongoing DARPA efforts in sensors, sensor exploitation, information management, and command and control. Pooling these programs together in one office will provide additional focus to agency efforts addressing the systemic challenges associated with performing surface target interdiction in environments that require very high combat identification confidence and an associated low likelihood for inadvertent collateral damage. The programs will exploit the synergies between:

- Appropriate sensor, sensor control, and sensor data exploitation capabilities to achieve confirmed target identification to ensure that specified targets (including challenging targets) are correctly engaged without undesirable collateral damage;
- Dynamic battle management systems, to ensure effective and efficient use of sensors, sensor platforms, weapons, weapons platforms, and resources required for exploitation and decision-making and assessment; and
- Supporting infrastructure to ensure rapid dissemination, timely processing, effective human-computer interaction, and the availability of suitable threat and terrain models.

Threats of interest include mobile and fixed surface targets in all environments, i.e., open, partially obscured, in "hide" (e.g., under foliage), in evasive maneuver, and in urban settings.

The **Tactical Targeting Network Technologies** (TTNT) program is developing, evaluating, and demonstrating the airborne wireless networking communications technology necessary for denying sanctuary to time-critical surface targets (for example, mobile surface-to-air missiles and launchers, and armor columns). To rapidly target mobile opponents, the technology will provide high performance, robust, and interoperable data communications for tactical aircraft to work: (i) with each other; (ii) with unmanned air vehicles; (iii) with intelligence, surveillance, and reconnaissance platforms; and (iv) with ground stations. These communications support essential targeting and sensor-to-shooter coordination, such as that which is currently occurring on a very limited scale with Predator operations in Operation Enduring Freedom. TTNT goals include: (i) real-time, battle-driven communication capacity assignment; (ii) minimal delay for high-priority messages; (iii) a data-rate that can support secure video transmission; (iv) low-cost insertion into most platforms; and (v) complete coexistence with existing tactical data links, such as Link 16. Link 16, the current common data link for most air, sea, and critical ground platforms, originated 30 years ago. While robust, Link 16 was not designed to support growing U.S. targeting communication needs. TTNT will develop the responsive communications infrastructure required to conduct collaborative, time-critical targeting and prosecution on a dynamic battlefield. And TTNT will enable emerging targeting systems, such as Affordable Mobile Surface Target Engagement and Advanced Tactical Targeting Technologies, to achieve their full capabilities. TTNT contracts have been awarded to four prime contractors: L-3 Communications Corp. (Salt Lake City, UT); Rockwell Collins Inc (Cedar Rapids, IA); BAE Systems (Wayne, NJ); and VIASAT Inc (Carlsbad, CA). Technology study contracts have been awarded to Ohio University (Athens, OH), Purdue University (West

Lafayette, IN), and the Southwest Research Institute (San Antonio, TX). The DoD Joint Spectrum Center is also under contract to the TTNT program. The close working relationship with the Joint Spectrum Center has allowed the program to address the issue of radio spectrum availability from the outset, permitting TTNT to anticipate and to avoid contention with both civilian and military users. Active monitoring of Asian and European leading edge civilian wireless technology development is being conducted via the Asian Technology Information Program (Albuquerque, NM). This activity ensures that rapidly evolving commercial wireless technologies are not overlooked if they can contribute to TTNT. In FY 2002, we will complete the initial system designs and conduct critical component tests, followed by a narrowing down to two or more designs for further development. These tests will be development tests to prove out the system concept and packing/integration techniques for minimizing the cost of widespread deployment. In FY 2003, the program will build brass-board designs and conduct hardware-in-the-loop tests of the candidate systems. If these development tests are successful, the proven concepts will be further tested in operationally realistic situations, with potential military user participation.

The **Affordable Moving Surface Target Engagement** (AMSTE) project is developing technologies to make it feasible and practical for the warfighter to precisely, rapidly, and affordably engage individual moving surface vehicles. AMSTE integrates multiple stand-off radars and long-range weapons into an integrated, networked engagement system, permitting stand-off fighters and surveillance systems to direct low-cost GPS-guided weapons against moving targets. 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 2001, the AMSTE program awarded contracts to Northrop Grumman Corp. Integrated Systems Sector (Melbourne, FL) and Raytheon System Co. (El Segundo, CA), to develop and assemble prototype AMSTE experimental systems (combining representative radar sensors, data links, and weapons) for live-flight experimentation. In the Summer of 2001, the contractor/Government teams conducted a series of developmental flight experiments that culminated in the first-ever successful deliveries of GPS-guided precision weapons against moving vehicles, targeted by standoff networked sensors using AMSTE precision fire control techniques. In FY 2002, the AMSTE program awarded a single contract to Northrop Grumman to develop and incorporate critical enhancements to prototype AMSTE experimental systems to address high-confidence track maintenance in highly cluttered environments for live flight experimentation. At the end of this year, a series of developmental flight experiments will culminate in the delivery of multiple GPS-guided precision weapons against moving vehicles with increasing complexity in both target densities and target dynamics. Further experimentation with the AMSTE system is planned for FY 2003, and the program will develop and incorporate prototype battle management command and control tools to support highly dynamic time-critical target engagements against moving targets with realistically complex target densities and target dynamics.

The **Dynamic Tactical Targeting** (DTT) program is developing new sensor control and data fusion technologies that will enable a tactically responsive, warfighter-managed, targeting process. While there are processes in place today that effectively enable the targeting of pre-defined or anticipated targets, recent U.S. military operations have demonstrated that the U.S. needs a more robust ability to conduct true "time-critical targeting." The new sensor control and data fusion paradigm in DTT will apply the technology necessary to prosecute such targets. With this new paradigm, DTT will extend the ability of the warfighter to obtain information and awareness of the battlespace faster and with the greater fidelity of detail and context necessary to execute in a timely fashion. Time-critical targets have been prosecuted in past operations. However, this was the result of right-place/right-time dynamics, not planning and awareness. DTT will change that. DTT will employ resource management and data fusion technologies to find, identify, and track virtually every vehicle in a 30 kilometer-by-30 kilometer area to focus weapon systems to target and destroy mobile, time-critical targets. The DTT program is directed at challenging surveillance and reconnaissance problems, particularly at reducing the time required to recognize and engage critical, fleeting targets. It will design, build, and demonstrate a process to efficiently manage multi-sensor surveillance of large areas and large numbers of objects, and to extract targets of high interest for hand-off to weapon systems. DTT will hand-off the targets extracted from the many moving objects in the battlespace to precision engagement systems like AMSTE. The goal is to track and identify 10 to 25 critical mobile targets in a 1000 square kilometer area containing approximately 1000 mobile objects. DTT will: (i) leverage existing national/theater intelligence, surveillance and reconnaissance (ISR) sources for timely access to critical data; (ii) dynamically task unattended ground sensors (UGS), unmanned air vehicle (UAV) sensors, and human intelligence (HUMINT) to fill ISR coverage gaps and provide relevant sensor observation in areas of tactical interest; (iii) fuse data from UGS and UAV sensors with ISR data from all sources to enable continuous estimation over time of target location, identity, and activity; and (iv) close the loop between sensor management and fusion to enable timely prosecution of critical fleeting targets. The product of the DTT program will be a transportable test-bed, developed in conjunction with one or more of the Services (Army Space Program Office, Air Force Research Laboratory, and/or Navy Space and Naval Warfare Systems Command) to demonstrate real-time targeting of mobile, time-critical targets in an operational environment. In FY 2002, the program is developing models of UGS, UAV and HUMINT data to enable fusion with national and theater sensor data. We will demonstrate adaptive allocation of ISR sensor resources to enable efficient search profiles, deployment of additional tactical sensors to fill coverage gaps, and track maintenance of objects/targets in the battlespace. In FY 2003, the program will conduct a laboratory demonstration of the DTT system to military users from all Services at the Air Force Research Laboratory. This demonstration will include automatic registration of all sensor data, fusion of national, theater, and tactical sensor data, and dynamic sensor management.

The **Real-time Battle Damage Assessment** project is developing and demonstrating novel techniques to assess damage to targets caused by small, precision munitions that may cause massive damage to soft vehicular targets, while leaving only scant visible damage on the exterior of the target. The project's goal is to determine, in real-time, whether a weapon has hit the target and the likelihood that the target is incapacitated. If this information can be determined immediately after the strike, extra sorties for re-strikes can be avoided. The project will use synthetic aperture radars systems, coordinated with weapons delivery, to image the targets before, during, and following the strike to enable damage assessment within seconds. In FY 2001, the project conducted instrumented data collections using airborne sensors and military vehicles (e.g., trucks, air defense vehicles, howitzers, and armed personnel carriers), as well as decoys being struck by a variety of munitions. We used the resulting database to develop prototype detection algorithms and to assess their effectiveness. From this, we have identified promising approaches that involve the analysis of transient radar returns that occur as the weapon hits the target. In FY 2002, this technique is being refined and evaluated using focused data collections emphasizing through-strike sensing. Both soft and hard targets with both kills and near-misses by munitions will be tested to assess the ability of the method to determine kill probability. This data will allow us to provide mature algorithms for damage indication and assessment, which will be tested using the advanced synthetic aperture radar system in the U-2, the intended Joint Strike Fighter radar in a BAC1-11 aircraft, and other radar systems. Our goal is to be able to determine when a target is hit with a 98 percent detection rate, rejecting 99 percent of the near-misses as no-kills.

The **Advanced Tactical Targeting Technology** (AT3) program is developing and demonstrating technologies to radically improve today's capability to target surface-to-air missile (SAM) threats. AT3 enables the rapid and accurate targeting of precision-guided weapons to kill modern, more capable enemy SAM systems. These new SAM threats use tactics, such as only staying "on the air" for short periods, that make them challenging targets for current capabilities. The AT3 concept employs non-dedicated platforms (e.g., tactical fighters, reconnaissance aircraft, unmanned air vehicles, unmanned combat air vehicles) to rapidly detect and locate enemy radars by sharing detections and measurements of radar signals using existing tactical data links. The targeting network operates transparently and in an *ad hoc* manner to provide target locations within 10 seconds of emitter turn-on, from 50 miles away, with an accuracy of 50 meters. The AT3 program has already demonstrated the basic feasibility of the approach in flight tests. In FY 2001, we concentrated on developing and building the full-up hardware and software systems that will be used for strenuous flight tests and investigated promising software techniques to enhance AT3's capabilities. The AT3 prime contractor, Raytheon Defense Systems, now has these systems ready for aircraft installation. In FY 2002 and FY 2003, the AT3 program will complete the real-time flight tests of the AT3 system against real threats and analyze the test data. In addition to the flight tests, the AT3 program is working diligently on promising transition routes with both the USAF and the Navy.

The goal of the DARPA **Counter Camouflage, Concealment, and Deception** program is to design, build, test and demonstrate a foliage penetration (FOPEN) synthetic aperture radar (SAR) to provide the warfighter with an all-weather, day or night capability to detect targets hidden under trees or camouflage. The FOPEN SAR will fill the surveillance/reconnaissance gap that currently exists for this large class of targets. Targets of interest include tanks, supply vehicles, mobile surface-to-air missiles systems, guerrilla bases, and drug laboratories. In data collected during FY 2001 at Camp Navajo (AZ), the DARPA FOPEN SAR demonstrated: (i) excellent image quality at 15 kilometer standoff ranges, and (ii) detection of military vehicles concealed under foliage. The detection performance for both single-pass detection and change-detection modes was evaluated during these tests. In FY 2002, the DARPA FOPEN SAR system is being calibrated and characterized in all modes, and will be flown in an extensive series of test flights to measure the system's capability to detect tanks and other military vehicles under various foliage conditions and imaging geometries. DARPA will also demonstrate the capability of the system to detect other targets, including drug laboratories and surface-to-air missile launchers hidden in foliage, and will participate in a number of military exercises, such as the Joint Combat Identification Test. FY 2002 is the last year DARPA will fund this program. In FY 2003 the FOPEN system will be transferred to the Army. The Army and Air Force will employ it in user demonstrations to support transition of this capability to the Services and to continue terrain characterization flights in support of the Army Future Combat Systems program.

COMBINED MANNED AND UNMANNED SYSTEMS

The **Unmanned Combat Air Vehicle** (UCAV) program is a joint DARPA/Air Force System Demonstration Program to demonstrate the technical feasibility, military utility, and operational value for a UCAV system that can effectively and affordably prosecute suppression of enemy air defenses / strike missions within the emerging global command and control architecture. The DARPA-managed demonstration program will facilitate a seamless transition into an Air Force-managed, effects-based, spiral development program to develop the initial operational capabilities to meet the Congressional goal that one-third of U.S. military operational deep strike aircraft should be unmanned by 2010. In FY 2001, the two X-45A demonstrator aircraft and the mission control system were transported to NASA Dryden Flight Research Center, where integration tests were conducted. In FY 2002, the program will complete the first set of X-45A flight tests and the initial design reviews for the low-observable X-45B. In FY 2003, the program will complete multi-vehicle X-45A coordinated flight tests, conduct the X-45B final design review, and begin fabrication of long-lead items. At the end of FY 2003, the UCAV program management will transfer to the Air Force.

The potential of the unmanned approach to hazardous air missions has also resulted in a joint DARPA/Navy **Naval Unmanned Combat Air Vehicle** (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 to demonstrate the technical feasibility of a UCAV-N system. The UCAV-N Advanced Technology Demonstration program is structured in two phases: Phase I consists of analysis and preliminary design, and Phase II involves 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 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, the detailed design and fabrication of UCAV-N, in March 2002. Phase II will continue through December 2004.

The goal of the **Unmanned Combat Armed Rotorcraft** (UCAR) program is to design, develop, integrate, and demonstrate the enabling technologies and system capabilities required to effectively and affordably perform armed reconnaissance and attack within the Army's Objective Force system-of-systems environment. The UCAR program will build upon the accomplishments of the unmanned combat air vehicle program to develop the next generation of autonomous and collaborative mission execution capabilities. UCARs will operate autonomously and will execute missions in collaboration with other UCARs, other unmanned systems, and with manned assets. UCAR will build upon the accomplishments of the Army's Comanche program to develop technologies that enhance the capability of aircraft to survive in a diverse threat environment. UCAR will use off-board sensors for target acquisition, while its on-board sensors specialize in long-range target identification. With both lethal and non-lethal weapons capabilities, UCAR will enable the Army to extend its lethal range by using the UCAR system to locate, identify, and prosecute targets farther in front of U.S. and coalition lines, thereby protecting manned and unmanned ground and air systems. Phase I of the program will begin in the third quarter of FY 2002. The objectives of Phase I are to fully explore the design trade space for the system, develop a conceptual design for the system, substantiate the effectiveness and affordability goals for the system, and develop an initial risk reduction and demonstration roadmap for the program. Phase I is a 12-month effort involving up to four contractor teams.

DARPA has been a leading force in the development of unmanned air vehicles (UAVs) for military applications. The success of these aircraft was recently shown in Afghanistan, where Predator and Global Hawk

UAVs provided vital information to warfighters. It is now time to push UAV technology to a new level: it may be possible to develop a UAV that can stay aloft five times longer than Global Hawk, today's longest-flying UAV. This will be accomplished using the very high energy-to-weight ratio of liquid hydrogen. A liquid-hydrogen-fueled airframe will be at the center of the DARPA **Ultra Long Endurance Aircraft Program** (UltraLEAP). Combining advanced airframe manufacturing techniques, fuel cell technology, and electric motor driven propellers, UltraLEAP will provide a staring battlefield sensor and communications relay platform for the warfighter at costs per hour of operation that are far lower than today's UAV platforms. In FY 2002, the program will evaluate supporting technologies and a proof-of-concept design. In FY 2003, we will conduct preliminary design of a demonstrator vehicle and conduct risk reduction on component technologies, including the fuel cell, liquid hydrogen fuel tankage, and an oxygen scavenging compressor.

The **Mixed Initiative Control of Automa-teams** (MICA) project is developing technologies that will enable one or a few warfighters to manage many teams of UAVs in an adversarial operational environment. The MICA program will provide a commander in the field with the operational and mission planning tools to select optimal combinations of unmanned platforms, weapons, and sensors to form heterogeneous UAV teams with different platform capabilities and diverse payloads enabling coupled reconnaissance, strike, battle damage assessment, and force protection activities. The program is developing automated methods for real-time dynamic mission planning, mission execution, and event-driven replanning for each UAV team. We will develop collaborative teaming strategies and tactics, and cooperative team member routing to meet mission objectives. At any point in an operation, a commander or operator will be able to intervene in team operations, approve automated asset allocations and cooperative courses of action, or communicate preferences regarding team activities. Stability, performance, and robustness of team operations with an operator-in-the-loop will be emphasized during the mixed initiative dialogue between the human and unmanned air vehicles. In FY 2002, the program is building an initial Open Experimental Platform to evaluate preliminary algorithms for composing heterogeneous teams, and for collaborative planning and cooperative execution of team maneuvers in simulation. This prototype Open Experimental Platform will be expanded to evaluate cooperative management of 2 to 5 teams of 5 to 10 UAVs with an operator-in-the-loop in FY 2003. Military operators will participate in the evaluation of MICA technologies using the Open Experimental Platform in a variety of operational scenarios, including suppression of enemy air defenses and time-critical targeting situations.

The **Software-Enabled Control** program will exploit 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 and unmanned combat air vehicles, as well as upgrades for existing airframes, such as the F-15E, F/A-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 2001, a prototype implementation of the hybrid multi-mode control software was completed for single-vehicle uses, including predictive modeling of environmental effects (e.g., wind gusts and turbulence) and safely controlling mode transitions under such effects. This technology will provide enhanced maneuverability/evasive capability for unmanned air vehicle and unmanned combat air vehicle systems, and enhanced robustness under extreme conditions for piloted systems. Multi-modal control technology will provide better controlled transitions between complex operational flight modes (inherent in vertical takeoff and landing unmanned air vehicles and high performance/transonic manned aircraft), thereby reducing safety risks to the warfighter and vehicle. In FY 2002, the program is developing adaptive hybrid control services to ensure stable operation and extend the control 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. In FY 2003, Software-Enabled Control will enter an experimental phase, wherein advanced adaptive control techniques will be tested with hardware-in-the-loop simulations and test flights with scaled-down rotary and fixed-wing aircraft. Planning will also begin for program final demonstrations using an F-15E and a T-33 unmanned combat air vehicle surrogate aircraft.

Autonomous Software for Learning Perception is developing autonomous software for learning, perception, and control. This enables mobile robots to autonomously perform a variety of military tasks in diverse, complex, and dynamic environments. It also supports effective interaction with humans. The ultimate goal for the program is to allow the warfighter to task a robot in the same terms a human is tasked. In FY 2001, the program demonstrated on-line learning techniques that automatically generated desirable, adaptive behaviors and response to voice command instructions. This resulted in successful autonomous task performance. In FY 2002, Autonomous Software for Learning Perception will demonstrate integrated perception, including fusion of data from multiple sensors and multiple ways of processing the same data. It will also demonstrate structured operator intervention for semi-autonomous operation. In FY 2003, the program will demonstrate a trainable, perception-based, autonomous, indoor navigation capability, and multi-sensor outdoor navigation. This will transition to the Future Combat Systems' Perception for Off-Road Robotics and the Army Research Laboratory's Robotic Collaborative Tech Alliance programs.

The Common Software for Autonomous Robotics component supported by the **Software for Distributed Robotics** (SDR) program is developing software technologies for large groups of extremely small and highly resource-constrained micro-robots. The coordinated action of many robots achieves a collective goal, while allowing the operator to task and query the ensemble of robots as a group, rather than as individuals. The payoff will be distributed "swarm" systems of robots that robustly perform important military tasks, such as area surveillance and mine clearing. SDR has already transitioned task allocation, reusable components and energy-conserving protocols to the Army Research Laboratory's Robotic Collaborative Tech Alliance, the Future Combat Systems - Communications program, and Urbot, being developed by the Unmanned Ground Vehicle/Systems Joint Program Office and the Space and Naval Warfare Systems Command. In FY 2001, the program evaluated networking protocols for distributed robot control that are more energy efficient than conventional implementations. It also demonstrated software for coordinating the operation of more than 10 robotic devices in a collective task. In FY 2002, SDR will integrate the energy-conserving network protocols, natural, implicit communications modes, and user interfaces on more than 50 robots. In FY 2003, SDR will demonstrate accelerated mobility and reconnaissance and shared representations to support collaborative communication between humans and robotic systems.

Future Combat Systems

The jointly funded, collaborative DARPA/Army **Future Combat Systems** (FCS) 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 and integrate 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 networked sensors along with manned and unmanned platforms are key FCS enablers. DARPA and the Army are developing the technologies to achieve this new way of fighting and managing the development risks carefully in order to field a highly successful combat system.

FCS is the networked system of systems that will serve as the core building block within all Objective Force maneuver units to develop overmatching combat power, sustainability, agility, and versatility necessary for full spectrum military operations. During FY 2001, four industrial teams, in cooperation with DARPA and Army leadership, engaged in developing FCS concepts, including the identification of technology alternatives and organizational designs. The program was accelerated in FY 2001 to meet the Army's goal of fielding an Objective Force capability this decade. This led to the DARPA/Army decision to competitively select an industry Lead Systems Integrator in the second quarter of FY 2002 to develop the program in preparation for a Defense Acquisition Board Milestone B decision in the third quarter of FY 2003.

The following nine programs are developing technology specifically for insertion into FCS, and they represent a major portion of the DARPA contribution to the DARPA/Army partnership:

Assured communications is critical in tactical environments where the threat of electronic attack is high. When forces are distributed and composed, in part, of robotic vehicular platforms, the consequences of an electronic attack can be catastrophic to successful operations. The **Future Combat Systems - Communications** (FCS-C) program is developing new, mobile, wireless networking technology capable of simultaneously providing high data-rates (greater than 1 megabits per second), low probability of detection, and robustness to enemy jamming. The FCS-C program proposes to meet these opposing constraints through a multi-tiered mobile *ad hoc* network utilizing both directional antennas at low-band (e.g., Joint Tactical Radio System (JTRS) bands) and highly directional antennas at high-band (millimeter-wave frequencies). In FY 2001, we pursued high-risk, high-payoff technology projects in the areas of: (i) high-band technology (e.g., transmitters, receivers, antennas); (ii) low-band (e.g., future JTRS) technology for dynamically exploiting complex radio frequency environments, including multi-path mitigation with diversity techniques, multi-user detection, and space-time processing; (iii) radio frequency information assurance techniques at the network layer and below; and (iv) mobile *ad hoc* network technology for smoothly blending the high-band and low-band technologies into a single network, including routing, quality-of-service for real-time traffic, topology optimization, acquisition and tracking, and mobility management – all using directional antennas. In FY 2002, two system integration teams were selected to integrate the technologies and perform a series of three demonstrations that show the increasing maturity of the system and its components, from a low-band-only directional capability to an integrated low- and high-band directional capability. In FY 2003, the system integrator team(s) will demonstrate a prototype FCS communications infrastructure in the field. The communications system must be able to maintain assured, mobile, wireless connectivity among surrogate FCS robotic platforms using directional antennas at both low- and high-bands. The FY 2003 field demonstration, which may be conducted with operational units, will also include operational vignettes including multi-hop teleoperation of robotic vehicles and network operation through an electronic attack that fully exercise the various constituent FCS communications technologies.

Future Combat Systems Command and Control is an applied research project to develop a new approach to Army Battle Command in support of Army Transformation through Future Combat Systems. Through the use of advanced information technologies and knowledge base engineering, this program will attempt to develop an advanced method of command and control, which integrates the previous stove-piped battlefield functional areas into a single, integrated information environment (the Commander's Support Environment) that will support the command and control of manned and unmanned systems. Future Combat Systems Command and Control will leverage information technology to facilitate the synthesis of information presented to a FCS commander by automating as much of the information/data integration as possible. This allows the commander and battle managers to leverage operational opportunities by focusing on fewer unknowns, clearly visualizing current and future operational end states, and dictating the tempo of operations within a variety of environments, while being supported by a staff reduced in size by a factor of 10. A series of four command and control experiments will be conducted to measure the experimental system against a specific set of program performance and effectiveness measures supported by an underlying simulation. In April 2003, we will deliver the integrated scaled systems and operational architecture for an FCS unit cell, a command and control experimental demonstrator supported by a simulation environment, and a platform for future FCS research within the Army.

The **Jigsaw** project is developing a three-dimensional (3-D) imaging laser radar capable of reliably identifying hidden targets through gaps in foliage and camouflage. The Jigsaw sensor will collect high-resolution, 3-D images from multiple viewpoints and combine them to form a composite 3-D image to enable the warfighter to see underneath the canopy and visually recognize targets, day or night. Jigsaw sensor and technology development is focused on application to the Army's Future Combat Systems. In FY 2001, Jigsaw performed system trade studies to assess the capabilities and performance of candidate laser radar architectures, developed registration and compression algorithms, and created visualization tools. The program also completed a ground-based Jigsaw data collection against vehicles hidden behind a dense stand of trees. The Jigsaw team successfully demonstrated the ability to register the resulting 3-D images and form a composite 3-D image for vehicle identification. In addition, Jigsaw initiated an end-to-end system modeling and simulation capability for assessing a wide variety of Jigsaw operational scenarios for the Organic Air Vehicle and the Army's Tactical Unmanned Air Vehicle. In FY 2002, two Jigsaw laser radar system design contractors will be selected to build prototype Jigsaw sensors to fly on a helicopter. In FY 2003, contractors will complete, integrate, test, and fly the prototypes against targets hidden by various densities of foliage, types of camouflage, and deployed in urban settings, such as alleyways and alcoves.

The purpose of the **Organic Air Vehicle** (OAV) program is to provide ground combat units, including Future Combat Systems unit cells, with a capability to detect adversary troops concealed in forests or behind buildings or hills, i.e., 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 an OAV design that is scalable between nine inches and three feet in diameter, weigh between two and 10 kilograms, and cost approximately $10,000 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 light detection and ranging, 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, flight control software was developed and autonomous flight tests were performed numerous times. In FY 2002 and FY 2003, Honeywell will continue development of the flight control software to allow for flight in adverse weather. Flights tests are scheduled throughout FY 2002, and the autonomous OAV will be ready for evaluation by FCS in April 2003.

The **A160 Hummingbird** program is developing a revolutionary advancement in the capabilities of helicopters. The program began in FY 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. The first flight of the A160 Hummingbird took place on January 29, 2002. The vehicle took off autonomously and flew for 20 minutes. Flight testing continues for the balance of FY 2002. In FY 2002 and FY 2003, the A160 program will integrate and demonstrate several surveillance payloads.

The **Unmanned Ground Combat Vehicle** (UGCV) program is developing prototypes to demonstrate the extent to which novel vehicle design approaches, unconstrained by the need to carry human crews, can increase deployability and resilience while reducing logistical burden on the overall FCS force. In Phase I of the program, completed in FY 2001, 11 preliminary designs were developed and evaluated against primary metrics of: (i) endurance (14 days and 450 kilometers between resupply events); (ii) obstacle mobility (one meter high and/or deep objects at slow speed, and 0.25 meter objects at 20 kilometers per hour); and (iii) payload fraction (at least 25 percent of the gross vehicle weight should be payload). Of these preliminary designs, seven were based on carrying approximately 150 kilograms of payload, while the other four were based on carrying 1500 kilograms of payload. The approximate sizes of the two vehicle classes are 0.7 tons and six tons, respectively. This covers a broad range of potential FCS payloads based on notional concepts from the FCS program and the Army. UGCV is expected to show extremely good air transportability (several vehicles could be carried by a C-130 cargo aircraft) and to have the potential for airdrop "ready-to-fight." DARPA is now in Phase II of the program, and two designs from each payload class have been selected for refinement. As a part of this refinement, each team is conducting experiments on critical subsystems, e.g., power and suspension systems. All of the designs utilize hybrid electric drive-trains to accommodate long silent-watch modes and high efficiency. In June 2002, two designs will be selected for full prototype fabrication and testing through FY 2003 and part of FY 2004. This testing is expected to validate the design predictions for mobility and endurance performance and allow preliminary payload interface testing to assure the Army that the UGCV technologies are relevant to FCS needs.

The **Perception for Off-Road Robotics** (PerceptOR) program is developing advanced perception systems for off-road robotic navigation in environments relevant to FCS. The program builds on the considerable work done previously by DARPA, the Army, and the Office of the Secretary of Defense, but takes a complementary programmatic approach. Although PerceptOR contractor teams are expected to accomplish perception development in their own field trials, DARPA also hosts several field experiments where the robot is operated in an unrehearsed mode. Four of these unrehearsed experiments are planned for Phase II of the program. The first unrehearsed experiment occurred in February 2002, at Fort A.P. Hill (VA). In Phase I, four teams developed independent perception prototypes (sensors, mounts, algorithms, and processing hardware). Each team integrated its perception system prototype aboard two commercial All Terrain Vehicles as surrogates for FCS. Three of these teams were selected to begin field-testing for Phase II. This Phase II testing is conducted in locations never before seen by the contractor teams, and it is conducted both day and night, as well as in inclement weather. PerceptOR will, in some cases, provide high-resolution terrain data collected previously by DARPA in the test area to evaluate the utility of this data in providing both a route planning aid, and on-board perception "context" interpretation. In January 2003, two teams will be selected for continued field experiments to evaluate operations in which sensors fail and communications are limited (or fail intermittently). The results of PerceptOR are expected to provide critical insight into the near-term robotic navigation capabilities available to FCS, and they will point the way to continued advancement in ground robot operations under combat conditions.

The **NetFires** (formerly **Advanced Fire Support System**) program will develop and test a containerized, platform-independent multi-mission weapon system as an enabling technology element for FCS. NetFires will provide rapid response and lethality in packages requiring significantly fewer personnel, decreased logistical support, and lower life-cycle costs, while increasing survivability compared to current direct-fire gun and missile artillery. The national security impact of NetFires will be to provide light, deployable U.S. forces extended range immediate precision fires against adversaries. NetFires will allow FCS to defeat all known threats, will be air deployable in C-130 (and smaller) aircraft, and will enhance the situational awareness and survivability of FCS by providing standoff target acquisition and extended-range, non-line-of-sight engagements. The program will develop and demonstrate a highly flexible modular, multi-mission precision attack missile and a loitering attack missile that can be remotely commanded. Both missile types will have a self-locating launcher and a command and control system compatible with Future Combat Systems. In FY 2001, NetFires finalized missile designs and initiated pintle motor tests, captive flight seeker tests, boost test vehicle launches, and completed aerodynamic wind tunnel tests. In FY 2002, the program will complete validation of the launcher system with boost test vehicle launches, refine the seeker concepts with further captive flight tests, and initiate missile launch and navigation and aerodynamics with controlled test vehicle launches. In FY 2003, NetFires will validate end-game missile performance and introduce new concepts of operations for light forces with extensive guided test vehicle launches at White Sands Missile Range and Eglin Air Force Base.

The **Digital Radio Frequency Tags** program is developing programmable, small, lightweight, low-cost prototype hardware to allow radars (moving target indicator and synthetic aperture radar) to receive data from ground forces. This capability will enable robust, high confidence U.S. and friendly force air-to-ground identification and data exfiltration from unattended ground sensors. In FY 2001, the Digital Radio Frequency Tags program completed a detail-level system design and demonstrated transfer of a test data message from a brass-board test unit through the Joint Surveillance Targeting Attack Radar System. Fabrication of 10 field prototype tag units is beginning in FY 2002, and all system components will be completed and tested. The prototype units will be completed and field-tested in FY 2003.

COMMAND AND CONTROL / LOGISTICS

Programs in this sub-area focus on improved mission planning, integration of information systems, and logistics.

The **Active Templates** program is developing and delivering critical command and control software tools for special operations forces (SOF), working in close collaboration with the Joint Special Operations Command. 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 2001, the DARPA-developed geo-spatial editor for planning and tracking SOF missions on a map or an image was tested in a large special operations exercise, and was subsequently adopted because it enables distributed special operations teams to maintain situational awareness. Early in FY 2002, temporal and spatial plan and situation editors were deployed and used as the primary command and control software for special operations in Operation Enduring Freedom. Later 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. In FY 2003, Active Templates will perform scalability experiments and demonstrations, showing that we can quickly produce ready-for-prime-time software for weather, communications planning, task organization, special logistics, personnel tracking, and a host of other mission planning and situational awareness applications – all of which are intended for early deployment.

The **UltraLog** 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 will serve as a template for creating agent-based, distributed command and control systems operating at all echelons that can dynamically recover from information attacks, infrastructure loss, and other real-world problems in complex wartime environments. In FY 2001, the program concentrated on building the foundation for survivability in the core agent architecture to include secure information management, increased fault-detection and tolerance, and highly robust adaptive communications. 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 program will perform its first large-scale evaluation and assessment in early FY 2002, including a red team attack of the logistics information system during a representative Major Regional Contingency scenario. The military concept of "ThreatCon" will be incorporated into the software agent architecture as a control mechanism to support enhanced survivability. In FY 2003, the program will use the results of the FY 2002 assessment in selecting and tuning the portfolio of technologies to develop and integrate into the UltraLog core. FY 2003 will conclude with a second, more challenging assessment of the performance of the UltraLog system in a more demanding and harsh wartime environment.

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. It is building 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 accomplish this 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 the Joint Theater Logistics ACTD is at the operational level: the Joint Task Force, its Service components, and major Service logistics organizations. In FY 2001, the Joint Theater Logistics ACTD continued to expand on and harden the current collaborative capabilities, while adding new functionality, such as the ability to collaboratively develop operational courses of action and track cargo movement in the Global Transportation Network using DARPA Control of Agent-Based Systems agent technology. 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 the Global Combat Support System in FY 2005.

SENSORS AND SENSOR EXPLOITATION

A key to U.S. warfighting success is control of the air and defeat of enemy ground-based air defenses. While the U.S. has good systems for finding, jamming, and killing radar-based air defenses, we have no similar capability to deal with optical- or infrared-based air defenses. The **Multifunction Electro-Optics for Defense of U.S. Aircraft** (MEDUSA) program will develop and demonstrate the ability to find and negate these air defenses, thereby restoring U.S. dominance at low-altitude and at night. In FY 2002, we will begin the development of critical laser, detector, and optical fiber technology for MEDUSA, and we will develop techniques in the laboratory to find and destroy enemy optical and infrared sensors. In FY 2003, we will demonstrate the advanced technology components in the laboratory and select a system design for the field demonstrations that will follow.

The U.S. is concerned about the threat of attack by large numbers of low-cost air vehicles, ranging 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 use of our current inventory of interceptors (designed for far more sophisticated threats) and running the risk of being overwhelmed by the sheer number of attacking platforms. The LCCMD program is developing and demonstrating affordable seekers for use on a low-cost interceptor system. The cost of the seeker(s) represents approximately two-thirds of the total cost of a typical interceptor system. The use of Electronically Steered Array (ESA) antennas promises to reduce seeker cost to less than $50,000 in production, provided that their component phase shifter costs are low enough. Microelectromechanical (MEMS) switches have become the low-cost choice for doing this, but this program uncovered reliability deficiencies in using MEMS for this application. In FY 2001, the program improved the reliability of MEMS to the degree necessary to start development of a MEMS-based ESA. In FY 2002, the program is initiating development of the MEMS ESA seeker and the fabrication of the MEMS components of the ESA. In FY 2003, the program will undertake fabrication of the MEMS ESA seeker. The U.S. Army Space and Missile Defense Command has expressed great interest in this program and has undertaken development of a low-cost interceptor vehicle. DARPA and the Army are finalizing a Memorandum of Agreement to integrate the low-cost seeker and low-cost interceptor to form a complete LCCMD missile.

U.S. sensor systems are increasingly challenged with more complex background operating environments and reduced signature targets, which are stressing current adaptive sensor systems beyond their original design capabilities. Current, and future planned intelligence, surveillance, and reconnaissance (ISR) sensor systems use rudimentary (*circa* 1950-60s) signal processing methods to attempt to separate targets from clutter. As ISR systems become more sophisticated, these crude signal processing techniques prevent the full exploitation of potential sensor performance. In FY 2002, DARPA is initiating the **Knowledge Aided Sensor Signal Processing and Expert Reasoning** (KASSPER) program, which will develop a new front-end signal processing architecture to exploit, in real-time, dynamic environmental knowledge databases in support of ISR sensor operations. In particular, knowledge of features such as the terrain (clutter) and road networks will be directly injected into the front-end of the signal processing to provide high performance adaptivity. In FY 2002, KASSPER will develop new algorithms for effectively incorporating environmental knowledge into the adaptive signal processing chain, along with estimates of performance improvements. In FY 2003, we will downselect among the algorithms and knowledge sources to focus on those that are most amenable to real-time implementation on an ISR radar platform.

The **Global Positioning Experiments** program addresses the problem of enemy jamming of the Global Positioning System (GPS), a critical component of U.S. military capability. The program will demonstrate the use of airborne pseudolites, which are high-power, GPS-like transmitters on aircraft that broadcast a powerful replacement GPS signal that "burns through" jammers and restores GPS navigation over a theater of operations. In FY 2001, we demonstrated at Wright Laboratory (Dayton, OH) and field-tests at Rockwell Collins (Cedar Rapids, IA) that beamformer antennas can protect the airborne pseudolite itself from jamming. In FY 2002, the program will combine the beamformer antenna with the pseudolite transmitter to show precision navigation signals in jamming. In FY 2003, we will demonstrate a full system of four airborne pseudolites that provides precision navigation for GPS-guided weapons.

COMMUNICATIONS

The **TeraHertz Operational Reachback** program is developing the free-space optical communications technology to provide high data-rate connectivity to the mobile and expeditionary warfighter. The threshold is a data-rate of 2.5 gigabits per second over a 400 kilometer aircraft-to-aircraft link, with a goal of reaching 10 gigabits per second. The objective system will exploit commercial wavelength technologies and DARPA developed electronic optical beam steering to achieve low-cost in a small form-factor. The TeraHertz Operational Reachback program will exploit the installed global terrestrial fiber infrastructure by placing a fiber access point near the theater, and then continue the connection into theater using the free-space optical path. This gives the deployed warfighter access to the global terrestrial fiber infrastructure and enables unparalleled access to information without the encumbrances of laying fiber in-theater. The program consists of three phases: technology-push (Phase I); subsystem prototyping and demonstration (Phase II); and end-to-end system prototyping and demonstration (Phase III). During FY 2002 and FY 2003, critical free-space optical component technology will be advanced. Large-angle electronic beam steering, high-power laser transmitters, small/compact sensitive optical receivers, and mobile free-space optical networking protocols will be developed. Beginning in FY 2003, we will prototype and demonstrate subsystems built on this critical core technology in a variety of laboratory environments. These demonstrations will address individual link (air-to-air, air-to-ground) performance. We will use modeling and simulation to predict end-to-end network performance between a fiber head point of presence to a simulated surface ship and land terminal via an aircraft link. Our transition targets are the Air Force, Army, Navy, and Intelligence Community.

The **neXt Generation** (XG) program will demonstrate both the enabling technologies and system concepts to improve spectral utilization of military radio frequency emitters by a factor of 20 through the dynamic frequency access of available spectrum. XG provides a mechanism for providing assured access to military spectrum resources needed for rapid deployments worldwide, while producing efficient utilization of the shrinking military bandwidth in the dynamic environment of the 21^{st} century. The technologies and concepts developed by the program will impact both DoD policy and systems under development. The XG program is beginning Phase I in FY 2002 by characterizing the spectrum utilization of military and non-military systems in their operating environments. XG is also beginning development of the critical technologies, such as dynamic media access and control algorithms and low-power spectrum monitoring sensors, that are required to implement an XG system. In FY 2003, the program will conduct its first test and evaluation of the component technologies and advanced spectrum characterization built upon the initial FY 2002 measurements. These first laboratory tests will be used to verify a potential improvement in spectrum access as measured in bandwidth, time and space. The goal is to demonstrate a factor of 10 improvement using the FY 2002 field measurement spectrum data.

The **Symbiotic Communications** program will develop a passive, all-weather airborne system that can produce real-time synthetic aperture radar images and very accurate Digital Terrain Elevation Data (DTED) that meets the National Imagery and Mapping Agency (NIMA) Level Four specification. In addition, the system will categorize terrain (e.g., "trees" versus "roads") and will provide ground moving target indicator (GMTI) for detecting and locating slowly moving ground vehicles. This system is a passive, bistatic receiver, which makes it difficult for adversaries to detect and counter. This approach will allow our warfighters to gather the battlespace mapping data they need without putting themselves at the additional risk of employing a sensor that must radiate to obtain its data, thereby giving away its location. In FY 2001, an expert Government team and two contractor teams developed system concepts and carried out ground-based experiments to validate technical feasibility and to refine performance predictions. In FY 2002, the program will conduct early flight tests using contractor-owned aircraft (a DeHaviland Twin Otter and a Convair 580) and perform additional RailSAR measurements to characterize terrain scattering phenomena. We will collect and process early flight test data to demonstrate that the special Symbiotic Communications waveforms and bistatic geometries provide the necessary image quality to meet the program goals. Successful completion of early flight tests in FY 2003 will demonstrate this passive, all-weather capability operating in non-real-time and producing synthetic aperture radar, GMTI, and DTED Level Three data. Remaining program goals will be to improve DTED accuracy to NIMA Level Four and demonstrate real-time processing and terrain characterization.

The **WolfPack** program is developing new electronic warfare technologies that can hold enemy emitters (communications and radar) at-risk throughout the tactical battlespace, while not interfering with friendly military and protected commercial radio communications. The WolfPack concept emphasizes an air-deployable, ground-based, close-proximity, distributed, and networked architecture to obtain radio frequency spectrum dominance. WolfPack uses 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 either disables communications and radar reception, or relays the geolocation information of the threat transmitter. In FY 2001, the WolfPack program initiated contracts to develop high-risk, high-payoff technologies, such as efficient wideband antennas with negative impedance matching components, precision geolocation techniques for urban terrain, spectrum denial techniques for dense threat environments, advanced sensor emplacement techniques, and extremely low-cost/expendable micro-sensors. In addition, we selected 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 initial demonstrations of component technologies for network management, sensor emplacement, emitter node and network identification, classification, and urban geolocation. In FY 2003, we will demonstrate technology test-bed units to validate the WolfPack concept. This will include laboratory and in-the-field demonstrations. In addition, we will complete preliminary WolfPack prototype design reviews. In the last quarter of FY 2003, we will be building prototype WolfPack system components for laboratory testing and/or simulation. This development will lead towards full integration into a prototype system by the end of FY 2004.

The **Airborne Communications Node** program is developing a multi-mission payload that will, in a single package, simultaneously provide 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 – air, ground and sea. It will enable high-bandwidth, beyond-line-of-sight connectivity, and will allow the tactical commander to reconfigure his available assets dynamically to satisfy changing mission priorities. In FY 2001, the program demonstrated subsystem performance through detailed laboratory testing and simulation. In FY 2002, we will validate multi-mission functionality (communications, signals intelligence, electronic warfare, information operations) of this single payload in an end-to-end system demonstration in a laboratory environment. In FY 2003, the program will demonstrate the multi-mission scalable capabilities to warfighters (all Military Services) through a jointly sponsored flight demonstration program.

The **Command Post of the Future** (CPOF) program has developed tools that radically improve a commanders' understanding of the tactical situation on the ground. This improved understanding leads to better tactical decisions and faster decision times, which, in turn, lead to a more effective employment of tactical forces. CPOF has achieved major technical breakthroughs in our ability to provide rapid and accurate situational awareness in two technology areas: battlefield visualization and collaborative planning. Using currently deployed systems, typical tactical ground commanders understand approximately 27 percent of the current situation (friendly/enemy disposition), and can take up to four hours to acquire this level of understanding. CPOF technology has been demonstrated to boost that level of situation understanding to greater than 90 percent in less than a sixth of the time. CPOF has also developed tools and a concept of operations for mobile command that enable a commander and his staff to maintain a deep understanding of the battlefield while they are away from the command post and distributed across the battlefield. These tools are embodied in the BattleBoard – a portable pen-tablet computer about the size of a laptop screen, that uses speech and pen-based drawing in place of the mouse and keyboard and has a wireless connection to the battlefield local area network and its digital information. A command organization equipped with BattleBoards can operate at various locations distributed across the battlefield and maintain full situational awareness and collaborative planning capability. This frees the commander to be at critical locations of the battlefield without losing the full understanding of the battlespace that comes from access to the data in the command post. Technologies developed under the CPOF program will be critical to enabling future, highly mobile tactical ground commanders to out-think and out-plan opponents on complex, dynamic battlefields. The CPOF BattleBoard technology and concept of operations for distributed command will transition to the Marine Corps as part of the Enhanced Combat Operations Center and to the Army as part of the Interim Brigade Combat Team. Component technologies (collaborative planning, visualization, and multi-modal interfaces) will transition individually to the Army and Marine Corps through insertion into programs of record.

DoD standard voice encoders (VOCODERs) operate at 2400 bits per second (baud) under normal circumstances, and up to 9600 baud in noisy environments. The goal of the **Advanced Speech Encoding** (VOCODER) program is to compress speech to bit-rates of 200 to 800 baud, while producing speech quality at least as good as that produced by the current standard and maintaining that quality (and bit-rate) in militarily relevant noisy environments. These gains will be accomplished by combining direct measurements of the glottal excitation function with acoustic data to reduce the update rates and numbers of parameters necessary to represent speech information. The program will provide a means for speaker authentication based on the direct measurements of the glottal excitation function, which provide a potentially unique and powerful set of physiological metrics. In FY 2002, we will collect direct measurements of the glottal excitation function and begin development of processing algorithms for noise suppression using these measurements in conjunction with acoustic data. In FY 2003, we will demonstrate voice encoding of speech in noisy environments at data-rates below 2400 baud with voice quality at least as good as the DoD standard encoder operating at 4800 baud.

The **Training Superiority** program will create a new approach to training our warriors to win in the new high-technology, complicated, and often isolated environment of future conflicts. The performance of the people who fight our weapons systems is as least as important to the ultimate warfare success as is the technology in those weapons. Thus, without a parallel revolution in training affairs, the revolution in military affairs may not be as effective. In FY 2003, with help from the Services and the Joint Chiefs of Staff, we will build a multi-disciplinary team around areas in urgent need of new training approaches, and begin building a new training system that includes auto-tutors, sensing of a student’s mental state, computer game-based learning, as well as network-based reach-back to subject-matter experts.

FUTURE WARFARE CONCEPTS

Land Warfare and Weaponry

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. In FY 2001, the program participated 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 conducted 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. During FY 2002, the program will complete fabrication of the third and fourth prototype vehicles. Relative to the first two vehicles, the third and fourth vehicles will be equipped with improved components and will incorporate an enhanced design in the area of battery power conversion, thermal management, and vehicle system control. The vehicles will also undergo survivability, automotive, and active suspension performance testing. The program office is currently discussing transition opportunities with U.S. Special Operations Command and the U.S. Marine Corps. In FY 2003, the vehicles will be integrated with additional mission-specific equipment and will undergo operational assessment.

The **Antipersonnel Landmine Alternatives** program is focused on long-term alternatives to antipersonnel landmines that would prevent adversaries from maneuvering at-will and provide the warfighter with enhanced capabilities to turn, canalize, and block opposing mounted forces. The research and development effort is focused on the Self-Healing Minefield that utilizes no antipersonnel landmines. Instead, the antitank obstacle is maintained by permitting the antitank mines to autonomously detect an adversary's breach attempt via mine-to-mine communication, and responding by repositioning a fraction of the mines remaining in the minefield to fill in the breach. In FY 2001, the program focused on refinement and field-testing of the major subsystems and integration of these subsystems into two sets of 10 prototype inert mines. During FY 2002, we will complete field-testing of the first generation prototype mines. We will refine mine subsystems and will construct a minefield of at least 50 mines at Fort Leonard Wood (MO), for field-testing to permit experimentation of system scalability to the tactical level. During FY 2003, we will evaluate opportunities to reduce the size of each prototype mine concept to permit expanded delivery options and reduced logistics requirements. We will also develop initial designs for a fully integrated tactical system that would include a warhead to enhance the opportunity for transition of this technology to the U.S. Army for refinement and development of a fully tactical system.

Ground robotic vehicles used in Future Combat Systems and for other uses must be able to navigate, communicate and maneuver in forested areas. To enable this capability, robotic ground forces will require knowledge of the *bare-earth* topography, i.e., the actual terrain height and slope with the vegetation features removed, as opposed to *first surface* measurements that characterize the topography at the treetop level. Information on local tree-stem density and diameter, canopy density and the location of important navigation and mobility features and of obstacles, such as roads, rivers and streams, bridges, fences, power lines, soil types and moisture, will also be required. The **Terrain Characterization** project is assessing the ability of foliage penetration synthetic aperture radar (FOPEN SAR) technology, working in conjunction with other sensors (e.g., microwave synthetic aperture radars and radiometers, hyper-spectral imaging systems, high-resolution photographic systems, and light detection and ranging altimeters), to characterize both the terrain beneath the foliage and the terrain cover. Data from many multiple-sensor modalities often can be rapidly obtained from military and/or commercial satellite and aerial mapping systems. The Terrain Characterization effort will establish the optimal sensor mix for characterizing terrain and determining the accuracies to which the topography and terrain covering features can be estimated. In FY 2001, the program investigated the capabilities of various sensors to support terrain characterization analyses, performed a multi-spectral data collection in northern Arizona, and initiated the investigation of terrain characterization techniques and algorithms. Dual-pass stereo synthetic aperture radar techniques for bare-earth topography were developed and applied to both the very high-frequency (VHF) and ultra high-frequency (UHF) bands of the FOPEN SAR data with very encouraging initial results, providing nominally Digital Terrain Elevation Data Level Two data. Multi-pass, multi-frequency, multi-polarization techniques are being developed that have the potential for providing bare-earth topography, canopy density and tree-stem density. Multiple-pass VHF and UHF interferometric techniques were developed and applied to FOPEN SAR data, with particularly encouraging results being achieved at VHF. The effort will conclude in FY 2002 after conducting several additional data collections in a variety of different locales and then quantifying the achievable performance levels. DARPA is working closely with the National Imagery and Mapping Agency, National Aeronautical and Space Agency (NASA), the U.S. Army Topographic Engineering Center (TEC), and the Cold Regions Research Laboratory. This research could benefit many diverse defense users, including TEC, U.S. European Command, U.S. Southern Command, and U.S. Pacific Command, as well as FCS. Civilian agencies would also benefit from significantly improved terrain mapping, environmental monitoring and forest management. For example, NASA Goddard is currently participating in the effort to support their deforestation/ carbon gas studies.

The **Mission Specific Processing** (MSP) program will develop technology to maximize the sensor data processing capability of Application Specific Integrated Circuits (ASICs) for the most constrained military platforms. The MSP program will enable high rates of sensor data processing in future miniature aero systems (unmanned air vehicles and missiles) and space-based systems that require extremely high sensor data processing capability, while consuming the minimum possible volume, weight, and power. MSP has the goal to provide an order-of-magnitude (10-fold) increase in ASIC processing capability over currently available ASICs in minimum design time. MSP enables new military missions and will ensure that the U.S. maintains technological dominance over adversaries in a world where commercial processors used in many DoD systems are also available to foreign entities. In FY 2001, the MSP program identified potential methods to obtain the 10-fold increase in sensor data processing capability of ASICs in minimum design time, and we identified military applications to demonstrate this increase. In FY 2002, the MSP program will conduct experiments through fabrication of test structures to verify the 10-fold increase in sensor data processing capability. In FY 2003, MSP will begin to fabricate full scale ASICs based on the most promising methods from FY 2002 to demonstrate the 10-fold increase in military sensor data processing applications.

The **High Power Fiber Lasers** program will develop and demonstrate single-mode fiber lasers with output powers of nearly one kilowatt from a single aperture. As part of the Department-wide effort to develop high-energy lasers for military applications, DARPA is pursuing a unique high-power laser approach that uses fiberoptics, similar to those used in telecommunications (but specially prepared), as the laser medium. If enough power can be developed within a fiber, it will still be necessary to combine the power from many fibers to get enough total power to be tactically useful. This is an out-of-the-mainstream approach to high-energy lasers. However, if both of these technical challenges can be overcome, this approach will lead to lasers that are much lighter and smaller than existing designs, allowing them to be placed in tactical aircraft, ships, and small ground vehicles. Having a high-energy laser of such versatility will greatly enhance the safety of U.S. airmen against surface-to-air missiles, and that of U.S. soldiers against cruise missile attack. Tens of kilowatts output power and capability to scale to greater than hundreds of kilowatts output power (and beyond) will be demonstrated through coherently combining the output power from multiple fiber lasers. High-power fiber lasers will provide a quantum leap in Defense capabilities by simplifying the logistic train and providing a deep magazine, limited only by electric power, in a compact footprint. For theater/area defense and self-protection of combat platforms, these lasers will provide speed of light engagement and flexible response against cruise missiles, reconnaissance unmanned air vehicles, rockets, and saturation attack. In FY 2003, greater than 100 watt single-mode output power from large mode area fiber lasers will be demonstrated.

Maritime Operations

The **Friction Drag Reduction** program, which is ending in FY 2002, is developing a sound theoretical understanding of the physical principles and mechanisms for reducing the frictional drag on ships' hulls by 30 percent as they move through the water. The technology is applicable to all platforms, i.e., surface ships, submarines, manned and unmanned vehicles. We are working with 11 universities to address, by means of computation and small-scale laboratory experiments, the drag-reducing effects of polymer additives and microbubbles. This includes direct numerical simulation and two-dimensional flow experiments in channels or test tunnels where the models are much less than 10 feet in length and in hydrodynamic flow test facilities. During FY 2001, recent advances in computational technology, such as applying advanced spectral methods to this very complex problem, have reduced computational times by over an order-of-magnitude. Most teams have optimized performance using parallel computing architectures to develop a multi-scale modeling capability for turbulent flow. "Multi-scale" includes both time- and length-scales, spanning over six orders-of-magnitude in time and 12 orders-of-magnitude in length (i.e., molecular to ship-scales in time and length). During FY 2002, the Friction Drag Reduction program will continue these modeling activities and will validate initial modeling efforts through small-scale laboratory experiments. The program will also develop constitutive relationships for the underlying physics associated with polymers or microbubbles in water for scaling drag reduction results to larger-scale models appropriate for predicting the drag reduction in operational vessels. We are developing a transition relationship with the Hydrodynamics Technology Center to conduct follow-on simulations and experiments to further develop this technology.

The **Loki** program seeks to develop the critical system technologies, such as a vortex combustor and related propulsion technologies, materials, structures, and sensing technologies at a small (one-tenth or less) scale to demonstrate the engineering and technical feasibility of a lethal, stealthy, high-speed maritime "fighter" platform. If successful, Loki will enable aggressive, offensive U.S. military combat operations in littoral regions. With greater and speedier access achieved, in part, through the operational flexibility and "combat punch" of these underwater "fighters," joint littoral campaign objectives would more likely be successful on an engagement schedule set by the U.S. In FY 2002 and FY 2003, DARPA will be conducting detailed performance analyses of major components and commencing with their development. Loki is in its early stages of studies and critical technology development, and we will be working with the Navy user community to identify application and transition opportunities as the program matures.

One of the key enabling technologies for Loki is a reliable, high energy density power source. The **Vortex Combustor Demonstration** program is an innovative effort that seeks to develop a high energy density (over 1000 Watt-hours per kilogram) air-independent, underwater propulsion technology that uses combustion of metal and water to produce thrust. If successful, this combustor has the potential to revolutionize undersea vehicle propulsion for large and small commercial and military platforms by greater than an order-of-magnitude improvement over lead acid battery technology. In FY 2002, DARPA, in conjunction with Applied Research Laboratory, Pennsylvania State University, Naval Air Warfare Center China Lake, and Naval Surface Warfare Center Carderock Division, is testing and evaluating the performance of a one-tenth scale vortex combustor. Initial demonstrations will be completed in FY 2003. This will have demonstrated the ability of such a device to operate underwater for at least an hour and to be throttled. In FY 2003, the program will verify operation for more than 10 hours, characterize engine static performance, and prepare for dynamic testing. If successful, the results of the Vortex Combustor Demonstration program will be integrated into the Loki program.

The goal of the **Robust Passive Sonar** program is to significantly increase the performance of tactical towed sonar systems operating in littoral environments. This will be accomplished by canceling out the primary cause of interference, surface shipping noise and extending target detection and capability. The Robust Passive Sonar program accomplishes surface shipping noise cancellation by innovative processing techniques coupled with multi-dimensional receive arrays and other external information. In addition, the program will extend target detection and tracking: (i) while the receive array is maneuvering by compensating for the acoustic array shape; and (ii) in the forward direction by suppressing noise from the receiver tow platform. Net system performance gains against surface shipping noise are expected to be 10 to 20 decibel, and it is expected that this system will dictate future array and acoustic sensor field designs. In FY 2001, the program began development of a processing system that will integrate various space-time adaptive processing algorithms to reject interference. We initiated testing these algorithms using historical data from existing towed acoustic arrays. In FY 2002, the program is conducting data collection exercises with the Navy in U.S. coastal waters using experimental acoustic array systems and Navy operational assets. These scientific experiments will emulate littoral operational geometries and provide the data necessary for algorithm development and testing. We will conduct a preliminary performance assessment of the integrated system. In FY 2003, we will complete processing system integration, and we will conduct a non-real time laboratory evaluation against each of the performance objectives of the program using the Robust Passive Sonar experimental data.

The **Undersea Littoral Warfare** program is exploring anti-submarine and countermine warfare techniques and technologies specifically applicable to the unique challenges of the littoral region, e.g., high traffic density, complex oceanographic environment with varying salinities, turbidities, noise, clutter, bottom, bathymetry, weather, tides, and currents. DARPA is working on advanced sonar systems and sensing technologies (such as in the Robust Passive Sonar program) to address these challenges. During FY 2001, the program pursued and demonstrated the Netted Search, Acquisition and Targeting (NetSAT) system, a networked approach for improved attack performance that exploits the use of a sonobouy field during the weapon run to identify, locate and mitigate the impact of countermeasures and target evasion tactics on torpedo operation. A bi-directional fiberoptic link enables return of torpedo information to a processor servicing the other sensors on the network, in addition to providing a command link for the weapon. The ability to rapidly discern the geographic picture from multiple viewpoints is expected to provide major (i.e., 10-fold) torpedo performance improvements in strong countermeasure environments, while requiring only modest modification of existing torpedo inventories. In addition, the Undersea Littoral Warfare program is developing approaches to undersea warfare that will revolutionize the ability to classify and identify underwater objects and improves search rates by more than an order-of-magnitude greater than is possible with current techniques. We investigated enabling technologies for unique weapons and payload concepts, focused on non-traditional approaches to sensing, tracking, and exploiting the maritime environment. During FY 2002 and FY 2003, DARPA will be developing approaches that promise to revolutionize our ability to classify and identify underwater objects, such as mines. We will also develop technologies for locating and tracking maritime targets of interest, including the use of innovative sensor and array technologies.

Air Operations

The **Quiet Supersonic Platform** program addresses enabling technologies for long-range supersonic flight that also reduce sonic boom to an acceptable level. Over the past year, aircraft designers responded to our challenge and showed that long-range and reduced sonic boom can be achieved at the same time using innovative aircraft configurations and technologies. In FY 2002, we will demonstrate for the first time that a specially shaped aircraft can produce a quieter sonic boom. We will also continue to develop the revolutionary aircraft and engine technologies that will enable the next-generation of supersonic military and civilian aircraft.

The **Hypersonics Flight Demonstration** program will develop and demonstrate advanced technologies for hypersonic flight. Flight-testing will be initiated as early in the program as possible and will progress from relatively simple and low-risk tests through the demonstration of an increasingly more difficult set of objectives. The ultimate goals of the program are to demonstrate a vehicle range of 600 nautical miles with a maximum sustainable cruise speed in excess of six times the speed of sound, and to dispense a simulated or surrogate submunition. Technical challenges include the scramjet propulsion system, thermal environment, and guidance and control in the hypersonic flight regime. Recently demonstrated performance in ground testing of the scramjet engine, coupled with advances in high-temperature, lightweight aerospace materials, are enabling technologies for this program. The program will pursue a two-pronged approach. The core program will focus on development and demonstration of capabilities requisite for an operational weapon. A separate effort will be performed in parallel to demonstrate advanced propulsion technologies and develop low-cost test techniques. The Office of Naval Research will partner with DARPA in the execution and funding of this program. In FY 2002, the first year of the program, teams will: (i) perform preliminary and detailed design efforts and supporting materials/structural demonstrations; (ii) conduct freejet aero-propulsion testing of the heavyweight vehicle configuration; (iii) perform ground test verification (static firing) of boosters; (iv) conduct captive-carry, drop, boost performance and boost separation flight tests; (v) conduct sled tests of simulated submunition deployment; and (vi) perform advanced combustion systems proof-of-concept testing on a gun-launched test range. In FY 2003, the program will conduct various vehicle subsystem tests and integrated vehicle tests. We will also perform several low-speed flight tests and sub-scale vehicle flight tests.

Current tactics against a cruise missile threat can be easily overwhelmed by a threat consisting of large numbers of low-altitude cruise missiles. The **Supersonic Miniature Air-Launched Interceptor** (MALI) program demonstrated an inexpensive supersonic air platform with a low-cost infrared sensor to provide cruise missile defense by exploiting large rear aspect infrared signatures and overtaking incoming missiles from the rear. The MALI's capability will increase the engagement range, increase load-out, and provide a shoot-and-forget concept so that other threats can be engaged. This force-multiplying weapon can be used by tactical fighters using triple ejection racks, or by the B-52. The program leveraged the recently completed DARPA Miniature Air-Launched Decoy program's technology and off-board surveillance and tracking sensors to provide tail-on missile end-game opportunities. The MALI program is in the final phases of flight testing, which will be completed this year. The MALI program successfully demonstrated: (i) complete air vehicle fabrication, assembly and ground testing; (ii) complete engine and infrared payload testing; (iii) inter-vehicle communications, mission processing and execution capability; (iv) hardware-in-the-loop demonstration of subsonic vehicle interceptor and collaborative formation flying mission; and (v) free flight intercept demonstration against a representative target. By program completion, the program will have completed supersonic engine flight verification and seeker/advanced payload verification.

The **Micro-Air Vehicle** (MAV) program is a joint DARPA/Army Advanced Technology Concept Demonstration (ACTD) to demonstrate the technical feasibility, military utility, and operational value of an MAV system that can effectively and affordably provide the lowest-level fighting team (platoon or squad) real-time information about the enemy around their position. The DARPA-managed effort builds on the previous MAV technology program and the Organic Air Vehicle (OAV) program. Those programs demonstrated small (down to six inches in size) unmanned air vehicles and autonomous flight of nine inches to twenty-nine inches ducted fan vehicles, respectively. The ACTD focuses on the small, six to nine inch diameter, ducted fans that a single soldier can carry in his/her backpack without displacing anything else. The unique attribute of the system is the ability to "perch and stare," which is the ability to land and continue to collect data. These systems are a cross between an unmanned air vehicle and an unattended ground sensor. While the vehicle is sitting collecting data (like an unattended ground sensor), it uses two orders-of-magnitude less fuel than while flying (i.e., one hour flight time uses the same fuel as one week of "perch and stare"). However, unlike unattended ground sensors, the MAV retains the ability to take-off and fly to another location, or to follow something of interest that is moving. In FY 2002 DARPA will have MicroCraft build 100 MAVs, and demonstrations will occur at U.S Army Pacific. Soldier feedback will be taken into consideration and, where practical, incorporated into the design. In FY 2003 another 100 vehicles will be built and delivered, and, after Army safety approval, will be put into the hands of the soldiers for further evaluation and field trials.

The **Canard Rotor Wing** is a revolutionary airplane concept that offers the potential to realize the basing flexibility of a helicopter and the speed and efficiency of a fixed-wing aircraft. This could have significant military impact in both unmanned and manned designs. In addition, a Canard Rotor Wing could be designed with a lower radar cross section than competing vertical take-off designs because there are no external propellers or rotors once wing-born flight has been achieved. Survivable, high performance, long-endurance aircraft would not be restricted to runways or big-deck carriers. Fabrication of all components of the eighteen-foot-long unmanned demonstrator aircraft was completed in FY 2001. We completed the final assembly and subsystem checkout in early FY 2002. In the second half of FY 2002, we will conduct ground testing, including critical full-power restrained testing. Flight testing will take place in late FY 2002 or early FY 2003.

High-Risk, High-Payoff Technologies

DARPA continues its traditional investments in the development of fundamentally new technologies, particularly at the component level, that may have far reaching military consequences, even though their specific application may occasionally still be somewhat unclear. Historically, these kinds of investments have been the technological feedstocks eventually enabling quantum leaps in U.S. military capabilities.

INFORMATION TECHNOLOGIES

DARPA is creating the intelligent information systems that will radically enhance our military's information dominance and transform our national infrastructure and economy. Our efforts build on traditional and revolutionary computing environments (networks, architectures, databases and processors) and strive to provide device/system control, human-robot and robot-robot collaboration, enhanced human cognition, and information-centric discovery. Information Technology at DARPA has given us a strong legacy: personal computers, the mouse, timesharing, firewalls, the Internet, asynchronous transfer mode, synchronous optical network, TCP/IP, packet-switching, search engines, natural language processing, and linear algebra libraries. Twenty years from now, we will be marveling at the *new* legacy of robotics, network-centric warfare, knowledge formulation, extreme-maneuvering control systems, embedded systems, and self-monitoring, self-healing, and resilient-to-attack software.

Networking

The *Networking* component comprises high performance, highly robust, and rapidly configurable networking capabilities essential for both secure national infrastructure and *ad hoc* military networks. The results will be applicable to wired, wireless, and mixed networks.

The **Network Modeling and Simulation** program will develop tools to predict the performance and vulnerabilities of complex networks, such as the Internet and highly dynamic military networks. The ultimate objective of the program is to simulate, design, and monitor performance and vulnerabilities of DoD networks with millions of nodes and application traffic. New and validated models derived from complex systems theory and simulation tools will also provide on-line, autonomous, and semi-autonomous network control capability (reducing human intervention), as well as rapid planning and design of mission-specific networks. In FY 2001, the program initiated the development of models and measurement techniques, as well as collaborative work with Navy and Air Force. In FY 2002, these models were the first to identify the vulnerability in the core Internet due to Code Red and Nimda virus attacks, specifically the global routing instability. Potential techniques for reducing the vulnerability were analyzed and reported to the Defense Information Service Agency. The program also demonstrated fast simulation techniques for on-line analysis of a Navy reconfigurable land-based tactical network with hundreds of nodes and links, ranging from routers on-board ships to satellite links and soldier radios. In FY 2003, the program will develop methods for prediction, control, and design that can scale to thousands of nodes.

The **Ultra High Performance Networking** program is advancing today's transparent, all-optical networking and gigabit wireless techniques to dramatically enhance the bandwidth reliably available to end-applications. All-optical, self-healing architectures are being developed to create high-confidence networking infrastructures. New paradigms in wireless link techniques are also being explored to make possible fade-immune networking in complex, harsh environments, such as adverse weather conditions and urban terrains with obstructions and interference sources. To focus the research, the program is further developing key DoD applications that take advantage of the robust capability to stream gigabyte to terabyte real-time sensor data. In FY 2001, the program demonstrated sparse band sensor processing technology, where multiple gigabit per second streams from radars operating in different bands were processed to dramatically enhance the sensitivity and resolution attained from independent sensors. In FY 2002, sparse band processing will be demonstrated in real-time over the DARPA Boston South Network test-bed with two radars in Westford, MA, and the processing in Arlington, VA. In FY 2003, the program will shift emphasis from application drivers to robust infrastructure technology, with a proof-of-concept demonstration of a hybrid free-space optical/wireless self-healing link operating at 600 megabits per second.

DoD applications can be highly bandwidth-intensive, and their demanding requirements cannot be met by the commercial networks that are optimized for web-browsing and low data-rate data streaming. The **Next Generation Internet** (NGI) program, coming to a close this year, built the key technologies, in both hardware and software, to provide end users access to extremely high-bandwidth (one to 10 gigabits per second) – an increase of 10 to 100 times over the 100 megabits per second capabilities now being deployed in commercial Intranets. NGI established a number of high-speed end-to-end networking records: (i) in March 2000, the Internet 2 consortium's "Land Speed" award went to a team who achieved an end-to-end (i.e., workstation-to-workstation) transmission rate of 957 megabits per second between Redmond, WA, and Arlington, VA, over the NGI SuperNet test-bed; and (ii) in November 2000, an award for best overall performance was presented to an NGI team at the Supercomputing 2000 conference for achieving a peak rate of 1.48 gigabits per second over SuperNet on an application for remote visualization of a terabyte scientific dataset in Berkeley, CA. New protocols were developed and demonstrated to address the vulnerability of existing networking protocols to bandwidth-intensive flows – a problem that first surfaced in NGI experiments. A national-scale SuperNet test-bed connecting several dozen sites at multi-gigabit rates has been deployed and continues to host experiments in gigabyte applications being developed under the Ultra High Performance Networking program. The NGI program has demonstrated the viability and necessity of innovative technologies, such as optical burst switching and all-optical routing in supporting multi-gigabit flows to end users. The NGI program has spawned a number of start-up commercial companies, ensuring the future commercial availability of gigabit technology for national security applications in the Intelligence Community and the DoD.

The **Quorum** (formally **Systems Environments**) program developed advanced resource management, middleware, and operating systems for mission-critical applications to share a common pool of networked, commercial-off-the-shelf processors, while still meeting their real-time deadlines. Resources are dynamically allocated to the most critical applications when experiencing workload surges, failures, and threat- or mission-mode changes, while still ensuring that other applications receive acceptable quality-of-service. Quorum technologies are the foundation for two key open architecture initiatives. First, the Aegis Baseline 7 Phase II, the new open architecture for the Aegis Weapons System, is based on the successful integration and demonstration of Quorum technologies into a test-bed at the Naval Surface Warfare Center. Its performance exceeded the Navy's "Ring of Death" requirements. Second, Boeing's Bold Stroke avionics architecture for the F-15 has been significantly extended with Quorum technologies to allow cross-platform coordination across tactical networks in support of time-critical retargeting. In both cases, Quorum's quality-of-service middleware and resource management technologies allow satisfaction of mission-critical requirements on an evolving commercial off-the-shelf technology base, reducing development and life-cycle costs. The Quorum program has led to a number of commercial products, commercially supported open-source products, and commercial and DoD standards for distributed computing architectures. Quorum pioneered the concept that mission-critical systems could be constructed from independently developed horizontal layers of system software working together to meet application quality-of-service requirements. Without Quorum, DoD would have to continue to rely on costly, vertically integrated, proprietary solutions that are only applicable to a single system.

Network Embedded Technology

The *Network Embedded Technology* component will develop software technology to build distributed, real-time, and embedded applications at several levels of granularity, ranging from tens of computing nodes to over a million nodes. By using major theoretical breakthroughs during the past decade in hybrid systems, statistical physics, finite-size scaling, generative programming, and distributed control, the programs have a solid foundation for achieving the ultimate goal of revolutionizing how software-intensive embedded platforms are built for the DoD.

MEMS-based distributed control devices blend information and physical processing at the most basic level, thus blurring the separation between computation and sensing, and actuation in the physical world. The **Networked Embedded Systems Technology** program is developing robust coordination services for networks of such devices. Networked Embedded Systems technology is targeted at applications that operate under extreme resource constraints of power, timing, memory, communication, and computation, while simultaneously being highly scalable and robust. Such applications included coordinated sensor and actuators elements for acoustic and structural damping in Delta rockets, sensor fields for surveillance, target tracking, and environmental monitoring and control. In FY 2001, the program initiated the development of essential coordination services for synchronizing clocks, forming consensus when data values disagree, and electing a single node as a leader. In FY 2002, the program is building upon these to obtain memory-, power-, and communication-efficient services that can be used at design time in a "plug and play" manner. Also, in FY 2002, the program is conducting experimental and theoretical investigations on "phase-transition" effects in computational problems (i.e., the dramatic change from being "easy" to being "unsolvable") in problems that involve the simultaneous satisfaction of multiple constraints. These effects are of crucial importance in obtaining efficient solutions involving thousands of variables in applications, such as active damping, coordinating actuator movements in space-based structures, and pursuer-evader scenarios. We will leverage these studies in FY 2003 to synthesize application packages for complex networks of thousands of nodes, such as in distributed avionics or space-based phased array antennae.

As DoD is faced with new environmental, economic, terrorist, and information warfare threats, DoD weapons systems must transition from platform-centric to network-centric. Developing a new generation of network-centric technologies that greatly enhance the adaptivity, assurability, and affordability of embedded software is therefore 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 of, and confidence in, the resulting weapons system software. The technology produced by the PCES program in FY 2001 yielded static analysis techniques for real-time embedded system synchronization and memory management properties, and it demonstrated how these techniques enhanced the flexibility and robustness of navigation and sensor control in operational avionics mission computing systems at Boeing Phantom Works (St. Louis, MO). In FY 2002, the PCES program is developing and applying intermediate representations and mechanisms for code composition and transformation that will automatically generate adaptive software to control and enhance the quality of surveillance and reconnaissance missions performed by unmanned air vehicles. In FY 2003, the PCES program will develop and demonstrate techniques for simultaneously enforcing real-time and fault-tolerance behavior of weapons targeting algorithms in the Unmanned Combat Air Vehicle system.

The **Model-Based Integration of Embedded Software** (MoBIES) program will provide the tools to automate the generation of highly reliable software that addresses the special needs of real-time embedded computing. Because embedded computers control nearly all complex weapons, communications, and vehicle systems, and because such systems are often mission-critical and safety-critical, there must be efficient and fundamentally sound techniques for producing the software. The MoBIES approach is to mathematically map the physics of the host application to formal expressions of the system's requirements. MoBIES does this with symbolic representations from which automated performance, safety, and correctness analysis can be performed, and which can be automatically refined into executable program code. In FY 2001, modeling tools were created that allow formal symbolic representations of application domains (e.g., avionics or vehicle control systems) to be created. We also created mathematical representations for performance constraints, such as processing deadlines and resource allocation. In FY 2002, we are developing individual design tools, along with standard interchange formats and behavioral specifications, so that we can create large, complex systems using collections of smaller, specialized tool components. We are also developing correct-by-construction automatic code generators so that we can translate formal system models into executable programs with guarantees that the resulting code will meet safety criteria. In FY 2003, we will integrate the tools and design technologies into application-specific design environments, so that we can test the resulting toolset for scalability, composability (a measure of modularity), and efficiency. We will also address technologies for customizing the embedded computing platform based on software designs. The end result of MoBIES will be a modular system design infrastructure that will allow domain experts to develop tools for embedded system production projects, which will then generate efficient, error-free software. MoBIES technology will eliminate manual steps in embedded software development, verification, and validation, so that we can efficiently and reliably produce large, complex, computer-based systems (e.g., next-generation aircraft and network-centric command and control systems) that are beyond the reach of conventional software engineering.

New and planned DoD combat systems, such as total ship computing environments and theater ballistic missile defense, are network-centric systems. Multiple quality-of-service dimensions, such as predictable latency/jitter/throughput, scalability, dependability, and security, must be satisfied simultaneously in real-time. The levels of quality-of-service in one dimension must be coordinated with, and/or traded off dynamically against, the levels of quality-of-service in other dimensions to achieve overall mission goals. To meet these needs, the **Adaptive and Reflective Middleware Systems** (ARMS) program is developing and validating the new generation of distributed real-time and embedded middleware technologies that can adapt dependably in response to dynamically changing conditions (e.g., during a battle) to utilize the available computer and network infrastructure to the highest degree possible in support of mission needs. In FY 2002, the ARMS program will develop manually optimized adaptive protocols, algorithms, middleware frameworks, and software tools that can manage distributed combat system resources dependably and predictably in real-time. In FY 2003, the ARMS program will formalize design expertise so that middleware frameworks and application components used on distributed combat systems can be optimized automatically rather than manually. These optimizations will be applied in the context of the DD(X) Total Ship Computing Environment.

The **Augmented Cognition** (AugCog) program will extend, by an order-of-magnitude or more, the information management capacity of the “human-computer” combination by developing and demonstrating enhancements to human cognitive ability in diverse and stressful operational environments. Specifically, this program will develop the technologies needed to measure and track a subject’s cognitive state in real-time. Military operators are often placed in complex human-machine interactive environments that fail when a stressful situation is encountered. The technologies under development in AugCog have the potential to enhance operational capability, support reduction in the numbers of persons required to perform current functions, and improve human performance in stressful environments. In FY 2002, the AugCog project is developing robust, non-invasive, real-time, cognitive state detection technology for measuring the cognitive processing state of the user. In FY 2003, AugCog will develop and test integrated multi-sensor interface technologies that will permit human state manipulation. This represents a new paradigm for human-computational systems interfaces.

The **Information Management** (IM) program, which concluded in FY 2001, increased the effectiveness and efficiency of intelligence analysis by increasing the amount of relevant information that an analyst could find and examine from an exponentially growing search space of potential sources. The program presented innovative views of the data, such as concept analysis or visualization of the content distribution of large documents, to assist analysts in determining relevance. It also developed technologies for providing analysis environments to analysts, allowing them to easily correlate a number of different types of information (e.g., maps, documents) and use textual and geospatial searches to quickly access information. IM also developed collaboration techniques to allow analysts to use the results of others’ searches to quickly refine their own. Research prototype systems developed under the IM program have been deployed in various military installations. A collaborative digital logbook, developed at the University of Arizona, was used on USS Coronado and in a Strong Angel exercise, and has been selected for deployment on all Navy ships. The IM Digital Object Architecture has been transitioned to the Defense Technical Information Center, Defense Virtual Library System and also to the U.S. Copyright Office Electronic Registration, Recordation, and Deposit System through a joint effort with the Library of Congress. GeoWorlds (an analyst environment) is used at U.S. Pacific Command and was included this past Fall in a limited objective experiment. The MuST Tool is used at U.S. Pacific Command to search and translate Indonesian web sites.

As information technology bridges the gap between the physical and digital worlds, computers should disappear into the background, while information becomes ubiquitous. The **Ubiquitous Computing** program, ending this year, has focused on developing the underlying technologies to: (i) provide accessible, understandable, and relevant information to mobile users, based on an understanding of the user's tasks and informational needs; and (ii) provide users with greater and more timely situational awareness – thereby increasing their survivability, lethality, and effectiveness. In FY 2001, the Ubiquitous Computing program delivered several products: (i) TinyOS, a small foot-print operating system that enables self-organization of small, resource and power-constrained computing devices, was deployed on the sensor nodes used in a distributed sensor network vehicle tracking demonstration at Twentynine Palms last year by the DARPA Information Technology for Sensor Networks program; (ii) a component-based architecture that provides seamless computing support to mobile ground troops, enabling them to have access to digital information needed for their tasks; and (iii) a utility providing secure, reliable, 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 addition to these "system-level" services, the Ubiquitous Computing program established the foundation for user-level context-awareness and task-centric computing capabilities that conserve user attention by automatically inferring user intent based on cues, such as physical location. Prototypes were developed to model user tasks that permit automatic migration to available resources. As a motivating scenario, consider a busy commander who must continuously participate in a teleconference while accomplishing other tasks and traveling to another meeting. As he moves from a conference room to his office to the street to his car, the ubiquitous computing services would automatically detect each context change and migrate the teleconference application from a dedicated videoconference system to his Internet-connected desktop personal computer, then to a wireless personal digital assistant, and, perhaps, finally to a cell phone. This would be accomplished while automatically adjusting the mode of the interface (video, audio, text) and its quality depending on the characteristics, performance, and bandwidth connectivity of the device being used taking into consideration other tasks competing for the commander's attention (e.g., driving a car). While this scenario is not yet completely realizable, the Ubiquitous Computing has demonstrated the essential enabling system architectures and services.

As software systems become increasingly complex, they must be self-monitoring and self-healing, and they must reconfigure and evolve themselves dynamically – even while the system is in operation. **Dynamic Assembly for Systems Adaptability, Dependability, and Assurance** is developing probes, gauges and tools so systems can: (i) monitor their operating systems and critical components; (ii) determine the suitability of components for insertion/(re)use; (iii) enable safe run-time component deployment and composition; (iv) guide adaptation, and integration; and (v) ensure that critical (user-defined) properties are maintained during and after composition, adaptation, and deployment. The program's successes include: (i) automated code generation that is 33 percent more reliable than Capability Maturity Model Level 4 human team; and (ii) emerging global standards for architectural language and architecture assurance. These techniques will also assure properties of "off-the-shelf" or "open-source" components with respect to the requirements of a specific system. These capabilities will provide dramatic improvements in our ability to compose commercial software components.

The **Autonomous Negotiation Teams** (ANTS) program (formerly **Mobile Code Software**) is solving time-critical constraints in logistics and mission planning and other distributed applications. The interaction of lightweight, mobile components (e.g., software agents emulating aircraft, pilots, weapons, and targets) uses a bottom-up organization approach and negotiation as techniques for resolving ambiguities and conflicts that arise in real-time scheduling. For example, scheduling daily sorties over a month for a squadron of pilots and aircraft requires balancing thousands of variables, such as aircraft maintenance time, individual pilots' flight times, and overall combat readiness level of an entire squadron. In FY 2001, ANTS demonstrated software agents' ability to approximate behavior tradeoffs and to utilize negotiation in advanced logistics scenarios of 1000 components and a three-second response requirement. This ANTS capability has now transitioned through an Advanced Concept Technology Demonstration and deployment in Marine Air Group Harrier squadrons. This is being extended in FY 2002 to cooperative flight scheduling and maintenance planning and, also, to prototype implementations in mission planning for unmanned combat air vehicle operations. Another thrust is to demonstrate cooperative tracking, in real-time, of moving objects by autonomous sensors. FY 2003 will culminate this effort with demonstrations of resolving conflicts under time limits by re-negotiating plans or modifying goals, maintaining stable performance in changing environments, and multiple target tracking with requirements of 0.25 foot error, 90 percent probability of disambiguation, and 500-millisecond response time.

Responsive Computing Architecture

The *Responsive Computing Architecture* component is developing integrated computing with fully distributed intelligence that will enable all levels of the system to respond in real-time to dramatic changes in mission requirements and operating constraints. The current projects are focused on energy/power management, quality-of-service, algorithm/application computing diversity, and scalable computing efficiency.

Energy and power management has now become a critical factor for computing applications. The **Power Aware Computing/Communication** program is developing integrated software/hardware power management comprised of novel techniques applied at all levels – from the chip to the full system. This will enable computing systems to reduce energy requirements by 10-fold to a 1000-fold in military applications ranging from hand-held computing devices to unmanned air vehicles. In FY 2001, the program developed and evaluated individual power aware technologies at the device, operating system, compiler, algorithm, and mission level. Results to-date indicate that individual power management techniques can be demonstrated in FY 2002 that will result in energy savings greater than 10-fold. In FY 2003, focused system technology risk reduction demonstrations, highlighting a composite of these high-payoff technologies, will be initiated for a number of energy-constrained systems, such as Land Warrior, distributed sensors, space sensors, and mobile devices.

The **Data Intensive Systems** program, completed in FY 2001, developed innovative data access techniques to reduce the processor-memory performance barrier that has been a limiting factor for large database applications, sensor based processing, visualization, and data-intensive simulations. During this three-year program, Data Intensive Systems implemented, demonstrated, and validated key technologies spanning processor-in-memory, adaptive memory, computing streams, and data organization. The program demonstrated execution time/run-time computing performance improvements of 10-fold to a 100-fold for a wide range of DoD target applications, such as radar beam steering controller, graphics rendering, and ray-tracing for a T-80 tank. These basic innovative technology developments are now being incorporated in commercial computing systems used by the DoD and Department of Energy simulation facilities, and are providing crucial data intensive technology underpinnings for future computer systems.

The **High Productivity Computing Systems** (HPCS) program, in concert with the **High Confidence Computing Architecture** program, will provide the DoD with significant technology and capability advancements for the national security and industrial user communities by developing a new generation of productive, high-end computers that fill the computing gap between today's late 1980s-based technology systems and the promise of quantum computing. This program is targeting high-end computing for medium-to-long-term national security missions where U.S. superiority and security is threatened. Critical target mission areas are intelligence/surveillance/reconnaissance, cryptanalysis, airborne contaminant modeling, weapons analysis, survivability design and emerging biotechnology. The plan is to implement the program in three phases, which are concept study (Phase I), research and development (Phase II), and full-scale development (Phase III). The HPCS Phase I industry concept study, initiated in FY 2002, will provide critical technology assessments, develop innovative HPCS concept solutions, and provide new productivity metrics. A new class of high-end computers may then be developed towards the end of this decade to meet the ever-expanding data processing requirements. The results from Phase I will be merged with other DoD long-range high-computer mission requirement assessments to establish the basis for system design, selected supporting technology, and early prototype developments in Phase II. Phase II HPCS research and early concept prototypes activities will be initiated in mid-FY 2003, following the evaluation and competitive selection of Phase I activities.

Agent-Based Systems

The **DARPA Agent Markup Language** (DAML) project is creating technologies that enable software agents to identify, communicate with, and understand other software agents dynamically in a web-enabled environment. Agents are software programs that run without direct human control or constant supervision to accomplish goals specified by the user. They 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 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 diverse military sources and systems as the DAML technologies are deployed in both command and control and intelligence applications. In FY 2000, DAML developed the first working draft of the software language and coordinated it with the World Wide Web Consortium. In FY 2001, the program released working versions of Briefing Tools, Search Tools, and Ontology Creation Tools, and defined and tested a new toolset of DAML technologies for military applications. In FY 2002, the focus of the DAML program is shifting from predominately independent language and tool development to the integration and refinement of these capabilities through integrated demonstration and experiments, which involve multiple nodes, ontologies, databases, and agents. Also in FY 2002, the DAML Search tool is being deployed on an operational intelligence network node, and selected DAML tools are being prototyped on other military and civilian systems. One such tool is the DAML-HTML Gateway, which builds DAML gateways (or "front ends") to existing HTML servers. Such gateways can be used until the site itself produces DAML directly. DAML is also being employed by the Air Mobility Command for mission planning. The DAML information will be used to automatically indicate to planners what constraints need to be considered in obtaining foreign clearance for missions to and/or the over flight of foreign countries. As DAML tools are refined in FY 2003, they will be deployed in additional intelligence applications and expanded into the command and control domain. As an example, the Navy Warfare Development Command intends to evaluate the use of DAML technologies in their Expeditionary Sensor Grid program. The Expeditionary Sensor Grid is a multi-tiered, warfighter-centered architecture of numerous and heterogeneous battlespace sensors that complement current and planned national and theatre systems. Moreover, Joint Forces Command is interested in DAML in support of their Operational Net Assessment function. This activity is focused on assisting the Joint Force Commander in deriving targeting objectives.

Today's complex military problem-solving tasks are either performed totally by human operations officers and intelligence analysts, or by humans with minimal assistance from 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 in future operations. In FY 2001, RKF demonstrated direct knowledge entry by a single, novice user into a knowledge base that addressed a challenging microbiology domain, i.e., RNA transcription. This demonstration confirmed that the RKF program was on-track to achieve its knowledge entry rate goals (2000 axioms per month) in a technically difficult domain. This rate is 10 times that of previous technology and should enable the creation of encyclopedic knowledge bases. For FY 2002, RKF is focusing on knowledge entry for a militarily significant challenge problem: creation of a battlefield situation reasoner in an air-to-ground scenario. This challenge problem will test combined RKF tools in an integrated knowledge base development system using mixed development teams of multiple logic and domain experts, and it will demonstrate a rate of 50,000 axioms per month from the domain experts. RKF tools developed and expanded during the challenge problem will be refined in FY 2003, and the knowledge entry rate (10^6 axioms per year) for a massive knowledge base will be demonstrated in a military application. The FY 2003 military application, is focused on time-critical targets (e.g., SCUD missiles) and will draw inferences about possible SCUD locations and movement given intelligence reports, terrain data and historical information.

Modern warfare and rapid response contingencies require that the military rapidly assemble disparate information systems into a coherent, interoperating whole. This system integration 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 has forged the technology for run-time interoperability of heterogeneous systems by creating the CoABS Grid. The CoABS Grid has been demonstrated to all three Military Services and is a key technology enabler for the Navy's Expeditionary Sensor Grid, a lead exemplar of net-centric warfare. In FY 2002, 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. The Navy's Expeditionary Sensor Grid experiment demonstrated that hundreds of individual sensor systems associated with weapons and tracking systems can be rapidly linked to produce a "network" that provides for a "net-centric" capability not previously accomplished in near-real-time. Another significant demonstration in the current fiscal year will be a coalition exercise involving five NATO nations and 14 CoABS performers in a military contingency, Binni, that represents, realistically, contingencies similar to Somalia, Haiti, Bosnia, and Afghanistan. In addition, 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. In FY 2003, the follow-on phase will establish the CoABS grid as a standard for collaborative teams of agents.

BIOLOGY-BASED TECHNOLOGY

This year, DARPA continues its foray into the application of the biological sciences for Defense. As in previous years, one of the major opportunities in this area is to use biology for the *Protection of Human Assets*. This is primarily represented by DARPA's robust program in Biological Warfare Defense described elsewhere. However, the exploration of the life sciences can also lead directly to incredible breakthroughs in *Enhancing Human Performance*. This is represented in DARPA's program in Biological Materials. In addition, the lessons learned from the biological sciences can provide significant insight into *Enhancing System Performance*. An overview of each of these areas follows:

Enhancing Human Performance: The human is becoming the weakest link in Defense systems. Sustaining and augmenting human performance will have significant impact of Defense missions and systems, enabling sustained human interactions for prolonged performance and enabling new human capabilities. Exploiting advances in brain structure and function and human behavior will be one focus of discovery that could dramatically affect future warfighting capability from the individual soldier and the operation of complex technologies in Defense missions. In addition, we plan to develop new biochemical approaches to understanding the origins and ameliorate the detrimental effects of sleep deprivation and other human physiological limitations.

Enhancing System Peformance: Advances in life sciences, when applied to Defense problems, offer considerable opportunities for enhanced warfighting capabilities. Areas such as autonomous systems, denied access, and signal extraction in cluttered backgrounds are examples of Defense issues that may have solution sets in the life sciences. DARPA will undertake new technological explorations of new systems with superior performance based on novel discoveries in the life sciences. We are particularly interested in using organisms to extract environmental signals in cluttered backgrounds (animal sentinels), exploiting neuro- and behavioral sciences to build intelligent machines and create new signal processing schemes, mechanical biomimicry for fault tolerant mobile robotic systems, and assembly of new structural and multifunctional materials. These new areas of discovery in the life sciences may be able to exploit possible solutions for enhanced warfighting capabilities.

There are a number of fundamental properties that common to these thrust areas. First, they cross multiple size scales, from atoms to meters. They also encompass varying degrees of complexity in form and function. It is likely that harvesting technologies from both areas will require a multidisciplinary attack with key, focused investments. Exploring the intersections of biology with other disciplines is the process that will unlock the unique, unparalleled capabilities of biological systems. Consequently, DARPA has a robust, fundamental program that addresses these critical issues and forms the scientific underpinnings that will allow significant progress in these focus areas.

Bio:Info:Micro

DARPA's fundamental research efforts at the intersection of biology, information technology, and the physical sciences, the **Bio:Info:Micro** program, began in FY 2001. The goal of the Bio:Info:Micro program is to develop novel devices and computational tools to develop new information for controlling and exploiting biological systems at the molecular and cellular level in ways that will ultimately be used to protect the warfighter and enhance human performance for carrying out military operations. The approach we have taken to fulfill the long-term objectives of the program is to support interdisciplinary basic research projects at universities, so that we can stimulate the development of a new generation of scientists and engineers performing science and technology at the intersection of biology with information technology and microsystems technology. This approach will yield a new cadre of scientific and technical talent that is capable of developing superior technologies to protect national security and enhance Defense capabilities.

We believe there will be several national security impacts from the Bio:Info:Micro program: (i) improved strategies for rational development of therapeutics based on an understanding of biology at the systems level; (ii) neuromimetic and neurocontrolled microsystems inspired by deciphering neural codes in the brain; (iii) new strategies for creating and controlling massively parallel processing networks inspired by deeper understanding of biological information processing; and (iv) new nanoelectronic and microphotonic arrays for spatially distributed sensors and transducers emerging from the development of new devices for nanoscale interrogation of biological systems.

In FY 2001, several new nanoscale devices were developed for studying cells, molecules and brain function: (i) a microfabricated fluidic device the size of a quarter that can continuously separate DNA molecules by size in seconds; (ii) a motorized housing the size of a quarter for precision movement of microelectrodes within brain tissue in order to enhance the ability to locate functional neurons; (iii) a nanodevice smaller than a human hair that can monitor cell function by sensing small changes in electrical charges on the surface of living cells; and (iv) optical techniques that can image single molecules in living cells. In FY 2002, we will continue device development, including miniaturization of moveable microelectrodes, nanodevices that can be used to detect single biomolecules interacting with each other, and a new spectroscopic technique to measure the absorption of a single molecule in a living cell. These devices will be applied to visualizing the location and number of regulatory molecules that control cell division and differentiation and to measuring and analyzing the electrical activity of neurons in functional brain tissue. In FY 2003, we anticipate that developments that enhance warfighter performance will begin to emerge from this phase of the program and to feed technologies directly into other, more applied technology programs at DARPA.

BioAdaptation

There is no current stand-off capability for monitoring the chemical environment quantitatively with high specificity. The goal of the **Biological Input/Output Systems** program is to demonstrate specific, measurable state changes (e.g., color) in plants and microbes in response to chemicals of interest to DoD (e.g., biological warfare and chemical warfare agents, fuels, explosives, and chemical precursors). These basic investigations will provide the DoD with entirely new ways of remotely and continuously obtaining information on chemical and biological materials via concealable devices (i.e., no power supply required; easy dissemination; unobtrusive) in the air, water, or soil. If successful, this effort will create fundamentally new detection capabilities via organism engineering, such as the ability to detect explosives or chemical warfare agents via remote observation. The Biological Input/Output Systems program began this fiscal year, with efforts expected to be underway by the third quarter of FY 2002 to generate quantitative outputs as a function of exposure to specific chemicals. These efforts will attempt to design genetic responses, signal transduction pathways, and novel pigment synthesis that will specifically and sensitively record the presence of analytes of interest to DoD, such as explosives and chemical agents. In FY 2003, we will demonstrate simultaneous detection of multiple chemical analytes (e.g., explosives and chemicals related to their manufacture) by engineered biological systems.

Nanostructure in Biology

Another critical area in understanding biology is the application of new physics to the understanding of biological structure. The **Molecular Observation, Spectroscopy, and Imaging using Cantilevers** program, just starting in FY 2002, will develop new instrumentation, computational tools, and algorithms for real-time, atomic-level resolution, three-dimension, static or dynamic imaging of molecules and nanostructures. This new information about biomolecules is very important for the DoD, since it will provide important new leads for the development of threat countermeasures, biomolecular sensors, and molecular interventions to enhance and improve human performance. This tool will help with detailed knowledge of doping profiles and defects in nanoscale electronic devices to assist in assessing their performance. It might also be possible to use these techniques to measure and control individual atoms or spins as the ultimate nanoscale switch. In FY 2003, we will demonstrate that this instrument is capable of detecting a single electron spin, enabling us to study spin-labeled single macromolecular complexes in their native functional state.

The **Simulation of Bio-Molecular Microsystems** program is developing innovative interfaces between molecular-scale processes in chemistry, biology and micro/nano-engineering (electronics, optics, MEMS) through experimental and theoretical analyses. The program began 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. These models will enable appropriate trade-offs between sensitivity (i.e., extremely low-concentration detection of target pathogens), selectivity (low probability of "false positives"), and speed-of-analysis for the design of devices/systems for bio-molecular detection. The program has so far demonstrated that sensitivity and selectivity can be increased by orders-of-magnitude through molecular process and device engineering. In one example it was shown that functionalizing gold nanoparticles with probe DNA enabled the detection of atto-molar (10^{-18}) concentration of target DNA with single-base pair selectivity. In FY 2002, the program is developing methods to characterize interfaces (with the biological components of the system) that allow one and two-way communications, smart control, and dynamic reconfigurability. The program will explore the use of MEMS and NEMS (nano-electro-mechanical systems) to interface with bio-molecules to transduce signals from molecular recognition processes and to enable control of bio-molecule performance in chip-scale systems.

Examples include the use of nanopores, nano-cantilevers, and nanotubes for molecular scale control of bio-molecular processes. In FY 2003, the program will design working devices that incorporate living components as sensors, actuators, and computational devices (e.g., nanopore molecular readers, arrays of nano-cantilevers for biological detection, and novel microfluidic systems that are dynamically re-configurable). We will also pursue methods to extract and integrate several bio-molecular devices on synthetic substrates to form larger-scale arrays that will enable large-scale parallelization (and automation) of biological sensing and detection, thereby reducing analysis time by several orders of magnitude. Examples include integrated systems that will enable sample acquisition/preparation, analysis and computation of results at the point-of-care location quickly, efficiently and reliably.

The **Engineered Bio-Molecular Nano-Devices/Systems** program will develop platform technologies to enable the creation of hybrid (organic-inorganic) nano-scale devices/systems for optical/infrared sensing, high-speed molecular sensing/readout, and bio-computing. These platforms will enable direct conversion of biological signals into digital information that can be stored or transferred (wirelessly) for further processing. Examples include a molecular readout system for DNA computing, ultra-fast bio-sensing with molecular level accuracy, and single photon sensing for imaging at low-light intensities. In FY 2003, the program will produce a platform for high-speed, direct molecular readout system for DNA computing. The readout process for DNA computing is currently very time-consuming and tedious, requiring several bio-chemical steps. The proposed system will completely eliminate these protocols and demonstrate (high-speed) direct digital conversion of DNA base-pair information.

Bio-Computation

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: (i) the ability to predict cellular-level effects of chemical and biological agents and the underlying pathogenic processes; (ii) the effect of stress on cell functions (such as circadian rhythms) that affect warfighter performance; and (iii) mechanisms for controlling these effects. In FY 2001, we developed the initial architecture for cell modeling and simulations. In FY 2002, the program is: (i) developing scalable, DNA-based computing and storage; (ii) investigating self-assembly of engineered DNA nano-structures; (iii) developing computational models that capture the behavior of mechanisms in living cells underlying pathogenesis and rhythms that are common to many organisms; and (iv) releasing the first version of cell modeling and simulation tools. In FY 2003, the program will demonstrate the effectiveness of modeling in predicting cellular dynamics, and will identify key intra-cell mechanisms that might be potential targets of interventions in bio-defense contexts. We will also demonstrate applications of DNA-based computing, including design of nano-structures that can potentially enable highly reliable crystallography and layouts for molecular electronics.

Brain Machine Interface

The **Brain Machine Interface** program will explore the creation of new technologies for augmenting human performance through the ability to access codes in the brain in real-time and integrate them into peripheral device or system operations. The following six areas will be addressed in this program: (i) extraction of neural and force dynamic codes related to patterns of motor or sensory activity required for executing motor or sensory activity, such as peripheral limb movements or control of a robot; (ii) determination of necessary force and sensory feedback (e.g., positional, postural, visual, and acoustic) from a peripheral device or interface that will provide critical inputs required for closed loop control of a working device; (iii) new methods, processes, and instrumentation for accessing neural codes non-invasively at appropriate spatiotemporal resolution to provide closed loop control of a peripheral device; (iv) new materials and device design and fabrication that embody compliance and elastic principles and capture force dynamics that integrate with neural control commands; (v) demonstrations of plasticity from the neural system and from an integrated working device or system that result in real-time control under relevant conditions; and (vi) biomimetic implementation of controllers (with robotics or other devices and systems) that integrate neural sensory or motor control integrated with force dynamic and sensory feedback from a working device or system. In FY 2002, projects have been selected to demonstrate the capability for brain integration into a peripheral device remotely and through a wireless interface. The program will also design, fabricate, and implement wireless interfaces to extract necessary control commands from the brain. In FY 2003, the program will extract codes related to the ability to move a peripheral device (robotic arm) and provide necessary sensory feedback.

Bioderived Materials

Impressive autonomy and adaptability are well known attributes of biological systems. The major emphasis of Bioderived Materials is to understand the characteristics that lead to these attributes in biological systems, and adapt them to DoD systems of interest, including robotics and sensors. Specifically, the goal of the **Synthetic Approaches to Bio-Optics** program is to synthetically reproduce the components of a biologically inspired vision system, which demonstrates a level of performance beyond standard optics of today with reduced size and complexity. This program will develop novel synthesis routes to fabricate materials having extreme optical and electro-optical properties. The use of hierarchical structure in materials will be exploited to achieve the material property challenges. This program will begin in late FY 2002, with efforts that range from new material concepts mimicking the multi-layer lenses in biological vision systems to microfluidic-based concepts that enable significant changes in performance. In FY 2003, we will demonstrate materials for a dynamically controlled-index lens with a field-of-view approaching 150 degrees that will enable, with a single set of optics, the ability to scan a broad area and then focus on a target when required.

The **Controlled Biological and Biomimetic Systems** program leverages the extraordinary capabilities of biological systems for military and dual-use applications. One program thrust is to actively collect information from insect populations to map areas for biohazards, such as industrial chemicals and biowarfare threats. Field trials are planned to lure and trap insects for identification of environmental pathogens. Tests have shown that insects will collect airborne bacterial spores on their bodies during flight. Honeybee demonstrations are planned to map for explosives at Defense installations scheduled for transfer to non-Federal entities. Another thrust area is to mimic the locomotive and sensory capabilities of animals in hardware systems. Beetles have sensitive infrared sensors; the USAF is studying their mechanism of action as a model for uncooled infrared detectors. Visual guidance mechanisms of winged insects are being evaluated for use in naval flight control subsystems, while applications to improve helicopter stability are under investigation. The anatomies and neural control systems of cockroaches and lobsters are being leveraged to design and build legged robots for off-road and littoral zone applications. Feedback from users suggests that legged robots offer unique advantages in terms of size and performance; military utility assessments are planned to benchmark legged robots against wheeled and tracked vehicles. The biodynamic and material properties of gecko feet are being used to develop small robots capable of climbing walls.

Biomolecular motors are nature’s nanomachines that convert chemical energy into mechanical work with performance and scale unparalleled by any man-made motors or machines. The primary goal of the **Biomolecular Motors** program is to develop an understanding of the fundamental operating principles of biomolecular motors and exploit this knowledge to harvest, modify and integrate these macromolecular assemblies into useful devices from the nano- to macro-scale. This will be accomplished through the exploration of single motors and multiple biomolecular and biomimetic molecular motor assemblies. Ultimately, laboratory-scale devices based on biomolecular motors will be fabricated and fully evaluated for performance, failure modes, and applicability to DoD systems. The exploitation of highly efficient biomolecular motors could lead to revolutionary systems with unparalleled performance for Defense applications. These include enabling a whole new generation of hybrid biological/mechanical machines that efficiently actuate materials and fluids at many scales and could enable new classes of sorting, sensing, and actuating devices. The ability to practice highly efficient chemical-to-mechanical energy conversion using complex fuels such as glucose, and to take advantage of energy transduction systems, such as adenosine triphosphate at ambient temperature, will also enable applications compatible with biological fluidic systems, both *in vitro* and *in vivo*. *In vitro* applications might include self-fueled lab-on-a-chip diagnostics, molecular sorters, hybrid actuators or power sources for robotic, MEMS, drug delivery, and other devices. *In vivo* applications might include perpetual physiological monitoring, drug delivery, tissue regeneration and repair, and prosthetic devices. Projects will be selected in FY 2002. In FY 2003, the mechanism of motor function, motor performance and efficiency for several types of biomolecular motors will be investigated as the basis of device designs.

Biochemical Materials

One of the keys to enhancing human performance is to understand the biochemical behavior of living systems and to exploit that understanding with the development of biochemical methods to remove the physiological limitations of the soldier or make the soldier more persistent in combat situations.

The **Continuous Assisted Performance** program is developing a range of different approaches to extend the capabilities of soldiers to perform their duties for up to seven days in the absence of sleep. This program is beginning in FY 2002, with a portfolio of efforts that include magnetic brain stimulation, understanding individual differences in resistance to sleep deprivation, effects of exercise and diet on resistance to sleep deprivation, and the discovery of novel pharmacologic approaches. The first significant accomplishments are expected by the end of FY 2003. Programs that successfully demonstrate the potential to extend performances will be expanded and the activities accelerated. Some of the projects could begin to transition to the Army Soldier Center (Objective Force Warrior), the Air Force, or the Navy Seals by the end of FY 2003, but most will not transition until later.

The objectives of the **Metabolic Engineering** program are to develop desiccated platelets, red blood cells, and stem cells with long shelf-life and minimal storage and transportation requirements, which will reduce the logistics needs for their use in crises. Two additional objectives are to identify how stem cells can be controlled in the body to facilitate healing and how naturally occurring hypometabolic states, such as hibernation, can be used in trauma care. During FY 2001, several protective mechanisms for cellular desiccation were identified, and trials were conducted with platelets and nucleated cells to look at delivery systems and mechanism for three products: trehalose, glycans, and heat stress proteins. In FY 2002, the program is continuing to evaluate these three methods for desiccation in all three target cells and move from *in vitro* testing for efficacy to *in vivo* animal studies in platelets. We will also evaluate the potential for developing stem cells that can be used in multiple recipients without tissue typing, and we will evaluate hibernation models for additional novel mechanisms for stabilizing trauma patients by reducing their metabolic demands following injury. In FY 2003, the program will continue to develop these three areas, specifically focusing on transitioning desiccated platelets to broad application, and moving red cells and stem cells to *in vivo* animal trials.

The goal of the **Persistence in Combat** program is to reduce the medical logistics tail in the battlefield by providing medical technology that allows a warfighter to remain physically functional while engaging the enemy. The Persistence in Combat program provides a paradigm shift from a medic-centric to a warfighter-centric model of self-care medicine to ensure military readiness and operational dominance. This goal is accomplished by: (i) immediate stabilization of hemorrhage; (ii) controlling pain; and (iii) accelerating tissue repair. Early pilot studies have accelerated the growth of cells in culture and restored eyesight in small animal models after toxin-induced injury. Based on success of FY 2002 experiments using low-level energy therapy to repair retinal injury in non-human primate models, in FY 2003 Walter Reed Army Institute of Research will develop a protocol for compassionate use in military personnel as a treatment for accidental laser eye injuries. Researchers will continue to identify the relationship between the nervous system and coagulation cascade to regulate internal hemostasis. Additional research using laser diodes will be performed to regenerate spinal cord tissue after acute traumatic injury. Together, these projects will develop novel technologies to enable a self sufficient warfighter in the battlefield.

BioMagnetics

The **Bio-Magnetic Interfacing Concepts** program will explore and demonstrate the utility of nanoscale magnetics as a portable, robust, and highly sensitive transduction mechanism for monitoring and controlling biological activity at the cellular and, ultimately, single molecule level. Living cells and tissues exhibit an extraordinary range of functionalities, including highly selective biochemical sensing (even in chemically noisy environments), protein synthesis, information processing, and color change. Recent developments in biotechnology offer the promise of exploiting these functionalities for sensing, diagnostic, therapeutic, and other DoD and commercial applications. However, exploitation of these functionalities in devices that can be taken out of a laboratory environment will require the development of biochemical signal transduction mechanisms that are robust, portable, and highly reliable in noisy environments. A transduction mechanism based on a bio-magnetic interface would meet these requirements and offers solutions to outstanding technical issues that continue to keep many innovative developments in biotechnology from being fielded for DoD use. For example, there are currently no hand-held biosensor devices that provide the level of sensitivity, specificity, and quantitative analysis that can be achieved using much more cumbersome (and fragile) laboratory biodetection systems. The Bio-Magnetic Interfacing Concepts program is beginning in FY 2002. Efforts during the first year are focusing on developing novel techniques for labeling cells and molecules with a well-defined magnetic moment, and novel magnetic sensor designs for detecting and quantifying magnetically labeled cells and biomolecules in a fluid environment. These efforts will continue in FY 2003 with the following goals: (i) selectively impart a well-defined magnetic moment to a wide variety of biological and chemical agents; (ii) quantifiably detect low levels of magnetically labeled biological and chemical agents; and (iii) demonstrate the use of magnetic actuation to switch on-and-off intracellular activity, such as protein synthesis, pigment change, or apoptosis (cell suicide response).

ELECTRONICS TECHNOLOGIES

The objective of the **University Opto-Centers** program is to establish multi-investigator university optoelectronic centers with programs closely coupled to photonic industry researchers to develop and demonstrate chip-scale optoelectronic integration technologies. The development of advanced chip-scale optoelectronic modules is essential for future, high performance military sensor and information processing systems. Under DoD sponsorship, university-based research provides the knowledge base and the highly capable expertise relevant to military critical problems to both innovate and support the development of these capabilities within Defense and commercial industries. In FY 2001, the program evaluated specific chip-scale integrated module designs and assessed the success of engaging industry commitment to the program. In FY 2002, the program is fabricating and testing individual chip-level sub-assemblies for later use in prototype development. For example, the traditional designs for optical spectrometers used in identifying chemical species are bulky and fragile. Under University Opto-Centers sponsorship, researchers at Cornell University have developed miniature optical spectrometers measuring a few millimeters on a side from a specially machined, single block of plastic. In another research project at University of California, Los Angeles, very compact designs for optical switches have been developed and demonstrated. These switches involve nanomechanical systems integrated with structures for switching optical beams carrying high data-rate signals. In FY 2003, the program will design and fabricate prototype modules using the system-on-a-chip approach developed earlier in the program. We will also construct test-beds capable of fully measuring and characterizing the mixed technologies implemented in the chip-scale components, and evaluate the performance characteristics of the prototype modules and determine the highest payoff dual-use development paths. One example of such a test-bed will be the so-called "lab-on-a-chip," which is capable of working with tiny amounts of fluids (picoliters), manipulating them precisely using optical beams, performing diagnostic tests, and reading the results optically.

The **Flexible Emissive Display** program began in FY 1999 and focused on the development and demonstration of large-area, high-resolution, flexible, emissive, rugged displays for DoD applications. The development of low-power, lightweight, inexpensive, flexible displays has important applications for aircraft, ships, land vehicles, and foot soldiers, including command and control centers distributing real-time, visual, net-centric information for Future Combat Systems. In FY 2001, the program demonstrated a low-cost, high-speed, roll-to-roll assembly process for plastic film, liquid crystal displays and also demonstrated 80 dpi, emissive, monochrome video using a flexible, lightweight, plastic organic light emitting diode display. These bright displays are efficient in their power consumption while readable in sunlight. The program is nearing completion and will demonstrate a full color emissive video display capable of greater than 80 lines on a flexible substrate. This development program has the potential to impact the distribution of real-time, digital information to the battlefield utilizing displays that conform to a variety of curved surfaces, such as a helmet face shield, a shirtsleeve, an aircraft cockpit instrument panel, or a vehicle windshield. The technology has not yet reached the transition stage. As a part of this program, the development of flexible electronics has military applications beyond displays, e.g., flexible photovoltaics is one area of interest.

The **High Definition Systems** program concluded in FY 2001 and developed leading-edge display technology on glass to meet diverse, but specific, DoD needs, including large-area, high-resolution, projection displays, miniature, helmet-mounted active matrix liquid crystal displays, and active matrix, electro luminescent displays for warfighter-portable information management systems. In addition, we developed bistable reflective displays capable of presenting information in direct sunlight with the power off. The program had two goals: (i) develop display technology that will enhance DoD system performance, but which is not expected to be commercially available in the foreseeable future; and (ii) to improve power efficiency by a factor of two and reduce weight by one-third in portable applications, and improve ruggedness by a factor of five – all attributes extremely important to the military. Early implementation of these new technology capabilities will provide DoD systems with superior access to digital information. In FY 2001, the program emphasized integrating High Definition Systems-developed technology into military system demonstrations to improve the performance and/or operational capabilities of existing systems. The Digital Mirror Device large-area projection system has replaced cathode ray tubes in AWACS and is being utilized as digital maps and information systems for the new Virginia Class submarine, currently under construction. The Digital Military Police program evaluated an eyeglass-based system under the Smart Module program using active matrix liquid crystal microdisplays. Many of the miniature displays are in the process of being fielded in warfighter systems, rotorcraft subsystems, and combat vehicle subsystems. The active matrix liquid crystal microdisplay has been selected by the U.S. Army for integration into the RAH-66 Comanche. A full-color active matrix, electro luminescent miniature 0.7 inch display was demonstrated in a medical head-mounted system that allowed minimally invasive surgery in military hospitals and field applications. In addition, the Digital Military Police program is evaluating a "zero-power" bistable RGB color digital map. The Army is also evaluating this same technology as a blue and yellow display with a near-infrared layer for night-vision goggle readability. With the rapid development of display technology in the commercial sector and the realization that displays have become commodity items with reasonably assured supply, the DoD intends to leverage commercial off-the-shelf displays wherever possible. While the High Definition Systems program concluded in FY 2001 and no funding was requested for FY 2002, DARPA will continue to assess disruptive, breakthrough display technologies. Currently, interest is focusing on identifying those subsystems of display imaging technology that, in unique applications, offer the military capabilities that currently do not commercially exist.

The objective for the **Vertically Interconnected Sensor Arrays** program is to develop and demonstrate imaging readout technology that will result in revolutionary improvement in the performance of Defense imaging systems. Examples include three- and four-band multispectral imaging and discrimination, three-dimensional laser radar imaging with high-resolution (less than 20 micron pixels), multifunction active/passive imaging in one focal plane array, uncooled operation with mercury cadmium telluride infrared photon detectors, and laser jamming avoidance. Three orders-of-magnitude improvement in dynamic range, which will enable vision of low- and high-brightness objects, is expected. In the visible spectrum, this could enable seeing into a dark cave on a bright sunny day with snow on the ground. This will be accomplished through the development and implementation of novel three-dimensional focal plane readout architectures. In FY 2003, the Vertically Interconnected Sensor Arrays program will initiate work to develop highly parallel, densely interconnected architectures with micron-size vias penetrating stacks of detectors, analog, mixed signal and digital circuits. Dense vertical interconnects, wafer bonding that can survive cryogenic cycling, and wide dynamic range (at least 16 bit) analog/digital conversion circuits will be demonstrated in the first 18 months.

The **Photonic Analog to Digital Converter Technology** program is developing and demonstrating applications of photonic technologies aimed at advancing analog-to-digital converter performance to achieve 10 bit resolution at sampling rates of up to 10 gigasamples per second. This level of capability provides better resolution and improved target imaging from radar signals, and far exceeds the existing or projected level of performance resulting from entirely electronic signal processing approaches. The ability to directly perform analog-to-digital conversion of multi-gigahertz signals at their source, while preserving their entire spectral content, will have significant impact on the performance of a wide range of radar, electronic warfare, and communication systems and create new architectural possibilities for these systems. An example is a wideband radar using chaotic or noise-like waveforms, which provides the advantages of low probability of intercept, insensitivity to jamming, and improved range-velocity resolution. In FY 2001, the initial photonic analog-digital converter evaluation and design for the demonstration module were completed, and work continued on developing components (e.g., lasers, modulators, and detectors). Sampling rates as high as 130 gigasamples per second and direct sampling of X-band radar signals with high fidelity were achieved. In FY 2002, the program is integrating photonic clock and sampler modules and electronic quantitizers into complete analog-to-digital converters with sampling rates up to 100 gigasamples per second. At the conclusion of this high-risk program in FY 2002, we anticipate that several more years of component technology research will be needed before transition to system development.

The objective of the **Analog Optical Signal Processing** program is to significantly enhance the performance of, and enable entirely new capabilities and architectures for tactical and strategic radio frequency systems by expanding the dynamic range-bandwidth and time-bandwidth limits by a factor of 1000 through the introduction of analog optical signal processing components into the system front-ends. Begun in FY 2002, the Analog Optical Signal Processing program has several activities currently underway: (i) analyzing analog signal characteristics of military radio frequency systems; (ii) creating, modeling, and simulating new photonic-based optical signal processing techniques of large bandwidth analog signals; (iii) evaluating anticipated system performance improvements due to novel signal processing algorithms and determining the resulting photonic component performance requirements; (iv) testing signal processing techniques of analog signals; and (v) evaluating signal processing algorithms and photonic component performance requirements. In FY 2003, the program will design, fabricate, and test individual photonic components capable of meeting military radio frequency signal processing requirements. We will determine the most promising approaches for development of integrated, chip-scale components using new materials and processing technology, and determine interface requirements. After we evaluate the suitability of the new components for use in prototype modules, we will down-select to the most promising approaches and begin prototype module assembly and construction of test-beds capable of fully characterizing the photonic-based radio frequency signal processing components. The advanced multifunction radio frequency system test-bed and an electronic warfare system test-bed maintained by the Tactical Electronic Warfare group at the Naval Research Laboratory will be used to provide system level performance validation of developed components. An example integration opportunity that would provide significantly enhanced survivability could be in the radar warning receiver in tactical aircraft by allowing for the detection of anti-aircraft fire control radars with low-power, advanced modulations – which would not normally be detected with the existing warning receivers.

Traditional approaches to electronic interconnects based on wire interconnections lead to information processing systems that are bulky, heavy, and power-hungry. Moreover, the communication bandwidth and speed possible with wire interconnects is lower than that of the processor itself, leading to bottlenecks within the system. The **VLSI Photonics** program, completed in FY 2001, has been developing photonics technology to use optical links instead of electronic wire links for chip-to-chip and board-to-board communications. This new technology will allow data transfer rates faster than a terabit per second. These communication speeds are crucial for high-speed processing applications, such as synthetic aperture radar and automatic target recognition. In addition, VLSI Photonics will enable a 100- to 1000-times reduction in power and size for these systems. The most important accomplishment in the VLSI Photonics program has been demonstrating the capability to manufacture vertical-cavity surface-emitting lasers with yields of over 99 percent on large-area (three-inch) wafers. Technology for manufacturing conventional lasers will never achieve this low-cost, large-area capability. Surface-emitting lasers have demonstrated the lowest threshold currents (25 microamperes) of any lasers ever manufactured, with estimated lifetimes of well over 50 years. The two major capstone demonstrations of the program began in FY 2001. The first involves data processing in synthetic aperture radar and the second involves hyperspectral imaging. Both of these applications generate large quantities of data that are currently difficult to process in real-time within the size, weight, and power constraints of on-board processing. The use of optical interconnection will speed up the data processing because of the large bandwidth capacity interconnections among the processing units. The final system demonstration is currently in progress. The program has developed and demonstrated the high-density optoelectronic transmitter-receiver modules with high-speed complementary metal oxide semiconductor circuits hybrid integrated in a single module. These modules are now being integrated with commercial off-the-shelf processing boards in order to implement the synthetic aperture radar processing and hyperspectral image processing. In addition, these high-speed links are being investigated for insertion into automated target recognition systems at Redstone Arsenal. Two start-up companies have also been launched to products to commercialize these technologies.

The **Photonic Interconnection Fabric** program seeks to generate new communications-dominated signal/image processing architectures and introduce a new paradigm for parallel computing. The results of this effort will be the critical technology that will enable the construction of workstation and supercomputer clusters that are used for such diverse applications as three-dimension computational electromagnetics for stealth platform design, nuclear weapons effects simulation, near-real-time scenario analysis, and on-board signal processing in support of signals intelligence missions. The FY 2002 projects brought to a successful conclusion the earlier efforts to deliver the hardware needed for very short-range data transport technologies, which are computer-to-computer interconnects of up to 300 meters in length. Some of the components developed under these projects are now under consideration for insertion into the F/A-18, F-22 and Joint Strike Fighter. In FY 2003, the program will demonstrate deeper level of photonic integration with complementary metal oxide semiconductor circuits and use VLSI Photonic technology to develop system test-beds.

The goal of the **Chip Scale Wavelength Division Multiplexing** (WDM) program is to develop new materials, components, and subsystems for use in wavelength division multiplexing-based optical communications, delivering high-capacity, mission-adaptable networks for use in data intensive military weapons systems. In FY 2002, the WDM program is conducting modeling, simulation, and analysis of artificial dielectrics and new materials for ultra-compact WDM components, conducting experimental efforts in the growth and fabrication of these new materials, determining suitable processing procedures, and planning construction of WDM components. In FY 2003, the program will fabricate and test novel WDM components using the new materials and processing technology. The most promising approaches will be identified and will then be used to initiate prototype module assembly for evaluation in specially constructed network test-beds.

The goal of the **High Power Wide Band Gap Semiconductor Electronics Technology** is to develop compact components and electronic integration power control and distribution technologies that operate at high temperature and high duty cycle for microsystem applications. The advanced high-power electronics components that are enabled by wide band gap semiconductors allow microsystem power systems to operate at duty cycles, or frequencies, of over 100 kilohertz when switching megawatts of power. This switching frequency is over 10 times higher than that achieved with conventional, silicon-based systems. The higher operating frequency of the power system allows the discrete passive inductors and capacitors to be two to three times smaller in size. The reduction in passive component size, along with the reduction in cooling requirements resulting from the higher operating temperature of wide band gap high-power devices, results in a large reduction in system size. The High Power Electronics Thrust is focused on enhancing the performance and operational capability of future DoD platforms being designed to operate primarily on electric power. Platforms such as the electric ships, more electric aircraft, and hybrid electric combat vehicles, require extensive power control and distribution electronics within a limited volume. Conventional power systems based on silicon technology are limited in performance and require large volumes for multiple components and cooling systems. In FY 2002, the program is initiating development of the requisite wide band gap materials to allow large-area, high total power components. The FY 2002 thrusts include: (i) developing low-defect density silicon carbide substrates suitable for production of one square centimeter-size components; (ii) developing silicon carbide thick epitaxial layers able to stand-off 10 kilovolt reverse blocking; and (iii) developing the silicon carbide process technology required to achieve the low on-state resistance necessary for high-efficiency power systems able to operate at elevated temperature. In FY 2003, the program will further: (i) reduce the defect density; (ii) increase the layer thickness to withstand 15 kilovolts; and (iii) validate the material quality with suitable device characterization. The technology development will work closely with potential system users to ensure the proper device operating parameters are being addressed. System examples where wide band gap high-power electronics can have a major impact include: (i) future electric Army and Marine Corps vehicles requiring in-wheel traction control, where the electronics must operate at over 200 C (compared to 125 C or less for conventional silicon components); and (ii) future electric warships for the Navy, where the ability to operate multiple-megawatt power switching systems at over 20 kilohertz, i.e., above audio frequencies, greatly reducing the ship's signature.

The **High Frequency Wide Band Gap Semiconductor Electronics Technology** is seeking to develop the semiconductor material technologies to demonstrate high performance, cost-effective, high-frequency, high-power electronic devices for future generations of military sensors and communication systems. The electronic material properties of silicon carbide and gallium nitride will allow the demonstration of microwave and millimeter-wave amplifiers with 10 to 100 times higher power density than the best gallium arsenide or silicon components to-date, enhancing the range and discrimination capabilities of future sensor systems. This program will focus on the development of low-defect epitaxial films, high-yield fabrication processes, and device structures for integrated electronic devices for emitting and detecting high-power radio frequency/microwave radiation, and high-power delivery and control. The High Frequency Thrust will enable the development and demonstration of solid-state, compact power sources and high-frequency, high-voltage analog circuits capable of operating in frequency bands between three to 35 gigahertz, and beyond. As a result of this effort, military sensor systems will experience significant architectural changes, while featuring increases in performance, jamming immunity, and multi-functionality. In addition, it is expected that many commercial applications will benefit from the advances to be achieved under this project. In FY 2002 to FY 2003, the program is demonstrating uniform growth of epitaxial wide band gap semiconductor films on substrates and bulk- and surface-process technologies for reducing or mitigating crystallographic defects in wide band gap materials. In FY 2004, the program will start designing low-loss integration platforms for high-power, high-frequency operation and high-power enclosures for microwave electronic assemblies. We will also demonstrate large periphery, high-power devices suitable for microwave and millimeter-wave operation, and large-area power switches devices, and we will develop radio frequency materials and device designs.

The goal of the **Semiconductor Ultraviolet Optical Sources** program is to develop wide band gap materials for optical emission in the ultraviolet for bio-sensing and covert communications applications. This program will develop high-conductivity p-type (positive charge carrier) material and highly efficiently active region material suitable for ultraviolet emission. We will exploit these results to enable the development of heterojunction bipolar transistors. In FY 2002, the program is demonstrating p-type (positive charge carrier) doping in high aluminum concentration nitride materials at concentrations sufficient for minority carrier injection devices. In FY 2003, the program will demonstrate minority carrier devices (e.g., light emitting diodes, laser diodes, and heterojunction bipolar transistors).

The objective of the **Ultra High-speed Digital Circuit Technology** program is to demonstrate the application of indium phosphide compound semiconductor materials for high-speed circuit application to digital signal synthesizers and related signal processing applications. In FY 2003, in two broad thrusts this program, will develop a manufacturable indium phosphide heterostructure bipolar transistor technology with wide-dynamic-range, mixed signal circuits operating at clock frequencies in the neighborhood of 100 gigahertz by device scaling to sub-0.2 micron critical device dimensions, while maintaining low parasitic resistance and capacitance. In addition, the level of device integration will be increase by more than 10-fold, moving indium phosphide integrated circuit technology to higher levels of complexity, pushing indium phosphide mixed signal integrated circuit technology to extreme speed (while maintaining useful breakdown voltage, noise margin, and acceptable power dissipation), and demonstrating wide dynamic range mixed signal circuits. This will enable chip-scale realization of complex radio frequency and mixed digital and analog functions. The long-term goal of the activity is to enable direct generation of microwave and millimeter-wave signals, such as direct digital synthesis with digital control of the waveform at the microsystem level, to allow agile, reconfigurable, wireless communication links, radar, and electronic warfare systems and very high-speed (greater than 40 gigahertz) digital signal processing. In FY 2003, the program will initiate development of indium phosphide compound semiconductor materials for very high-speed circuit applications.

The **Self-Synchronized Noise Systems** program will exploit advances in nano-scale complementary metal oxide semiconductor, high-speed silicon-germanium, and MEMS radio frequency filter technologies to demonstrate the capability to generate, detect, and process chaotic (noise-like) electromagnetic signals. This program is based on the properties of self-synchronizing, very wideband noise-like signals that utilize chaotic noise-like signals to achieve low probability of interference, low probability of detection, and anti-jam waveform capability to enable high-resolution, bi-static wideband imaging from multiple narrowband emitters. We will utilize the development of high performance signal generators and detectors that implement and invert chaotic functions that have self-synchronization properties. In FY 2003, the Self-Synchronized Noise Systems program will demonstrate capability to detect and process chaotic electromagnetic signals and develop high performance signal generators and detectors. The aim is to develop chips that build off technologies emerging in wireless communication for advanced military radar applications.

Thermal imaging is critical for most military missions that rely on image information. Applications include small unit operations, target acquisition, missile seekers, and threat warning. The goal of the **Uncooled Integrated Sensors** program is to address the technology necessary to produce affordable, infrared sensor arrays essential to major weapon systems and to enable infrared imaging in very small (about 25 gram) packages for use in micro-air and robotic ground vehicles. Major systems considered include the Low Altitude Targeting and Navigation for Night system and the Joint Direct Attack Munition. DARPA has overseen significant strides in converting thermal imaging technology from relatively heavy, unreliable cryogenically cooled thermal detectors to uncooled thermal detectors. The detector concept typically is a micromechanical bridge that changes electrical resistance when heated in response to incident thermal radiation. The ability to integrate this thermally sensitive microstructure detector array with the best low-noise array electronics is the basis for this technology.

The Uncooled Integrated Sensors program has catalyzed a major shift in focal plane array technology. For many years, the standard uncooled array had a 50 micron pixel size and an array format of 320-by-240 pixels and sensitivity of about 0.1 degree. 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. The Uncooled Integrated Sensors program aims to develop 640-by-480 or larger arrays of smaller pixel devices operating at the theoretical limit, 10 times more sensitive than current devices, while achieving this high performance in extremely small, low-power configurations and demonstrating this technology in new applications. The critical elements of the technology that the Uncooled Integrated Sensors program addresses include the infrared material, detector array fabrication, read-out electronics, packaging and testing, and module assembly. Included processing and fabrication research focuses on affordable array production at low volume in the configurations required by existing weapon systems. In the fall of 2001, this program demonstrated uncooled arrays with 640-by-480 array format and 25 micron pixels. Despite the usual reduction in thermal sensitivity with pixel size, researchers maintained the sensitivity at 0.050 degrees, exceeding current uncooled array performance. These efforts will revolutionize thermal imaging, providing lower cost, more robust arrays for current systems, and enabling infrared capability for micro-vehicles. An array incorporating the 25 micrometer pixel structure demonstrated two times the target acquisition range of the typical uncooled infrared sensor. In FY 2002, contractors under the program will integrate the 640-by-480 format, 25 micron pixel array into a 250 gram package. Another contractor will put this camera on the Pointer unmanned air vehicle, with flight demonstration slated for August. Furthermore, the program will continue to explore new concepts for a near-ideal, thermally sensitive structure. These devices have the potential to achieve the uncooled thermal device theoretical limit, which is greater than 10 times better than current performance. Other efforts aim to incorporate higher responsivity materials into array structures and initiate development of integrated two-color, near-infrared thermal focal plane arrays. These devices incorporate near-infrared sensitive material and thermal infrared sensitive uncooled microstructure into each pixel. Goals of FY 2002 include 640-by-480 array format uncooled sensors with 20 micron pixels, and sensitivity of about 0.020 degrees. Researchers have achieved this sensitivity through unique engineering improvements to the micromechanical structure. Demonstrated uncooled sensor performance proves that uncooled infrared sensors can replace many of today's cooled sensors, while meeting demanding requirements for the next generation of micro-imaging systems.

The objective of the **Multi-function Imaging Microsystems** program is to develop and demonstrate a new class of uncooled low-power, lightweight sensors, with an integral intelligent imaging capability, including target discrimination, multi-spectral band imaging, sensor radiation shielding and on-chip signal processing. In FY 2003, the program will demonstrate a 320-by-240 photon detector array integrated with a microbolometer array, 320-by-240 imaging with solid state radiation shield temperature reduction of 20 K, and a mid-wave infrared room-temperature 320-by-240 array with sensitivity suitable for imaging.

The objective of the **Photonic Wavelength and Spatial Signal Processing** program is to develop integrated electronic and optoelectronic device and module technologies that allow the dynamic and reconfigurable manipulation of both the wavelength and spatial attributes of light for adapting, sensing, and image pre-processing. The reconfiguration and data pre-processing capabilities of these technologies will allow the design and manufacture of real-time sensing and imaging systems. This will be a significant improvement over the current generation of sensing and imaging systems, most of which are not capable of real-time data collection, analysis, and presentation. The availability of these technologies will enable, for example, 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 viewing. During the first year of the program, FY 2000, we developed the basic source and detector device technologies that cover the spectral bands between 350 nanometers and 14 micrometers. In FY 2001, the program demonstrated emitters and detectors in the spectral band 350-500 nanometers. In FY 2002, the program is developing micromachined optical elements for the spectral bands 300 to 500 nanometers and three to five microns. We will also begin integration of passive elements into beam conditioners. In FY 2003, the program will demonstrate integration with a packaging module and demonstrate that module in a test-bed for bio-chemical sensing and spectral imaging. The demonstration will be first conducted in a laboratory environment. It will validate the locking of a quantum cascade laser to an extremely narrow linewidth (less than five hertz), which implies a sensitivity of better than 10^{-13}. This initial demonstration will also involve the integration of high performance mid- and long-wave infrared optical components. The second phase of the demonstration will result in a chip-scale and fully integrated version of the aforementioned bench-top experiment. We will transition this technology to DoD hyperspectral/imaging programs and systems. We are working closely with the U.S. Army Chemical School and the U.S. Army Soldier and Biological Chemical Command, as well as with the Department of Energy's Office of Nonproliferation Research and Engineering.

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 2001, the program demonstrated key components of a maskless wafer writer and key components for lithography of 0.07 micron features. In FY 2002, the program is developing key tool components, materials and processing for both maskless and projection approaches for lithography at 0.05 microns, and is fabricating prototype devices for military applications with features at 0.1 micron. In FY 2003, the Sub-0.1 Micron Lithographies program will develop and demonstrate key subsystems for both maskless and projection approaches for lithography technologies that will extend to 0.05 microns and below, will fabricate prototype tools for fabrication of devices with 0.07 micron features, and will explore nanolithography with features down to the range of 10 nanometers. Also in FY 2003, the Support Technologies program will develop mask technology (writing, inspection, and repair) and resists and metrology for lithography for 0.05 micron and below, and will exploit advances from longer-term developments in direct write-on-wafer projects.

The objective of the **Three-Dimensional Imaging** program is to develop focal plane sensor devices to capture three-dimensional images of a target with a single short laser pulse. The requirement to image from quickly moving platforms and to rapidly engage multiple targets necessitates single flash systems. These devices, with a single 10 nanosecond flash of laser illumination, record both target intensity and target depth information. The promise of three-dimensional imaging is improved ability to identify targets, friend or foe, embedded in foliage or cloud. The greater diversity of three-dimensions vs. two-dimensional profile data, and the immunity of three-dimension vs. two-dimension imagery to shadowing effects, support this promise. The 2002 goal of this program is to achieve single flash imagery with 0.15 meter depth precision at greater than one kilometer range. The Three-Dimensional Imaging program focuses on the materials, detector, and unique electronics technology required to obtain, using a 10 nanosecond eye-safe pulse, a target depth-profile or three-dimensional image of the target. This task requires that every array pixel, or channel, links to a high-speed pre-amplifier followed by a high-speed timing circuit. The preamplifier must process the pulse and the timing circuit must be fast enough to record the pulse. Imaging engineers have never attempted making such high-speed devices integrated inside imaging arrays, and challenges include maintaining low enough noise in the pre-amplifier, channel-to-channel cross talk, and heat dissipation. Prior three-dimensional imaging systems used very small arrays (e.g., four-by-four or one-by-32) and used difficult-to-fabricate, non-integrated channel circuitry. Under this program, array formats remain only about 64-by-64 pixels, much less than a typical digital camera, which has a 640-by-480 array format. Existing pre-amplifiers generate too much noise, necessitating gain at the detector. Under this program, DARPA has directed substantial support toward the development of uniform eye-safe wavelength detector arrays with gains of less than a factor of 100. This is the first effort in support of array devices with gain. In December 2001, the Three-Dimensional Imaging program hosted field demonstrations at the Eglin Air Force Base three-dimensional imaging test range. During this session, the program demonstrated a 32-by-32 detector array operating in single-photon detecting geiger mode. Though not single pulse three-dimensional, this technology provides three-dimensional imagery at a slower rate with less demanding electronics. This system acquired three-dimensional movie imagery with depth precision of about 0.5 meter at a range of 400 meters. The geiger mode array stores only the pulse return time in every pixel and relies on sub-frame averaging to establish depth precision and intensity. (This system is significant since DARPA holds considerable interest in frame averaging of three-dimensional data. Frame averaging is the central paradigm of the Jigsaw program, which incorporates the added difficulty of platform motion from frame to frame. Some of the Three-Dimensional Imaging contractors are participating in Jigsaw.) In FY 2002, we expect to demonstrate single flash imagery. The program shall test the first single flash arrays, collecting analog intensity and depth information in every pixel. Barring setbacks, at least three prototype arrays will become available this year: a 48-by-64 format with multisampling, a 64-by-64 with threshold detection, and a 128-by-128 with multisampling and a unique image tube detection approach. DARPA expects additional contractor efforts under this program to culminate in FY 2003. These efforts include alternative small gain detector arrays and array electronics designs.

The objective for the **Adaptive Focal Plane Arrays** program is to develop and demonstrate infrared focal plane arrays that are electrically tunable, thus enabling real-time reconfiguration of the arrays for intelligent chip-scale sensing and imaging missions. In FY 2003, the first year of the program, we will demonstrate the next generation of imaging sensors providing multiple imaging functions on a single compact array suitable for the microsystems planned for future combat platforms, and will focus on multi-band detectors with integral target discrimination and high operating temperature, matching or exceeding performance that is only available in large, more costly sensors. We also plan to integrate heterogeneous detector materials to realize chip-scale hyper-spectral imaging.

The **Molecular-level, Large-area Printing** (MLP) program investigated novel processes for the inexpensive fabrication of thin-film structures with nanometer dimensions on arbitrarily shaped surfaces. As an example application, the weight and complexity of an imaging system is significantly reduced if a curved, rather than flat, focal surface detector array is incorporated. In FY 2001, the program completed, demonstrated, and characterized a 200-by-200 pixel density array on a spherical surface. Molecular-level, Large-area Printing tooling is now being pursued by at least two start-ups which have licensed technology developed under this program. Of particular note is the observation that suitable surface coatings reduce the defect level in fabricated structures with successive prints, i.e., the process is self-cleaning. The Molecular-level, Large-area Printing program clearly demonstrated the major weight/volume reduction and performance improvement through the use of curved focal surface arrays. Curved focal surface arrays are being developed for the large space telescope program and are being considered for wide field-of-view infrared imagers and helmet-mounted sensors.

The goal of the **Steered Agile Beams** (STAB) program is to develop small, lightweight laser beam steering technologies for the replacement of large, mechanically steered mirror systems for 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. In FY 2001, the program developed, fabricated, and evaluated the beam steering, emitter, and detector components and down-selected to the most promising approaches. In FY 2002, the program is developing design goals for assembled components and fabricating individual laser beam steering components. In FY 2003, the program will evaluate competing laser beam steering component technologies and will down-select to the most promising approaches. We will complete prototype design studies, assemble and test components suitable for use in prototype demonstration and evaluation, and we will assess performance characteristics of the prototypes and make recommendations for future development. We are working with the Air Force Research Lab to conduct a "Shields Up" demonstration of the STAB technology. This will be a validation experiment to demonstrate the ability of the STAB technology to be integrated into infrared countermeasures systems. AFRL will then transition technology into the Air Force inventory. We are also working with the U.S. Army Research Lab and U.S. Army Communications-Electronics Command to demonstrate the feasibility of STAB technology to serve as the key enabling technology for tactical laser communications on the battlefield.

The goal of the **Radio-Frequency Lightwave Integrated Circuits** program is to produce photonic technology that will enable development of high performance radio frequency components that can route, control, and process analog radio frequency signals in the very broad, but militarily crucial range of 0.5 to 50 gigahertz. Applications include antenna remoting, antenna beam-forming (scanning, null scanning and multifunctional-shared apertures), signal synthesis, frequency conversion and channelization, as well as very wideband remote processing. High performance radio frequency systems are critical to a wide range of advanced military radar, electronic warfare, and secure communication applications, but 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. In FY 2001, the program identified key applications for integrated radio frequency photonic modules, producing initial prototypes and demonstrating methods to evaluate their performance. In FY 2002, the program is integrating recently developed emitters, waveguides, detectors, and integrated circuits to produce radio frequency photonic component prototypes. In FY 2003, the program will: (i) complete the design and fabrication of radio frequency photonic prototypes; (ii) construct test-beds capable of producing realistic systems demands for the demonstration and evaluation of radio frequency lightwave integrated circuit components and assemblies; and (iii) measure and analyze the operational impact of the photonic domain for advanced radio frequency signal transmission, conditioning and processing.

The **Intelligent RF Front End** program will demonstrate the benefits of **Digital Control of Analog Circuits**, enabling a new generation of Intelligent Microsystems with functionalities not achievable with today's conventional integrated circuit technologies. This program will demonstrate analog/radio frequency electronic components that have the ability to self-assess and adapt in real-time (sub-microseconds) by self-tuning their impedance-matched networks, thereby extending the operational performance of analog components to the intrinsic semiconductor device limits. This technology will result in a new generation of analog, microwave, and millimeter wave components with greater than a factor-of-150 improvement in power-bandwidth and linearity-efficiency products, enabling real-time system adaptability and reconfigurability to rapidly changing battlefield scenarios and mission requirements. In FY 2002, the program will demonstrate real-time active self-assessment and monitoring of radio frequency/analog functions using nano-complementary metal oxide semiconductor digital and mixed signal technologies to achieve stability, signal agility, and multifunctionality. In FY 2003, the program will develop techniques and algorithms to monitor active device status, demonstrate MEMS tunable device optimization (less than one microsecond, 10-to-one tuning ratio), and fabricate tunable MEMS control integrated circuits and self-assessment control integrated circuits.

The **Semiconductor Technology Focus Center Research** program concentrates on exploratory and fundamental semiconductor research efforts that solve the most critical, long-term scaling challenges in the fabrication of high performance complex integrated circuits. This program will develop new design and fabrication approaches and will demonstrate technologies for reaching nano-scale device dimensions and hyper-scale integrated circuits that will meet future military needs. Primary application of such capability is for computationally demanding applications that are also space, weight, and power constrained. These include wideband radar and surveillance receivers with significantly enhanced performance compared to today's technology. New capability, such as intelligent radio frequency front-ends, where the chip/module can sense and adapt to its environment (e.g., high-noise and jamming) in real-time, will also be possible because of the large amount of on-chip digital signal processing available. Previously funded by the Director, Defense Research and Engineering but managed by DARPA, funding for this effort is now budgeted by DARPA to more closely align the resource authority with the managerial responsibility for the program. In FY 2003, the program will: (i) develop the interface methodology for efficient handling and compilation of design object information for complex military integrated circuits; (ii) develop circuit architectures that reduce long interconnects; and (iii) develop novel device fabrication and integration approaches for deeply-scaled transistors and architectures for high performance mixed signal circuits for military needs. Example applications include: "trillion transistor chips" that can be designed in much shorter time than currently possible (thus allowing highly complex, but highly functional chips to be designed into military hardware); chips that are integrated, not by metal wires as done today, but by light; systems that are both "smart" (adapts to environment and use conditions) and multi-functional (i.e., have radio frequency communications, sensors for detecting such battlespace features as chemicals and troop movements, and processors to do all the "thinking" without human intervention); and chips that can be reconfigured, i.e., as the mission changes, so can the chips ("reusable chips").

The objective of the **Technology for Efficient, Agile Mixed Signal Microsystems** (TEAM) program is fabricating high performance, mixed signal systems-on-chip that will be the core of the embedded electronics in new platforms that are constrained by size and on-board power. Systems of primary interest include "radar on a chip" and "radio on a chip," as well as novel microsystem sensors. The large amount of functionality (analog/radio frequency for radio frequency applications into the tens of gigahertz range and digital for massive/fast digital signal processing of the signals) will provide such capabilities as true "single chips." The primary recipients of the TEAM technology will be DoD contractors who build the sensor and communication platforms for military applications. The program is designed to include both technology development and system design tasks. This is expected to provide both the "specs" required of the technology based on system design requirements and new system concepts triggered by the achievement of performance and integration levels not available today. In FY 2002, TEAM is developing and demonstrating nano-scale silicon-based structures and associated fabrication processes to achieve high-speed analog/radio frequency functions. We are optimizing device and process parameters for high-speed mixed signal circuits, and we are producing test devices for analog/radio frequency parameter extraction. We will demonstrate complementary metal oxide semiconductor-compatible fabrication processes that can yield integration levels greater than 10,000 nano-scale devices, and we will initiate highly parallel, densely interconnected architectures with micron-sized vias penetrating stacks of detectors, analog, mixed signal, and digital circuits. In FY 2003, the TEAM program will demonstrate operation of high performance mixed signal circuits based on nano-scale devices and low-noise interface and high-isolation (up to 100 decibel) between high performance analog circuits and associated digital signal processing. We will also fabricate mixed signal systems on chip with nano-scale transistors.

The **Distributed Robotics** program is developing micro-robots that work together in groups in dynamically changing environments. The program consists of contractors developing enabling technologies, as well as individual robots and groups of robots. The small robots will be approximately five centimeters (two inches), or smaller, in any single dimension. They will work cooperatively together in groups of five to 10 robots and be capable of different modes of locomotion (e.g., land, water, and vertical climbing) and will adapt their behavior based on remote user inputs or onboard sensors. The program currently has seven contractor teams investigating different approaches, such as crawlers, jumpers, vertical climbers, and airborne systems, as well as robots that can change their shape and locomotion mode. All contractors demonstrated initial mobility and sensor capabilities at the Marine Corps Warfighting Laboratory in September 2001. One contractor team demonstrated eight robots working collaboratively to map an internal section of a building. Other robots were thrown into a house to provide visual information about the location of people and objects inside to a small team prior to their forced entry. The program will be completed in FY 2002 with demonstrations at a military operations in urban terrain (MOUT) site (to be selected). Potential applications are for use in the Pathfinder Advanced Concept Technology Demonstration for airfield seizures, Army and Marine Corps MOUT operations, and urban search and rescue.

The objective of the **Chip Scale Atomic Clock** program is to demonstrate a low-power chip-scale atomic-resonance-based time-reference unit with stability better than one part per billion in one second, which is 10,000 times better than the best quartz-crystal clocks. The ultimate size of the Chip Scale Atomic Clock, within one cubic centimeter, is at least 200 times smaller than the smallest atomic reference unit. The small size allows atomic time reference to be put inside hand-held devices. Application examples of this program will include the time reference unit used for jam-resistant Global Positioning System signal-locking. In FY 2002, the program will demonstrate feasibility and theoretical limits of miniaturization of cesium and rubidium cells. In FY 2003, the program will demonstrate subcomponent fabrication, including atomic chamber, excitation and detection function. The miniaturization of these subcomponents is crucial in achieving the ultimate goal of integrating the entire atomic clock function on a chip inside a volume of less than one cubic centimeter, excluding batteries.

As the information and data processing capability of electronic and optoelectronics chips increases, the power consumption and, therefore, the waste heat generated by systems based on these chips, also increases. Waste heat generated by chips limits their efficiency and, hence, overall performance. The **Heat Removal by Thermo-Integrated Circuits** (HERETIC) program, which concluded in FY 2001, developed thermal management devices that are co-located with the chips generating the heat, thereby allowing cooling to be programmable, on-demand, and applied where it is needed most. This approach prolongs the life of advanced information and communication systems and increases efficiency. The program demonstrated new thermal management schemes exploiting thermoacoustic effects and bandgap engineering in periodic superlattices to provide over 10 degrees of cooling over areas approaching a few square centimeters. In addition, we demonstrated integrated micro-aerosol evaporator and condenser technologies for cooling high performance signal processing electronics. Thermal tests of HERETIC technologies were performed in a commercial engineering workstation, in a body-worn portable computer for the future soldier, in Pentium-class thermal test chips, in power transistor assemblies, and in other devices for military communications systems. The Army's Land Warrior program and the Air Force Joint Strike Fighter program are now considering further refinements and optimizations in the developed technologies for those specific applications. The HERETIC program has clearly demonstrated the value of localized heat removal and will be enabling for the future high performance, three-dimensional integrated circuits that will be at the core of new Defense systems.

ADVANCED MATERIALS

The importance of the development and application of materials technology to the success of Defense systems and components is often taken for granted. In point of fact, most of the fundamental changes in warfighting capabilities have been, and will continue to be, the direct result of improvements in existing or the discovery of new materials. The breadth of this impact – from stealth technology, which succeeds because of the ability to design materials with specific responses to electromagnetic radiation, to the information age, enabled by advances in materials for computation and memory – is truly remarkable.

In keeping with the criticality of this technical area, DARPA has consistently maintained a robust and evolving program focused at addressing the critical challenges of future Defense systems for which materials are enabling. The approach DARPA takes is to push those new materials technological opportunities and discoveries that can change way the military operates. In the past, DARPA's work in materials has led to new capabilities in high-temperature structural materials for aircraft and engines and nothing short of enabling the world's microelectronics industry. In its role of technologically transforming today's military forces, DARPA is providing materials innovations that will enable more capable and more survivable warfighter systems that rely on fewer and fewer soldiers, while imbuing the warfighter with unprecedented kinds of actionable information.

Our vision for the new Defense capabilities enabled by advanced materials technology include: (i) enhanced performance of the individual soldier significantly beyond his/her current abilities to move, carry, sense, react, survive, endure, and hide; (ii) unmanned systems with mobility, control and self-awareness derived from living, biological systems; (iii) elimination of the logistics burden of materiel, resources, maintenance; (iv) ultra-fast/ultra-secure electronics, devices, software, and architecture for communications, processing, memory; (v) detection, protection, and decontamination of chemical and biological warfare agents used against our forces; (vi) robust sensor systems; (vii) low-weight, energy-efficient platforms; (viii) unlimited availability of energy/power on the battlefield; and (ix) Defense-specific manufacturing at commercial mass production costs.

Functional Materials

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. It also includes a new concept, "metamaterials," in which, in FY 2000, the program demonstrated light-emitting polymers for flexible displays with performances almost equivalent with inorganic alternatives.

Functional Materials 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, we demonstrated a novel electronically steered array using a potentially very low-cost para-electric lens that is suitable for missile seeker applications. 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 "metamaterials" for achieving electromagnetic properties unobtainable in nature (see below). In FY 2002, the program will demonstrate actuators that mimic biological muscles for robotic applications and fast, affordable, hand-held sensing and metamaterials 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, and static random access memory. 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. In FY 2003, the program will explore the thermal and electrical conductivity properties of polymers for use in electronic packaging and electromagnetic applications.

As mentioned, "metamaterials" are engineered composites that exhibit superior properties that are not observed in the constituent materials or nature. The objective of the DARPA **MetaMaterials** program is to develop, fabricate, and implement new, bulk metamaterials that will fill the tremendous voids that exist in the design space for a number of applications that are of critical importance to the Military Services. In particular, the MetaMaterials program will develop magnetic metamaterials for power electronics and electric drive and propulsion, and microwave and optical metamaterials for antenna, radar and wireless communication applications. During FY 2001, considerable progress was made in understanding the physics of nanocomposite permanent magnets for achieving increased energy product, a figure-of-merit that determines the amount of work that can be extracted from a permanent magnet motor/generator. In addition, a completely new class of metamaterials, "left-handed" or "negative index" materials, was demonstrated and shown to exhibit novel focusing properties at microwave frequencies. In FY 2002, these efforts are continuing and will work towards demonstrating material performance capabilities that exceed the current state of the art. For example, one goal for FY 2002 is to demonstrate a significant enhancement in the energy product for bulk, nanocomposite permanent magnets. Another goal is to further explore, understand, model, and demonstrate the implications of a material with negative index of refraction. In FY 2003, the emphasis of the program will shift toward optimization of metamaterial performance and efforts will begin to focus on implementing the newly developed metamaterials in one or more DoD applications that will demonstrate the new and/or enhanced capabilities that can be achieved as a result of the metamaterials' superior properties.

Structural 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. New approaches to predicting the onset of failure of materials in order to quantitatively predict the remaining performance of systems. The program is also developing improved body armor for the individual soldier.

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 an Army demonstration of that armor system planned for late 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 demonstrated iron-based amorphous metals (which won an "IR 100" award) that exhibit extraordinary hardness, wear-resistance, and strength properties. We also initiated fundamental studies to discover the mechanisms by which structural amorphous metals are formed. We developed approaches for predicting compositions likely to form amorphous metals. In FY 2002, we are synthesizing non-magnetic iron-based blast resistant alloys for Naval applications, aluminum/titanium-based materials for air and space applications, and non-beryllium-containing projectile materials. We are continuing development of approaches for processing these advanced materials in bulk at reasonable cost. In FY 2003, we will evaluate the properties of these materials in the context of making significant improvements for Defense applications. Activities are underway at the Army Research Laboratory to evaluate the ballistic performance of refractory metal amorphous alloys as potential replacements of depleted uranium rounds. Naval Surface Warfare Center Carderock Division is evaluating iron-based bulk structural amorphous materials and coatings for corrosion resistance. Air Force Research Laboratories are engaged in the evaluation of aluminum and titanium-based structural amorphous materials for airframe (F-22/F-119) and space-based applications.

The **Multifunctional Materials** program explores materials that combine the function of structure with another critical system function (e.g., power, repair, and ballistic protection). For example, in FY 2001 the program demonstrated 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. A micro-air vehicle wing was demonstrated that functioned simultaneously as the structure, the antenna, and the fuel cell wall (hydrogen inside, air outside). Additionally rechargeable "powerfibers" were demonstrated that function as both batteries and reinforcement in composite structures. In FY 2002, the program will fabricate composite power structures using the "powerfibers," enabling structure-derived distributed power. In FY 2003, we will demonstrate massively actuating, damage-tolerant power structures and materials with unique electromagnetic properties.

A major limitation in the readiness of combat systems/platforms is the lengthy inspections with the resultant conservative "go/no-go" operation decisions made to avoid the failure of materials in critical components, such as the power plant. The goal of the **Prognosis** program is to manage assets by determining remaining usable life and quantitatively and reliably predicting future operating capability. As a result, commanders will have the ability to adaptively manage, deploy, and use combat systems/platforms that otherwise would have been removed from service. In FY 2002, we are initiating a program to establish the tractability of predicting damage evolution of existing flaws under simulated mission profiles and with multiple, interacting failures of turning gas turbine components. We will investigate: (i) novel methods for interrogating materials (using local and global sensors); (ii) failure mechanisms that capture the intrinsic behavior of the materials; and (iii) linking this signature to physics-based, multi-scale models of the damage accumulation processes and their cascading effect on future performance. In FY 2003, we plan to extend the predictions to future capability of complex subsystems by exercising our models and interrogation tools against the F100 (the engine used in the F-16) and the F404/F414 (the engines in the F/A-18).

In FY 2002, we are initiating a program in **Friction Stir Processing** that offers revolutionary capability in directed, localized and microstructure and property modification at any arbitrary location of metallic components and weldments. The process employs a non-consumable rotating tool to create a localized column of plasticized (worked) metal. This results in substantial improvements in the local materials properties, such as strength, ductility and corrosion resistance. It can be used both as a means to selectively improve properties or as a repair technique both during production and, potentially, in the field to repair battle damage. This process can be directly applied to aluminum, nickel-aluminum bronze, and stainless steel weldments. In FY 2003, we plan to demonstrate the reproducibility of the process and the effectiveness of this technique to improve the materials properties.

Mesoscopic Materials

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, including the ability to print ruggedized electronics and/or antennas on conformal surfaces, such as helmets and other wearable gear, which will provide new capabilities for 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. Other exciting developments have been the demonstration of printed zinc-air batteries that have four times more volumetric power density than commercial batteries, the demonstration of direct write fractal antennas, and the demonstration of direct write solar cells. With these demonstrations in-hand, MICE contractors are moving forward with commercialization strategies that will facilitate the transition of MICE tools to the electronics industry. In FY 2002, MICE contractors will continue to demonstrate the utility of MICE tools for fabricating antennas, passive and active electronic components, and power sources on conformal surfaces and at low temperatures. In addition, during FY 2002 and FY 2003, MICE contractors will begin working together to establish a MICE Center of Excellence. This Center would allow potential DoD and commercial customers to sample, in a hands-on environment, the utility and versatility of MICE technologies.

Smart Materials

The broad, but strongly interdisciplinary field of smart structures and materials seeks to apply multi-functional capabilities to existing and new structures. By definition, smart structures and materials are those that can sense external stimuli and respond with active control to those stimuli in real- or near-real time. The most common analogy is to a human: the nervous system senses the stimuli; then the brain processes the information causing a muscle (actuator) to respond. 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. We concluded the final

Smart Wing wind-tunnel test of a scale-model unmanned combat air vehicle in the NASA Langley Transonic Dynamics Tunnel in FY 2001. In that test, we also demonstrated flexible skins with piezoelectric motors that permit continuous trailing edge shape change for improved aerodynamic performance. Fabrication of five full-scale helicopter rotor blades in the Smart Rotor effort is currently being completed; a whirl tower test of the blades with a limited authority independent blade control capability is planned for May 2002. 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 July 2002. The program will end with a test at a NASA Ames wind-tunnel in September 2002.

The **Piezoelectric Single Crystals** (PiezoCrystals) program exploits the discovery of a class of materials that provide a revolutionary improvement in converting an electrical signal into a mechanical motion. These rock-hard materials are able to change their shape under electric stimulus over 10 times more than conventional materials. In the Defense sector, these materials will lead to revolutionary advances in Navy sonar systems. Their use in smart materials applications will have a multiplier effect in Army helicopter rotorblade control, Air Force airfoil shape control, and Navy active vibration control (acoustic stealth) applications. In civilian markets, major impacts will be made in medical ultrasonic diagnostic imaging, optical switches in telecommunications, and precision machine tool control. The materials development task of this thrust has already (in FY 2001) led to three materials manufacturers that are producing material in prototype quantities, at a cost level suitable for device demonstrations. Current efforts focus on demonstrating the enhanced device performance characteristics these materials afford. For example, an innovative torpedo homing transducer element, which is three-tenths the size of present devices, has shown, in laboratory tests, more than three times the bandwidth and a sound source level four times higher than the conventional device it will replace. The analysis of the military system impact of such a large device improvement projects substantial increases (e.g., up to a factor of four) in the effective torpedo targeting range. Realistic field demonstrations of device performance begin in FY 2002. By the conclusion of FY 2003, demonstrations of the system impact are expected in torpedo homing, submarine bow sonar sensor arrays, torpedo countermeasures, mine-hunting imaging sonar, optical radar beamformers, active mirrors for directed energy weapons, and medical diagnostic imagers. In parallel with the demonstrations in FY 2002 and FY 2003, the materials researchers will define technology routes to bring the materials cost down to levels compatible with production. The next phase of this thrust will be two pronged: (i) targeting high-impact Defense systems for joint DARPA-Service projects leading into acquisition; and (ii) developing materials technology to the point where these materials can be afforded in an acquisition program (about an order-of-magnitude lower than present cost levels, which are suitable for prototyping purposes).

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, including the Army, Marine Corps, and Special Forces, 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 2001, the program evaluated innovative actuation concepts using chemical energy sources, such as hydrocarbon fuels and monopropellants to provide mechanical motion, and began developing designs for a lower extremity system. Analytical studies of human motion were performed; this will be continued in FY 2002. In FY 2002, researchers are developing, characterizing and testing integrated actuation and power technologies. In FY 2003, prototype lower body exoskeleton components including power and actuation, controls, and exostructure, will be fabricated and evaluated in the laboratory. Load-bearing locomotion demonstrations are currently planned for FY 2004 in coordination with our military advisors.

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. Eleven Phase I projects were completed, and six of these were selected for Phase II in FY 2002. Significant developments included micromachined teeth and ratcheting mechanisms for adaptive optics applications, a thin-film shape memory alloy-driven hydraulic pump for missile guidance and control, working prototype concepts for chemo-mechanical actuators, prototype mechanical and non-mechanical valves for smart material-driven hydraulics. Bench-top testing to demonstrate device functionality is planned for FY 2002, along with demonstration of the appropriate breadboard control electronics. The program plans integrated prototype actuator device tests in FY 2003. Final, application-oriented system tests are scheduled for FY 2004. Target applications include unmanned vehicles, missiles, and robots.

The overall goal of the new **Morphing Aircraft Structures** program is to create and advance enabling technologies for – and, ultimately, design, build, and demonstrate – a seamless, aerodynamically efficient, air vehicle capable of radical shape change. Air vehicles are currently designed for single missions, such as reconnaissance or attack. The levels of performance achieved by these structures for such specific missions are dictated to a significant degree by vehicle geometry. The ability to change critical physical characteristics of the vehicle in-flight would enable/allow a single vehicle to perform multiple mission profiles. The ability to morph would heavily influence system performance characteristics, such as turning radius, endurance, payload, and maximum velocity. These new technology development efforts should provide proof-of-principle demonstrations of a flight traceable morphing wing within 30 months of the project's start. We expect significant tasks in FY 2003 to include: (i) a performance benefits analysis and sensitivity study (including an evaluation of flight control and stability characteristics); development of specific device concepts to achieve the desired changes in geometry, and bench-testing of relevant subcomponents/subsystems.

Power and Water Systems

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 unacceptable 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 specific energy 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. In FY 2001, projects were initiated in: direct oxidation fuel cells, including 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 demonstrate direct electrochemical oxidation of hydrocarbon fuels at moderate temperatures in a single cell solid oxide fuel cell suitable for a hand-held system. In FY 2003, the program will demonstrate a 20 watt portable direct methanol fuel cell system with 50 percent higher performance than the first generation.

The objective of DARPA's **Water Harvesting** program is to ensure sustainable water supplies to maintain agility and length of deployment for the U.S. Army's Objective Force. The program will include approaches to harvest water from any available source to eliminate 50% of water logistics requirements for two to 10,000 warfighters – anywhere, anytime. Specifically, the program will develop technologies that will generate 3.5 quarts per day per soldier for two to 12 warfighters from apparently nonexistent sources (e.g., water from air, fuel, or mud) as well technologies to purify/desalinate 3.5 quarts per day per soldier for two to 10,000 warfighters from conventional sources (e.g., puddles, ponds, rivers, or the sea). In both cases, power requirements will be significantly less than conventional approaches. In FY 2002, the program will begin to examine a variety of technical approaches to achieve these goals. In FY 2003, we will conduct feasibility demonstrations of the most promising concepts with the U.S. Marine Corps.

MATHEMATICS

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** 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. Algorithms for both design and operation of sensor systems are being developed that will allow back-end exploitation processes, such as target identification and tracking, to automatically configure and set the operating modes of sensor elements to ensure the most relevant data are always being gathered as scenarios evolve. The Integrated Sensing and Processing program 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. During FY 2001, the program pioneered statistical methods to allocate the sensing channels in a configurable chemical sensor and developed feedback strategies to manage the elements of an adaptive optical sensing system. In FY 2002, the program is developing new mathematical frameworks for global optimization of design and operation of several different types of sensor systems. It is also beginning implementation of software prototypes of the new methodology in test-bed hardware systems, such as missile guidance and automatic ground target recognition modules. Work in FY 2003 will validate and evaluate algorithms incorporating the new methodology and support continuing iterative development of new design and operation methods for sensor systems.

The **Virtual Electromagnetic Test Range** program is developing and bringing to practice 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. Successes in the Virtual Electromagnetic Test Range program will provide the predictive modeling phase of aircraft design with an order-of-magnitude savings in man-hours. Moreover, we may be able to obtain two orders-of-magnitude reduction in computation expenses. We also predict an order-of-magnitude reduction in range and model costs. 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 2002, the program is demonstrating the capability for high-fidelity prediction from multi-sensor apertures and arrays. In FY 2003, the final year of the program, the focus will be on transitioning the mathematical developments into standard design practice within the Defense airframe industry.

MICROELECTROMECHANICAL SYSTEMS (MEMS)

DARPA has played a pivotal role in the rapid expansion and military demonstration of **Microelectromechanical Systems (MEMS)** technology, which enables new ultra-miniaturization of mechanical components and their integration with microelectronics while, at the same time, improving performance and enabling new capabilities. The MEMS program is currently focused on developing integrated, micro-assembled, multi-component systems for applications, e.g., aerodynamic control, signal processing using electromechanical computation, inertial measurement and guidance, and microfluidic chip-technologies to be used for biological detection, toxin identification, DNA analysis, cellular analysis, drug preparation, and drug delivery. The program is also exploring a greater variety of materials for MEMS devices and subsequently for integration of the MEMS devices with electronics.

Compact portable power sources capable of generating power in the range of a few hundred milliwatts to one watt are critical to providing power for untethered sensors and other chip-scale microsystems. The objective of the **MEMS Micro Power Generation** program is to replace today's technologies that rely on primary and rechargeable batteries, which severely limit mission endurance and capabilities, by extending microelectronic machine technology to develop micro-power generators based on mechanical actuation and thermal-electric power generation. Operating with traditional fuels, these micro-power generators will be capable of generating sustained power in the desired range for use with remote, field-deployed microsensors and microactuators. The MEMS micro-power generation program is focused on power needs of less than one watt. DARPA has another program, Palm Power, developing battery replacement technologies that provide 20 watts of power. In FY 2002, the program is demonstrating: capabilities in fuel processing; energy conversion to electricity; thermal and exhaust management; and MEMS micro-heat engines utilizing micro-power sources. In FY 2003, the program will demonstrate integration of various power-generation components with microsensors and microactuators. It will also demonstrate stand-alone, remotely distributed microsensors and actuators with built-in power supply and wireless communication.

The goal of the **Nano Mechanical Array Signal Processors** program is to create arrays of precision, nano-mechanical structures for radio frequency signal processing that will greatly reduce the size and power consumption of various communication systems, including UHF radios, communicators, Global Positioning System (GPS) receivers, and massive wireless communication networks. These new microsystem chips will provide the warfighter and unmanned reconnaissance vehicles with geolocation, communications, and extended awareness capabilities. In FY 2002, the Nano Mechanical Array Signal Processors program is demonstrating fabrication techniques to control surface morphology, geometry, and material properties at the sub-micron scale, demonstrating temperature stability and electrical tenability of individual nano-resonators suitable for UHF communication, and initiating development of nano-mechanical array signal processors that will enable ultra-miniaturized (wristwatch or hearing-aid size) and ultra-low-power UHF communicators/GPS receivers. In FY 2003, the program will demonstrate several alternatives to achieving uniform arrays of up to 1024 nano-resonators with geometrical control and material uniformity at plus-or-minus 20 percent before trimming, and to plus-or-minus one percent after trimming and tuning. We will also demonstrate interconnect and isolation (multiplexed, serial, or random access) of individual resonators. This will lead to the ultimate goal of integrating a uniform array of resonators to replace analog frequency-domain signal processing complementary metal oxide semiconductor circuits, while achieving 100 times reduction in size and power consumption, and 10 times improvement in spectral performance.

The objective of the **BioFluidic Chips** program is to demonstrate technologies for self-calibrating, reconfigurable, totally integrated bio-fluidic chips with local feedback control of physical/chemical parameters and on-chip, direct interface to sample collection. In FY 2001, the BioFluidic Chips program developed closed-loop bio-fluidic chips to regulate cellular transduction pathways, and we fabricated and tested individual microfluidic chip components and integrated sensors for flow control. In FY 2002, the program is demonstrating optimization of subsystems and components for integration into prototype systems. In FY 2003, the program will modify subsystems based on preliminary testing of prototype systems, finalize testing of prototype systems to optimize integrated performance, and demonstrate prototype BioFluidic Chips systems in field insertions. Field insertions have been planned for two types of devices thus far. The first set of prototypes will be identified and tested by U.S. Army Soldier and Biological Chemical Command (Edgewood, MD), for improving the automation, reduction of reagent consumption, and throughput of sample analysis for pathogen detection and identification. The second group of prototypes will be tested in animals: the prototypes will be affixed to the animals' skin for the continuous, minimally invasive extraction and analysis of ionic and molecular analytes present in tissue fluid. This technology insertion will be conducted and evaluated at Walter Reed Army Institute of Research for combat casualty care.

The objective of the **Acoustic Micro-Sensors** program is to demonstrate a miniature acoustic sensor system based on MEMS transducers and advanced non-linear signal processing techniques for three-dimensional detection, capture, and tracking of sound sources in noisy environments with optimum sensitivity. The technologies developed under this program will have a major impact in battlefield surveillance, where deployed networks of miniature sensors will collaboratively operate to detect and identify targets of interest, thereby enhancing battlefield awareness. In FY 2001, we demonstrated MEMS-based three-dimensional acoustic transducers and transducer arrays with 20 times more sensitivity over the sub-sonic, sonic, and ultra-sonic bands, with 60 times less consumed power, extending the endurance of future sensors from four days to potentially 60 days of continued operation. In FY 2002, the program is integrating a MEMS-based, three-dimensional acoustic transducer array with read-out electronics to demonstrate an acoustic microsystem for remote detection and tracking of voices or sound sources in noisy outdoor environments.

The objective of the **Chip-Scale MEMS Micro-Coolers** program is to demonstrate MEMS technology for fabrication of chip-scale micro-cooling elements. By isolating and cooling only the area containing one or a few transistors or MEMS resonators (less than 10 microns-by-10 microns) that can benefit substantially from operating at cryogenic temperatures (100 K and below), we can shrink the equivalent functions of a compressor, valves, and cooling elements to the chip-level with MEMS techniques. There are numerous applications in which the performance of a single device or a single circuit determines the overall performance of a much larger system. For example, the noise figure (i.e., sensitivity) of a communications receiver is often determined largely by the noise generated from the input transistor of its low-noise amplifier. As another example, the sensitivity of an accelerometer is often governed by either the Brownian noise in its proof mass or by the noise generated by the input device of its sense amplifier. In FY 2003, the program will demonstrate feasibility, theoretical limits, and tradeoffs of using MEMS technology for thermal energy exchange. This will lead to the ultimate goal of achieving 500-fold reduction in size and power consumption over the smallest cryogenic cooler. The success of this program will impact the performance of virtually all DoD electronic components, including radio systems, radar systems, guidance electronics, and fieldable computers.

BEYOND SILICON

The **Beyond Silicon** thrust is aimed at maintaining the phenomenal progress in microelectronics innovation that has served military systems designers so well over the last 30 years. Taking advantage of advanced materials deposition and processing techniques, techniques that enable increasing control over material and device structures down to nano-scale-dimensions, the principal goal of the Beyond Silicon program is to achieve low-cost-to-manufacture, reliable, fast, and secure information systems critical to meet future military needs.

Beyond Silicon is composed of seven programs. The objective of these programs is to investigate the feasibility, design, and development of powerful information technology devices and systems using approaches to electronic device designs that extend beyond traditional complementary metal-oxide semiconductor scaling, including non-silicon-based materials technologies, to achieve low-cost, reliable, fast, and secure computing, communication, and storage systems. This investigation is aimed at developing new capabilities, ranging from promising directions in the design of information processing components using both inorganic and organic substrates, designs of components and systems leveraging quantum effects and chaos and other innovative approaches to computing designs incorporating these components for such applications as low-cost seamless pervasive computing, ultra-fast computing, and sensing and actuation devices.

The first of the Beyond Silicon programs is **Antimonide Based Compound Semiconductors** (ABCS). Its goal is to develop low-power, high-frequency electronics circuits and infrared (IR) 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 femtojoule per operation. Specific IR source goals include operating above thermoelectric cooled temperatures and much greater efficiency with continuous wave in the mid-wave IR and single mode continuous wave operation in the long-wave IR range. In FY 2001, this program demonstrated non-silicon based transistor technologies and demonstrated nanostructured materials for quantum-based electronic and optoelectronic device applications. In FY 2002, ABCS substrate technology is accelerating recent breakthroughs in lateral epitaxial overgrowth and thin film delaminating and rebonding to develop a source for ABCS substrates with essentially any desired thermal and/or electronic property. In FY 2003, the ABCS program IR sources will exploit the unique band gap engineering approaches available with the ABCS family of materials to increase the operation temperature above 230 K and extend emission over the long-wave infrared range. The program will also achieve multi-watt output array technology along with increases in efficiency for individual devices, and will deliver the first six multi-batch ABCS substrates.

Another program within Beyond Silicon, **Integrated Mixed Signal (A/D) and Electronic/Photonic Systems** (NeoCAD), is developing and demonstrating innovative approaches to computer aided design of mixed signal (analog/digital) and mixed electronic/photonic systems. The objective is to enable the design and prototyping of ultra-complex microsystems with a high degree of integration and complexity for military and commercial applications. In FY 2001, NeoCAD developed fast algorithms for non-linear analysis of mixed signal systems (analog and photonic devices), and extended algorithm methods to non-linear problems. In FY 2002, NeoCAD is developing model order reduction methods (for analog and photonic devices) to enable the creation of behavioral models, and is developing and demonstrating top-down design capabilities for analog, mixed signal, and mixed electronic/photonic systems that match the efficiency currently achieved with digital designs. In FY 2003, NeoCAD will demonstrate the tools for designing and prototyping selected mixed electronic/photonic circuits and mixed signal systems (e.g., analog-to-digital converters) for military applications, such as airborne and satellite communication, missile radar guidance, and ground forces communication. It will also develop a design methodology for analog, mixed signal, and mixed electronic/photonic systems utilizing analog behavioral models in a digital design environment, extraction methodologies for analog and photonic devices, synthesis and layout rules for analog and photonic devices, and hierarchical design libraries.

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 validation from years to days to minutes. This program breaks the current development approach of "hardware first and software last" point solutions by moving beyond conventional computer hardware and software to flexible, "polymorphous" computing systems. A polymorphous computing system (chips, processing architecture, memory, networks, and software) will "morph" (take or pass through varying forms or implementations) to best fit changing mission requirements, sensor configurations, and operational constraints during a mission, for changing operational scenarios, or over the lifetime of a deployed platform. In FY 2001, the program identified reactive mission computing requirements and dynamic mission operational constraints required to support future dynamic mission scenarios. In FY 2002, the program is developing candidate polymorphous computing architectures, morphware standards, and mission constraint implementations. In FY 2003, the program plans to demonstrate the viability of this technology through proof-of-concept demonstrations. Early results indicate that this revolutionary technology will provide the military with sensor computing platforms that will be technology invariant, yet highly optimizable, for each new mission. In addition, DoD embedded computing platform life cycle cost reductions of up to 45 percent are anticipated.

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 began in FY 2001, with investigations of components and architectures of quantum information processing systems, along with algorithms and protocols to be implemented on those systems. QuIST researchers recently demonstrated the world's first implementation of quantum factoring, which has applications in encryption and security. 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 FY 2003, this project will demonstrate a coordinated modeling capability for the design of quantum devices and the control of the quantum states of these devices. We will also demonstrate a small quantum memory of at least five qubits, which is a first step toward quantum memories of practical size. (Five qubits is equal to 32 conventional bits. A practical quantum computer would have a memory capacity of at least 50 qubits.) Ultimately, we would like to demonstrate a memory of several hundred qubits, which would be more powerful than any conventional memory in existence today.

In a revolutionary departure from today's painstaking circuit fabrication methods, the **Moletronics** (Molecular Electronics) program is pursuing the construction of circuits using nano-scale 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, more than 100 times that of current silicon integrated circuits) and low-power. The requirements for electrical power drive now much of our 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. This is in addition to other types of novel molecular-scale memory devices that take advantage of the unique properties of molecules. In FY 2002, Moletronics is demonstrating that nano-wires have conductivities near that of bulk metal, and will quantify the defect-tolerance required for a molecular-based computer to still function. In FY 2002 and FY 2003, we will optimize the performance of several classes of molecular devices, demonstrate a molecular-scale 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. Further, demonstrations of new and refined prototype memory arrays are planned, as is a demonstration of a self-assembled adder circuit. In FY 2003, Moletronics will develop hierarchically directed assembly processes to assemble molecular devices, wires, and interconnects, demonstrate efficient defect-search algorithms, and model the scalability of molecular circuit architectures to high counts and high device densities. That is, we also should see progress toward two other important program goals: (i) the refinement of architectures that will permit scale-up in the extent of prototype molecular-scale circuits; and (ii) the novel use of biological structures for bottom-up assembly of molecular electronic circuits. Practical applications of molecular electronics may occur within a few years in dynamic random access memory. Hewlett-Packard is among the performers of the Moletronics program, and it has filed and received many patents in memory circuits using molecular electronics. In addition, new startup companies, such as Molecular Electronics Corporation, ZettaCore, NanoSys and Nantero, are spin-offs of the Moletronics program, and are racing to reach product maturity in practical applications of molecular memory circuits.

The **Interconnected Nano-scale Electronics and Substrates** program aims to exploit the accomplishments of the Moletronics, and other nano-technology-based approaches to electronic logic by developing interconnect technologies to integrate massive numbers of nano-scale switching devices with conventional, deeply-scaled microelectronics. This will enable the applications of nano-electronic devices and components to high performance sensor signal and data processing with very low-power dissipation to allow more capable sensors incorporating very large (more than one million) numbers of sensor elements. This program will develop the fabrication technology for creating, placing, and interconnecting massive numbers of nano-scale switching devices with high performance interfaces to integrated microelectronic substrates. In FY 2003, the Interconnected Nano-scale Electronics and Substrates program will develop surface preparation and selective transfer for establishing templates on a active substrates for direct interfaces with nano-scale devices and circuits.

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. For example, we can ultimately expect spin electronic devices to improve both storage densities and processing speeds by factors of at least 100 to 1000. This will give the warfighter the ability to process and assimilate much more data than is currently possible by other means, thereby making him much more situationally aware. Many DoD systems will also benefit from this significantly enhanced performance because the more sophisticated signal processing will allow 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 demonstrated that spin information can easily propagate across boundaries between very different semiconductors in a complex heterostructure without any loss of spin information. We demonstrated a spin light emitting diode (spin-LED) that emitted more than 85 percent circularly polarized light, and we discovered several new and technologically important ferromagnetic semiconductors with transition temperatures above room temperature. In FY 2002, we intend to demonstrate very high-speed optical switching using spin precession to control the optical polarization, as well as a spin transistor. In FY 2003, we intend to demonstrate a terahertz-speed spin resonant tunneling device that operates at room temperature.

Index of Programs

DARPA Programs Cross-Referenced by Program Element and Project Number

(President's FY 2003 Budget)

DARPA Program	PE	Project
A160 Hummingbird	0603764E 0603285E	LNW-03 ASP-01
Acoustic Micro-Sensors[2]	0602712E	MPT-02
Active Templates	0603760E	CCC-01
Activity Detection Technologies ("Sensors")	0602383E	BW-01
Adaptive and Reflective Middleware Systems	0602302E	AE-01
Adaptive Focal Plane Arrays	0602712E	MPT-02
Advanced Fire Support System ("Netfires")	0603764E	LNW-03
Advanced Lithography	0603739E	MT-10
Advanced Medical Diagnostics	0602383E	BW-01
Advanced Speech Encoding	0603760E	CCC-02
Advanced Tactical Targeting Technology	0603762E	SGT-01
Affordable Moving Surface Target Engagement	0603762E	SGT-04
Air and Water Purification ("External Protection")	0602383E	BW-01
Airborne Communications Node	0603760E	CCC-02
Analog Optical Signal Processing	0602712E	MPT-02
Antimonide Based Compound Semiconductors	0602712E	MPT-08
Antipersonnel Landmine Alternatives	0602702E	TT-04
Augmented Cognition	0602301E	ST-19
Autonomous Negotiation Teams	0602301E	ST-19
Autonomous Software for Learning Perception	0602301E	ST-19
Babylon	0602301E	ST-11
Beyond Silicon	0602712E	MPT-08
Bio:Info:Micro	0601101E	BLS-01
Bio-Computation ("Bio Computational Systems")	0601101E	BLS-01
BioFluidic Chips	0603739E	MT-12
Biological Input/Output Systems	0602383E	BW-01
Biological Time-of-Flight Sensor ("Sensors")	0602383E	BW-01
Bio-Magnetic Interfacing Concepts	0602712E	MPT-09

[1] Last funded in FY01
[2] Last funded in FY02

DARPA Program	PE	Project
Biomolecular Motors ("Bioinspired Bioderived Materials")	0602712E	MPT-09
Biosensor Defense Systems ("Sensors")	0602383E	BW-01
Bio-Surveillance	0602301E	ST-28
Brain Machine Interface	0601101E	BLS-01
Canard Rotor Wing	0602702E	TT-07
Chip Scale Atomic Clock	0602712E	MPT-02
Chip Scale Wavelength Division Multiplexing	0603739E	MT-15
Chip-Scale MEMS Micro-Coolers	0603739E	MT-12
Coherent Communications, Imaging and Targeting ("Compact Lasers for Coherent Communication, Imaging and Targeting")	0602702E	TT-06
Command Post of the Future[2]	0603760E	CCC-02
Communicator	0602301E	ST-11
Compact Hybrid Actuators ("Smart Materials and Actuators")	0602712E	MPT-01
Continuous Assisted Performance ("Biochemical Materials")	0602712E	MPT-09
Control of Agent Based Systems	0603760E	CCC-01
Controlled Biological and Biomimetic Systems ("Bioinspired and Bioderived Materials")	0602712E	MPT-09
Counter Camouflage, Concealment, and Deception	0603762E	SGT-04
Cyber Command and Control[1]	0602301E	ST-24
Cyber Panel	0602301E	ST-24
DARPA Agent Markup Language	0602301E	ST-11
Data Intensive Systems	0602301E	ST-19
Deep View	0603285E	ASP-02
Digital Control of Analog Circuits	0603739E	MT-15
Digital Radio Frequency Tags	0603762E	SGT-02
Distributed Robotics[2]	0603739E	MT-04
Dynamic Assembly for Systems Adaptability, Dependability, and Assurance	0602302E	AE-03
Dynamic Coalitions	0602301E	ST-24
Dynamic Tactical Targeting	0603762E	SGT-04
Engineered Bio-Molecular Nano-Devices/Systems	0601101E	MS-01
Enhanced Consequence Management Planning and Support System ("Consequence Management")[1]	0602383E	BW-01

[1] Last funded in FY01
[2] Last funded in FY02

DARPA Program	PE	Project
Evidence Extraction and Link Discovery	0602301E	ST-28
Exoskeletons for Human Performance Augmentation ("Smart Materials and Actuators")	0602712E	MPT-01
Fault Tolerant Networks	0602301E	ST-24
Flexible Emissive Display	0602708E	
Friction Drag Reduction[2]	0602702E	TT-03
Friction Stir Processing ("Structural Materials and Devices")	0602712E	MPT-01
Functional Materials	0602712E	MPT-01
Future Combat Systems	0603764E	LNW-03
Future Combat Systems - Communications	0603764E	LNW-03
Future Combat Systems Command and Control	0603764E	LNW-03
Genetic Sequencing of Biological Warfare Agents[1]	0602383E	BW-01
Genisys	0602301E	ST-28
Genoa	0603760E	CCC-01
Genoa II	0603760E	CCC-01
Global Positioning Experiments	0603762E	SGT-01
Heat Removal by Thermo-Integrated Circuits ("HERETIC")	0602712E	MPT-02
High Confidence Computing Architecture	0602301E	ST-11
High Definition Systems[1]	0602708E	
High Frequency Wide Band Gap Semiconductor Electronics Technology	0602712E	MPT-02
High Power Fiber Lasers	0602702E	TT-06
High Power Wide Band Gap Semiconductor Electronics Technology	0602712E	MPT-02
High Productivity Computing Systems	0602301E	ST-19
Human Identification at a Distance	0602301E	ST-28
Hypersonics Flight Demonstration	0602702E	TT-03
Immune Building ("Bio/Chem Defensive Systems")	0602383E	BW-01
Information Assurance and Survivability	0602301E	ST-24
Information Management ("Software for Situational Analysis")	0602301E	ST-11
Innovative Space-based radar Antenna Technology	0603285E	ASP-02
Integrated Mixed Signal (A/D) and Electronic/Photonic Systems	0602712E	MPT-08
Integrated Sensing and Processing	0602702E	TT-06

[1] Last funded in FY01
[2] Last funded in FY02

DARPA Program	PE	Project
Intelligent RF Front End ("Digital Control of Analog Circuits RF Front Ends")	0603739E	MT-15
Interconnected Nano-scale Electronics and Substrates	0602712E	MPT-08
Jigsaw	0603764E	LNW-03
Joint Theater Logistics ACTD[2]	0602702E	TT-11
Knowledge Aided Sensor Signal Processing and Expert Reasoning	0603762E	SGT-04
Lightweight Body Armor ("Structural Materials and Devices")[2]	0602712E	MPT-01
Loki	0603763E	MRN-02
Low Cost Cruise Missile Defense	0603762E	SGT-03
Low Cost Tactical Imager	0603285E	ASP-02
MEMS Micro Power Generation	0603739E	MT-12
Mesoscopic Integrated Conformal Electronics ("Mesoscopic Structures and Devices")	0602712E	MPT-01
Metabolic Engineering ("Biological Adaptation Assembly and Manufacturing")	0601101E	BLS-1
MetaMaterials	0601101E	MS-01
Micro Air Vehicle ACTD	0603764E	LNW-01
Microelectromechanical Systems (MEMS)	0603739E	MT-12
Mission Specific Processing	0602702E	TT-06
Mixed Initiative Control of Automa-teams	0602301E	ST-19
Mobile Code Software ("Autonomous Negotiation Teams")	0602301E	ST-19
Model-Based Integration of Embedded Software	0602302E	AE-01
Molecular Observation, Spectroscopy, and Imaging using Cantilevers (MOSAIC) ("Nanostructure in Biology")	0601101E	BLS-01
Molecular-level, Large-area Printing[1]	0603739E	MT-04
Moletronics	0602712E	MPT-08
Morphing Aircraft Structures ("Smart Materials and Actuators")	0602712E	MPT-01
Multifunction Electro-Optics for Defense of U.S. Aircraft	0603762E	SGT-01
Multi-function Imaging Microsystems	0603739E	MT-15
Multifunctional Materials ("Structural Materials and Devices")	0602712E	MPT-01
Nano Mechanical Array Signal Processors	0603739E	MT-15
Naval Unmanned Combat Air Vehicle	0603285E	ASP-01
NetFires	0603764E	LNW-03

[1] Last funded in FY01
[2] Last funded in FY02

DARPA Program	PE	Project
Network Modeling and Simulation	0602301E	ST-19
Networked Embedded Systems Technology	0602301E	ST-19
neXt Generation	0603760E	CCC-02
Next Generation Internet[1]	0602110E	NGI-01
Operational Partners in Experimentation	0603760E	CCC-01
Orbital Express	0603285E	ASP-02
Organic Air Vehicle ("Organic All-Weather Targeting Vehicles")	0603764E	LNW-03
Organically Assured and Survivable Information Systems	0603760E	CCC-01
Palm Power ("Advanced Energy Technologies")	0602712E	MPT-01
Perception for Off-Road Robotics ("PerceptOR")	0603764E	LNW-03
Persistence in Combat ("Biochemical Materials")	0602712E	MPT-09
Photonic Analog to Digital Converter Technology ("Photonic A/D")[2]	0603739E	MT-04
Photonic Interconnection Fabric	0601101E	ES-01
Photonic Wavelength and Spatial Signal Processing	0602712E	MPT-02
Piezoelectric Single Crystals ("Smart Materials and Actuators")	0602712E	MPT-01
Polymorphous Computing Architectures	0602712E	MPT-08
Power Aware Computing/Communication	0602301E	ST-19
Prognosis ("Structural Materials and Devices")	0602712E	MPT-01
Program Composition for Embedded Systems	0602301E	ST-19
Quantum Information Science and Technology	0602712E	MPT-08
Quiet Supersonic Platform	0603285E	ASP-01
Quorum[1]	0602301E	ST-19
Radio-Frequency Lightwave Integrated Circuits	0603739E	MT-15
Rapid Knowledge Formulation	0602301E	ST-11
Rapid Multilingual Support ("Babylon")	0602301E	ST-11
Real-time Battle Damage Assessment	0603762E	SGT-04
Reconnaissance, Surveillance and Targeting Vehicle	0603764E	LNW-01
Responsive Access, Small Cargo, Affordable Launch	0603285E	ASP-02
Robust Passive Sonar	0603763E	MRN-02

[1] Last funded in FY01
[2] Last funded in FY02

DARPA Program	PE	Project
Satellite Protection and Warning / Space Awareness	0603285E	ASP-01
Self-Synchronized Noise Systems	0603739E	MT-15
Semiconductor Technology Focus Center Research	0601101E	ES-01
Semiconductor Ultraviolet Optical Sources	0603739E	MT-04
Simulation of Bio-Molecular Microsystems	0601101E	BLS-01
Smart Materials and Structures Demonstrations	0602712E	MPT-01
Software for Distributed Robotics ("Common Software for Autonomous Robotics")	0602302	AE-02
Software-Enabled Control	0602302E	AE-02
Space Surveillance Telescope	0603285E	ASP-02
Spins In Semiconductors	0601101E	MS-01
Steered Agile Beams	0603739E	MT-15
Strategic Intrusion Assessment[1]	0602301E	ST-24
Structural Amorphous Materials ("Structural Materials and Devices")	0602712E	MPT-01
Structural Materials	0602712E	MPT-01
Supersonic Miniature Air-Launched Interceptor[1]	0603285E	ASP-01
Symbiotic Communications	0603760E	CCC-02
Synthetic Approaches to Bio-Optics ("Biologically Based Materials & Devices")	0602712E	MPT-09
Systems Environments ("Quorum")	0602301E	ST-19
Tactical Optical Sensing	0603285E	ASP-02
Tactical Pointing Determination of Imaging Spacecraft	0603285E	ASP-02
Tactical Targeting Network Technologies	0603762E	SGT-04
Technology for Efficient, Agile Mixed Signal Microsystems	0602712E	MPT-02
TeraHertz Operational Reachback	0603760E	CCC-01
Terrain Characterization ("Counter Camouflage, Concealment and Deception")	0603762E	SGT-04
Three-Dimensional Imaging	0603739E	MT-15
Tissue Based Biosensors ("Sensors")	0602383E	BW-01
Total Information Awareness	0603760E	CCC-01
Training Superiority	0602702E	TT-04
Translingual Information Detection, Extraction and Summarization	0602301E	ST-11

[1] Last funded in FY01
[2] Last funded in FY02

DARPA Program	PE	Project
Triangulation for Genetic Evaluation of Risks	0602383E	BW-01
Ubiquitous Computing[1]	0601101E	CCS-02
Ultra High performance Networking	0602301E	ST-19
Ultra High-speed Digital Circuit Technology	0602712E	MPT-02
Ultra Long Endurance Aircraft Program ("Ultra Long Endurance Hydrogen Powered Unmanned Air Vehicles")	0602702E	TT-07
UltraLog	0602702E	TT-10
Unconventional Pathogen Countermeasures ("Anti-Virals/Immunizations; Anti-Bacterials/Anti-Toxins;Multi-Purpose")	0602383E	BW-01
Uncooled Integrated Sensors	0603739E	MT-03
Undersea Littoral Warfare	0603763E	MRN-02
University Opto-Centers	0601101E	ES-01
Unmanned Combat Air Vehicle	0603285E	ASP-01
Unmanned Combat Armed Rotorcraft	0603285E	ASP-01
Unmanned Ground Combat Vehicle	0603764E	LNW-03
Vertically Interconnected Sensor Arrays	0602712E	MPT-02
Virtual Electromagnetic Test Range	0602702E	TT-06
VLSI Photonics	0602712E	MPT-02
Vortex Combustor Demonstration	0603763E	MRN-02
Wargaming the Asymmetric Environment	0602301E	ST-28
Water Harvesting ("Mesoscopic Structures and Devices")	0602712E	MPT-01
WolfPack	0603764E	LNW-02

[1] Last funded in FY01
[2] Last funded in FY02