REVISION 1

FACT FILE

A Compendium of DARPA Programs

Defense Advanced Research Projects Agency

August 2003

FORWARD

Purpose: DARPA's mission is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming U.S. national security by sponsoring revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their military use. This document provides short summaries of selected DARPA programs in FY 2003 and FY 2004, 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 the eight Strategic Thrusts and three Enduring Foundations described in DARPA's Strategic Plan, each with various sub-areas:

DARPA's Strategic Thrusts

Counter-terrorism

Assured Use of Space

Networked Manned and Unmanned Systems

Robust, Self-Forming Networks

Detect, Identify, Track and Destroy Elusive Surface Targets

Characterization of Underground Structures

Bio-Revolution

Cognitive Computing

DARPA's Enduring Foundations

Materials

Microsystems

Information Technology

An index in the back of the document provides assistance in locating individual programs; a table of cross-references to Program Elements in the President's FY 2004 budget appears behind the index.

This document is designed to be used in conjunction with DARPA's Strategic Plan (February 2003)†, and the Descriptive Summaries in the FY 2004 - FY 2005 Biennial Budget Estimates (February 2003)*. The Strategic Plan describes, in broad terms, DARPA's current top-level strategy. The Descriptive Summaries provide more detail on all of DARPA's programs.

---

† Available online at "http://www.darpa.mil/body/strategic.html"

* Available online at "http://www.darpa.mil/body/pdf/FY04_FY05BiennialBudgetEstimatesFeb03.pdf"

TABLE OF CONTENTS

DARPA's Eight Strategic Thrusts

Through the years, DARPA has continuously refocused much of its work in direct response to evolving national security threats and to new and revolutionary technological opportunities. In February 2003, DARPA published its *Strategic Plan*, which describes how it is pursuing its central mission through today's changing circumstances. That report details the eight strategic research thrusts that DARPA is emphasizing today:

- Counter-terrorism
- Assured Use of Space
- Networked Manned and Unmanned Systems
- Robust, Self-Forming Networks
- Detect, Identify, Track, and Destroy Elusive Surface Targets
- Characterization of Underground Structures
- Bio-Revolution
- Cognitive Computing

The following sections contain brief descriptions of each thrust, along with programs within the thrust.

COUNTER-TERRORISM

Protection against acts of terror and the networks that perpetrate them is foremost in everyone's mind today. DARPA has a counter-terrorism strategic thrust with two major elements: Biological Warfare Defense (BWD) and Information Awareness.

BIOLOGICAL WARFARE DEFENSE

DARPA's **Biological Warfare Defense** program is comprehensive and aggressive. It covers sensors to detect an attack, technologies to protect people in buildings and manage the response to an attack, vaccines to prevent infection and therapies to treat those exposed, and decontamination technologies.

Biosensors

To detect the presence of threat agents, 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.

The **Triangulation for Genetic Evaluation of Risks** (TIGER) program offers 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 detection and classification of known, unknown, and bioengineered threats in complex mixtures. In FY 2002, we deployed a "laboratory quality" TIGER system that analyzed the biological makeup of real background environments. Through FY 2003, the team will continue to refine the detection strategy in light of the newfound knowledge gained by analyzing bacterial and viral samples from various sources. The results will lead to a well-characterized prototype design by FY 2004.

DARPA's **BWD Detection** program is 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 developed a pox biochip for the detection of the family of pox virus related to smallpox. In FY 2003, we have developed a single chip to hold all DNA toxin gene sequences for rapid identification of biological toxins. In FY 2004, Brucellosis and Yersinia Pestis (plague) ribosomal sequences will be added to the microarray biochip.

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 began a rigorous evaluation of BioTOF brassboards with completely automated sample collection and processing. Five brassboard units have been constructed in FY 2003 to support extensive characterization of the BioTOF performance against background, simulant and live agent releases. The lessons learned from analyzing this data, along with improvements in the sample processing procedure, will be incorporated into the development of an advanced prototype in the latter part of FY 2003. In FY 2004, we plan to continue testing BioTOF under collaboration with U.S. Soldier Biological and Chemical Command.

Traditional sensors and detection technologies require previous knowledge about the structure or identity of the threat, and they 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. In FY 2002, we demonstrated a number of working prototypes based on the physiological responses from cells and tissues. We organized a blind test of 12 different working cell-based prototypes against chemical and biological agents of interest. The systems performed extremely well in determining change from background (as a trigger to determine introduction of a sample that could be harmful) and classification of that change (whether a chemical or biological agent). Cells have also been engineered to a wider number of threats (12 strains for B-cells for bioagents). We have also made significant progress in stabilizing cells for these prototypes in both liquid and dry stabilization formats. In FY 2003, we are continuing to develop mathematical and statistical protocols to better define the multivariate responses and their relation to risk assessment. We will also begin to work with transition partners, such as U.S. Army Soldier and Biological Chemical Command and U.S. Army Medical Research and Material Command, who are interested in developing these assays for the field.

The **Engineered Bio-Molecular Nano-Devices/Systems** program will develop novel biotic-abiotic interface technologies and algorithms to enable real-time, automatic recognition of biological/chemical species based on unique molecular signatures. The goal is to develop direct, dynamic, stochastic and combinatorial sensors that not only recognize known species, but also, using a combination of molecular signals and signal processing algorithms, will be capable of rapidly detecting unknown or engineered species – a key issue for soldier protection and homeland defense. In FY 2003, the program will develop and demonstrate biotic-abiotic interface architectures that are capable of extracting single molecule (stochastic) signals directly from bio-molecular sensors and receptors and transducing these signals into measurable electrical currents in real-time. In FY 2004, the program will characterize the interface stability, signal sensitivity, and bandwidth. We will extract bio-signatures for various biological/chemical species, and we will quantify the performance of the sensor device in terms of sensitivity, speed, and accuracy. In FY 2005, the device architecture will be scaled up to massively parallel arrays to enable array processing of signals from bio-molecular events. We will implement advanced signal processing algorithms to enable rapid and automatic recognition of various target species.

Building Protection

The goal of the **Immune Building** program is to identify effective strategies for improving the infrastructure of military buildings to make them more resistant to chemical and biological warfare attacks. Improved buildings will provide better protection for their occupants, be restorable to their full function quickly, and help preserve forensic evidence for treatment and attribution. The program is leveraging other technology development efforts (e.g., decontaminating foams/sprays, sensors) and adding new component technologies specifically for this application (e.g., chlorine dioxide to decontaminate inaccessible spaces; low-pressure-drop filtration to inhibit the spread of agents; and high-efficiency ultraviolet radiation sources to neutralize agents in ductwork). In addition, the program includes systems-level experimentation to test the interaction of these components with building heating, ventilation, and air-conditioning systems and to evaluate the end-to-end effectiveness of alternative building protection strategies – including strategies that incorporate real-time, active control of building airflow. In FY 2002, industry teams set up and instrumented two full-scale test beds: one in Anniston, Alabama, and the other at the Department of Energy Nevada Test Site, Nevada. During FY 2003, these teams will perform full-scale testing of candidate components and strategies and will submit their results for independent evaluation by the Government. The Government will select a site for operational demonstration of Immune Building strategies and, during FY 2004, begin preparing the site for that demonstration. To help transition Immune Building principles from the testbeds to the demonstration site – and to other buildings in the future – the program is developing a planning tool for building developers. The first version will be released in FY 2004.

Medical Diagnostics and Countermeasures

The **Unconventional Pathogen Countermeasures** (UPC) program is developing broad-spectrum countermeasures for threat pathogens. This includes antiviral and antibiotic drug discovery and development, as well as new approaches to vaccination. 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: (i) a drug designed to attack the DNA of bacteria, viruses, and malaria; (ii) a family of drugs that target a common and critical enzyme in anthrax and other bacteria; and (iii) 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 transitioned 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 the end of 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. Threat viruses take over host genetic mechanisms. During FY 2004, we will mature thioaptamer blockers that prevent viruses from controlling the host genetic machinery and antigenomic activators that selectively eliminate virally infected cells without causing toxic shock. In addition, the UPC program will initiate new programs to develop novel antibiotic medicinal chemistry programs that may have low probability of resistance development.

The **Acceleration of Anthrax Therapeutics** program is maturing advanced therapeutics programs that were initiated in the Unconventional Pathogen Countermeasures program, along with an additional therapeutic candidate designed to metabolically support organs at risk in advanced disease. The program will advance the development of the projects to Investigational New Drug (IND) status and will work closely with the Food and Drug Administration (FDA) in discussions on the work plan and subsequent submission of the IND application. In this next phase of the program, the FDA-required human safety studies will be conducted in parallel to the primate efficacy studies. During FY 2003, studies will be conducted to demonstrate protection and/or treatment of inhalational anthrax infection with these new drugs. In particular, several of these new drugs are targeted at the treatment of late-stage (symptomatic) infections, with the goal of extending the "point of no-return" for the treatment of critical patients. Based on the excellent progress of the program, we anticipate that the majority of the projects in this program will be conducting phase I human safety trials by early FY 2004.

In the event of a biological attack, the United States 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. The **Advanced Medical Diagnostics** program is identifying disease markers that can serve as rapid indicators of exposure. Under this program efforts continue to define gene expression profiles following exposure to biological threat agents. In FY 2002, researchers identified unique genes that are only turned on following exposure. These genes can now be used to identify chip-based diagnostic systems and therapeutic targets of action. Additional efforts initiated in FY 2002 expanded the investment in rapid sequencing, using natural enzymes responsible for reading DNA to sequence DNA in real-time. These efforts have demonstrated the ability of DNA polymerase to read DNA in real-time, while sequencing the nucleic acid species. This will obviate the need for timely amplification, which also introduces errors in the process. Progress was also made on new mathematical tools for evaluating large dimensional databases from physiological datasets. These efforts have proven to be quite effective in predicting patient outcome given a set of physiological responses from a number of clinical symptoms. FY 2003 is the last year of the program, and we will be extending these tools to improve predictions for human patients based on results from physiological animal experiments. We will expand our activities in new mathematical approaches to these large datasets, as this is quickly becoming the bottleneck in providing new, advanced diagnostic tools for the warfighter.

Through the **Engineered Tissue Constructs** program, we hope to develop an interactive and functional *in vitro* human immune system from a common stem cell source using tissue engineering.

The long-range goal is to test and develop new vaccines *in vitro* with appropriate cellular and humoral responses. It will respond just as a natural human immune system does in every respect. This model would take vaccine development out of the rodent and places the response in the species of interest. In FY 2002, we began by developing the technologies necessary for this: (i) a printer capable of depositing cells, matrix and differentiation factors in a controlled manner in three dimensions; (ii) bioreactive scaffolds; (iii) new, more versatile bioreactors; and (iv) isolating and expanding stem cell populations. In FY 2003, we are combining these technologies with the biological knowledge to develop an artificial lymph node by controlling the differentiation of stem cells into the hematopoietic lineages required for lymph node function. To test the artificial lymph node, we will insert the integrated system into a mouse lacking an immune system. In FY 2004, we will complete technology development for the printing system, the bioscaffolds, and the bioreactor. On the biological side, we will demonstrate functional, immunological outputs from the engineered tissue construct.

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. Today's masks have higher-than-desirable breathing resistance, and their capacity (the period of time they effectively filter) is limited. To-date we have demonstrated that microfibrous carrier, combined with thin layers of packed-bed polishing sorbents, 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 showed a reduction in the pressure drop by at least a factor of two over current C2A1 canisters used in existing gas masks, while maintaining a longer period of time for the filters to operate effectively. In FY 2003, we plan to employ this unique filter material for initial prototypes of first-responder masks and for use by Special Operations Forces, with eventual transition into an improved Joint Services gas mask, replacing the outdated C2A1 canister.

Warfighters must also be able to obtain potable water quickly from any conventional water source (puddle, pond, stream, river, lake or sea). Their water purification devices and beverage containers must be integrated in order to work and stow well together. In one project, a pen-sized mixed chemical oxidant unit kills or inactivates microbial pathogens, prevents regrowth 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 passed EPA protocol for the purification of nonbrackish water. They are now being selectively field-tested by the Marines Corps and Special Operations Forces personnel in Afghanistan, and they are being sent to Iraq. The Army and Air Force are also planning to transition this device into field applications. In a related project, a soldier-portable hydration system will produce microbiologically safe drinking water and beverages from nonbrackish sources of unknown quality. It will provide an efficient storage and delivery system for hands-free, on-the-move hydration by including a mixed oxidant disinfection cap on the backpack water supply.

One of the program's key design objectives is the ability to purify all available water sources in the field, including demineralizing sweet but brackish water and desalinating seawater utilizing a hand-held apparatus. This is now accomplished by a soldier-portable desalination hand-pump operating with a disposable reverse osmosis cartridge. The pump is capable of making one liter of potable water in five minutes via a unique, hand-operated pulse-pumping system. Early prototypes of this device will be available for field trials by the Marines at selected test sites in FY 2003. With the pen, cap, and pump, the warfighter can drink safely on-demand in any place, at any time, wherever conventional water sources are available. In FY 2003, the Marine Corps is planning to develop an acquisition strategy for their Individual Water Purification Systems, consisting of production-quantities of the disinfection pen, and preliminary prototypes of its in-canteen version, the disinfection cap-operated Camelback system, and the desalination hand-pump. Additional work in this area is being continued under our Water Harvesting program.

INFORMATION AWARENESS

The DARPA Information Awareness Office is the focal point for DARPA's effort to develop and demonstrate integrated prototypes of information technologies and components across a research and development computer network environment in support of DoD's counter-terrorism mission. If successful, these new capabilities will counter asymmetric threats by achieving Terrorism

Information Awareness useful for preemption, national-security warning, and national-security decision-making.

The most serious asymmetric threat facing the United States is international terrorism. This threat is characterized by loosely organized, shadowy criminal networks that are difficult to identify and define. To deter and prevent attacks such as those against the United States on September 11, 2001, terrorist networks must be detected, identified, and tracked. DARPA is conducting research 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 enable these capabilities, DARPA is conducting research in four distinct program categories: (i) technology integration and experimentation; (ii) language translation technologies; (iii) data search and pattern recognition technologies; and (iv) advanced collaborative and decision support tools. Ultimately, our plans entail a spiral architecture design and implementation process that will develop, demonstrate, and leave behind prototype integrated technologies, which significantly improve the sharing and analysis of the data already legally available to the intelligence and counterintelligence communities.

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 information technologies are unlikely to yield adequate results in this new asymmetric threat environment. Foreign terrorists do not need to act in 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 is available to most governments. The availability of biological and chemical weapons, in addition to novel methods of attack, poses a broad and continuing threat to the United States.

To address today's threat, we need to turn information technology around and use it against foreign terrorists, making better use of existing, legally available information so that we can predict and preempt attacks – or, at the very least, strike back with speed, certainty, and finality. We will need new technology for effectively managing all this information, for providing better access with improved controls, for improving the efficiency of data analysis, for communicating results to decision-makers, and for protecting the privacy of U.S. persons as well as the human and communication intelligence sources and methods used by intelligence agencies to collect information. DARPA's research seeks to improve the interpretation of raw data using numerous automated and semi-automated technologies that amplify the efforts of human analysts to provide greatly improved attack prediction and preemption capabilities. We also seek to multiply the value of existing information and analysis by enabling cross-agency collaboration via technologies that rapidly assemble teams of authorized users to share and analyze legally collected information on foreign terrorist activities already in their possession. DARPA's Information Awareness Office was established to create and integrate component technologies to address these varied needs and deliver a broader, more powerful set of tools to the intelligence community.

Example technologies of interest include:

- Collaboration and sharing over TCP/IP networks across agency boundaries;
- Methods for virtually linking databases of various intelligence agencies;
- 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;
- Privacy protection;
- 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 and counterintelligence communities, Unified Combatant Commands, and other agencies of the national security community.

Terrorism Information Awareness

The **Terrorism Information Awareness** (TIA) program will develop information technologies into integrated prototypes to better detect, classify, and identify potential foreign terrorists so that we may have a better understanding of their plans, thereby increasing the probability that the United States can preempt adverse actions. TIA is not an intelligence collection program.

The TIA program will integrate technologies developed by DARPA (and elsewhere, as appropriate) into a series of increasingly powerful prototype configurations that can be stress-tested in operationally relevant environments using real-time feedback to refine concepts of operation and performance requirements down to the technology component level. The ultimate goal is to create a counter-terrorism information architecture that: (i) increases the information coverage by an order-of-magnitude – via access and sharing, not by increased data collection – and that 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 terrorist threat-indicative 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, thereby enabling decision-makers to 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 technology maturation and transition partners. 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, integrated, leave-behind component 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.

The following component programs contribute to TIA:

The goal of **Genoa II** is to develop technology to support collaborative work by cross-organizational teams of intelligence and policy analysts and operators as they develop models and simulations to aid in understanding the terrorist threat, generate a complete set of plausible alternative future scenarios, and produce options to deal proactively with these threats and scenarios. Rapid technological leaps in information access, sharing, and collaborative analysis are key to fighting terrorism. Genoa II will enable the rapid creation of high performance *ad hoc* teams spanning the full range of organizations with counterterrorism responsibilities and equip these teams to generate a more complete set of possible hypotheses about terrorist capabilities and intent, and a more robust set of options for preempting the threat. During FY 2003, a basic suite of evidential reasoning and collaboration tools has been developed and is being evaluated. The evidential reasoning tools provide the basic capability for analysts to construct, reason about, and explain structured arguments. The collaboration component provides a basic peer-to-peer collaboration capability for organizations to form and manage *ad hoc* teams whose members are connected to one another along the edges of their parent organizations. These "edge-to-edge" organizations eliminate traditional bureaucratic stovepipes found in top-down organizations, permitting workers to establish *ad hoc* groups to share and cooperate with their counterparts at other organizations.

During FY 2004, the evidential reasoning suite will be extended to include tools for hypothesis comparison, argument critique, analogical reasoning, storytelling, scenario generation, stochastic option generation, risk assessment, and option selection. The collaboration suite will be enhanced to provide an initial "center-edge" collaboration environment, to include context-based business rules, social network analysis-based team management, and consensus analysis. The center-edge collaboration environment is essential to the effectiveness of edge-to-edge organizations. The output of *ad hoc* teams operating along organizational edges must be reported back to management to allow for its inclusion in critical decision-making processes.

The **Genisys** program will produce technology for integrating terrorist threat databases and other information sources to support effective intelligence analysis aimed at preventing terrorist attacks on the citizens, institutions, and property of the United States. The overall goal is to make databases easy to use and easy to populate so we can increase the level of information coverage, get answers when we need them, and share information between agencies faster and easier. To predict, track, and thwart attacks like those on September 11, 2003, the United States intelligence analysts need information about terrorist networks and their supporters, material, training/preparation/rehearsal activities, desired targets, and specific plans, as well as the status of our defenses. Current commercial technology is far too complex and inflexible to easily integrate relevant existing databases or to analyze intelligence data collected in paper and unstructured formats. To help analysts track sophisticated threats, we need our information systems to be easier to use, so our technologies must be more sophisticated. In FY 2003, we are developing concepts for a virtual distributed database architecture and algorithms that allow analysts and investigators to more easily get answers to complex questions by eliminating their need to know where information resides or how it is structured in multiple databases. In FY 2004, we will create technology for effectively representing and resolving uncertainty and inconsistency in the data values so that intelligence analysis will be faster and more certain.

The **Genisys Privacy Protection** program will create new technologies to ensure personal privacy in the context of increasing data analysis for detecting, identifying, and tracking terrorist threats. Information systems and databases have a unique potential for identifying terrorist signatures through the transactions they make, and Americans are rightfully concerned that related data collection, integration, and analysis may threaten their privacy. The Genisys Privacy Protection program will enable *security with privacy* by providing terrorist threat information data to analysts, while controlling access to unauthorized information, enforcing laws and policies through software mechanisms, and ensuring that any misuse of data can be quickly detected and addressed. Research being conducted under other Information Awareness Office programs may indicate that information about terrorist planning and preparation activities exists in databases that also contain information about innocent U.S. citizens. Privacy protection technologies, like those being developed under the Genisys Privacy Protection program, would be essential to protect the privacy of U.S. citizens, should access to this sort of information ever be authorized by the appropriate authorities. In FY 2003, we are developing algorithms that prevent unauthorized access to sensitive identity data based on statistical and logical inference control, create roles-based rules to distinguish between authorized and unauthorized uses of data, and automate access control. In FY 2004, we will enhance these algorithms and provide an immutable audit capability so that investigators and analysts cannot misuse private data without being identified as the culprits. These technologies are also applicable to protecting intelligence sources and reducing the potential "insider threat" in intelligence organizations.

The objective of the **Evidence Extraction and Link Discovery** (EELD) program is a suite of technologies that will automatically extract evidence about terrorist threat-indicative relationships between people, organizations, places, and things from unstructured textual data, such as intelligence messages or news reports. This information can then point to the discovery of additional, relevant relationships and patterns of activity that correspond to potential terrorist events, threats or planned attacks. These technologies would be employed to provide more accurate, advance warnings of terrorist activities by individuals and networks. They will allow for the identification of connected items of terrorist threat information from multiple sources and databases whose significance is not apparent until the connections are made. To avoid needless, distracting and unintended analysis of ordinary, legitimate activities, these technologies will also ensure that intelligence analysts view information about *only* those connected people, organizations, places, and things that are of counter-terrorist interest and concern, and which require more detailed analysis. In FY 2002, EELD demonstrated: (i) the ability to extract relationships in several sets of text; (ii) the ability to distinguish terrorist threat characteristic, relevant patterns of activity from similar legitimate activities; and (iii) improvements in the ability to classify entities correctly based on their connections to *other* entities. These advances have been applied to significant intelligence problems on real data. In FY 2003, the diversity of detectable relationships is being increased, the complexity of distinguishable patterns is being increased, and the ability to automatically learn patterns will be demonstrated. In FY 2004, EELD will evaluate and transition selected components to the emerging Terrorism Information Awareness network nodes in the Defense and intelligence communities and will integrate the ability to learn terrorist threat-indicative patterns of interest with the ability to detect instances of those patterns. In summary, EELD develops technology not only for "connecting the dots" that enable the U.S. to predict and preempt attacks, but also for deciding which dots to connect – starting with people, places, or organizations known or suspected to pose terrorist threats based on intelligence reports; recognizing patterns of connections and activity corresponding to scenarios of counter-terrorist concern between these people, places, and organizations; and learning patterns to discriminate as accurately as possible between real threats and apparently similar but actually legitimate activities.

The purpose of the **Mis-Information Detection** (MInDet) program is to reduce DoD vulnerability to open source information operations by developing the ability to detect intentional mis-information and to detect inconsistencies in open source data with regard to known facts and adversaries' goals. As a new program, MInDet will improve national security by permitting our intelligence agencies to evaluate the reliability of a larger set of potential sources and, therefore, exploit those determined to be reliable and discount the remainder. Other potential uses include the ability to: (i) detect misleading information on various Government forms that relate to national security (e.g., visa applications), which would suggest that further investigation is warranted; (ii) identify foreign sources who provide different information to home audiences and to the United States; and (iii) identify false or misleading statements in textual documents. In FY 2002, researchers under Small Business Innovation Research contracts demonstrated the ability to detect public corporations that might be potential targets of Securities and Exchange Commission (SEC) investigations – based on their SEC filings – well in advance of actual SEC investigations. They also demonstrated the ability to distinguish between news reports of deaths in a particular country as suicides or murders – depending on whether the source were the official news agency or independent reports. In FY 2003, MInDet will explore a number of techniques for detection of intentional mis-information in open sources, including linguistic genre analysis, learning with background knowledge, business process modeling, and adversarial plan recognition. In FY 2004, MInDet will select techniques with demonstrated ability to discriminate misinformation and transition them to selected intelligence and Defense users.

The purpose of the **Scalable Social Network Analysis Algorithms** program is to extend techniques of social network analysis to assist with distinguishing potential terrorist cells from legitimate, non-terrorist groups of people, based on their patterns of interactions, and to identify when a terrorist group plans to execute an attack. Current techniques in social network analysis take into account only an unspecified type of connection between individuals. What is needed is the ability to simultaneously model multiple connection types that indicate the presence of a terrorist network, and combine the results from these models. Also needed is the ability to analyze not only a single "level," such as connections between people or between organizations, but multiple "levels" simultaneously, such as interactions between people and the organizations of which they are a part. Based on publicly available information about the 9/11 hijackers, contractors working under Evidence Extraction and Link Discovery and Small Business Innovation Research contracts have already demonstrated the feasibility of using these techniques to identify the transition of terrorist cell activity from dormant to active state by observing which social network metrics changed significantly and simultaneously. In FY 2003, we will develop a library of models of social network features that represent potential terrorist groups. In FY 2004, we will develop algorithms that allow for the discovery of instances of these models in large databases.

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 (e.g., 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 2003, WAE is extending its predictive technology research to develop and integrate group-specific predictive models comprised of unclassified-English, unclassified-Arabic, and classified information into a single predictive model. These models will be tested in real-time in conjunction with our operational partners. Additionally, WAE is developing terrorist-specific intervention models based upon their respective motivational factors. These intervention models are consistent with, and support, the information operations process currently employed by our transition partners. In FY 2004, WAE will develop and test the integrated predictive technology that will provide a real-time, group-specific, continuous indication and warning estimate and corresponding intervention hypothesis testing tool. These integrated, predictive technologies will be tested in real-time in conjunction with our operational partners.

The goal of the **Rapid Analytic Wargaming** (RAW) program is to develop a faster-than-real-time analytical simulation to support U.S. readiness for both asymmetric and symmetric missions in the operational, analytical, and training domains. In order to more realistically portray and project today's asymmetric threats, the program will develop technologies to generate a full spectrum of known and emergent behaviors that will expand existing tools developed for more conventional conflict simulation. In FY 2003, RAW has, in cooperation with our operational partners, begun the development of an abstract behavioral framework for rapidly modeling the future decision-making and behavioral characteristics of key leaders of U.S. adversaries. The development of this modeling framework to-date includes validating a subset of the indirect assessment tools of specific personal attributes related to future decision-making and behavior. In FY 2004, RAW will use this abstract behavioral framework to develop predictive models of political decision-making and terrorist behavior of two key leaders of U.S. adversaries. The RAW program will, in cooperation with our operational partners, then validate these predictive models against an historical test set.

The **Human Threat Identification at a Distance** (HTID) 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 against terrorist 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, HTID 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, HTID developed a multispectral infrared and visible face recognition system and plans to evaluate and demonstrate this system at a variety of force protection sites in FY 2003. Key techniques were identified to determine critical factors affecting the performance of biometric components and methods, and algorithms were developed for fusing multimodal biometric technologies and deriving biometric signatures. The program also designed and administered the Face Recognition Vendor Test 2002 and plans to use the results in FY 2003 to direct face recognition research and provide input to the design of the United States Border Entry/Exit System. In FY 2003, HTID is performing an operational evaluation of a long-range (25 to 150 feet) face recognition system and will further develop biometric fusion algorithms for up to five biometric components. The program will also conduct multimodal fusion experiments and performance evaluations. Advanced human recognition capabilities will be demonstrated in multiple environments. In FY 2004, the HTID program will develop multimodel fusion algorithms for human identification and for locating and acquiring subjects out to 500 feet in range. A human identification system that operates out to 500 feet using visible imagery will be developed and demonstrated. Gait and face recognition will be fused into a human identification system, and an operational evaluation of a multimodel human identification system will be performed. Discussions are underway with the Navy regarding technology transitions for further development in the arena of port protection. The HTID program will conclude in FY 2004.

Face recognition technology has matured over the last decade, with commercial systems recognizing faces from frontal still imagery (e.g., “mug shots”). These systems operate in structured scenarios where physical and environmental characteristics are known and controlled. Performance under these conditions has been documented in the Face Recognition Vendor Test 2000 and 2002. These evaluations document the advances in this technology. However, these evaluations have also identified performance shortfalls in critical operational scenarios, which include unstructured outdoor environments. The ability to operate in these operational scenarios is critical to military, force protection, and counter-terrorism intelligence applications. New techniques have recently emerged that have the potential to significantly improve face recognition capabilities in unstructured environments. These include three-dimensional imagery and processing techniques, expression analysis, and face recognition from infrared and multispectral imagery. The **Next Generation Face Recognition** (NGFR) program will initiate development of a new generation of facial-based biometrics that can be successfully employed in a wide variety of unstructured military and intelligence scenarios. Rapidly developing, maturing, and deploying these new techniques in fielded systems requires a large, well-coordinated effort. NGFR is a proposed program under consideration by DARPA and projected to begin in FY 2004. Details of the NGFR program are still being developed prior to approval by DARPA.

The current concept for conducting large-scale face recognition experiments is as follows: All face data will be de-identified, and all faces of a person will be given a random identifier. For research experiments, the true identity of a person is not needed. The large-scale experiments would be conducted at a central facility, and face recognition researchers would bring their systems to the facility to perform experiments. The use of a central facility means that experiments can be performed without distributing data. At the conclusion of an experiment, all face images and derived information that could allow for reconstruction of the faces will be deleted and removed from researchers face recognition systems.

The NGFR program will produce face recognition systems that are robust to time differences between facial imagery (aging) and variations in pose, illumination, and expression. The required breakthroughs in face recognition will be a result of the coordinated synthesis of the four key components of the program. NGFR is a new program for FY 2003 that arose from new research areas identified in the HTID program. In FY 2003, the NGFR program will explore new face recognition technologies and approaches and use them to improve the accuracy of existing technologies. In FY 2004, the program plans to incorporate advances resulting from this research into a variety of prototype systems to demonstrate their capability across varied operational scenarios. In FY 2005, advanced imaging face recognition technologies, such as three-dimensional, infrared, and multispectral imaging technologies, will be developed. By the end of the program in FY 2006, NGFR plans to conduct large-scale experiments and evaluations.

The **Threat Activity Recognition and Monitoring** (TARM) program will develop an automated capability to reliably capture, identify, and classify human activities in surveillance environments. Currently, these types of activities are identified and analyzed by humans studying real-time and recorded video sequences. TARM technology will dramatically improve the speed and ability to discover and identify anomalous or suspicious terrorist threat-indicative activities. In particular, this includes detecting hostile operatives collecting data on deployed forces or DoD facilities at home or abroad. The capability to automatically identify and classify anomalous or suspicious terrorist threat-indicative activities will both greatly enhance force protection initiatives by providing increased warning for asymmetric attacks, and it will increase the reconnaissance and surveillance capabilities for intelligence and Special Operations Forces. The basis of TARM capabilities will be human activity models. The approach will be multisensor and will include video, agile sensors, low-power radar, infrared, and radio frequency tags. The program will produce component technologies, and prototype systems for demonstrating and evaluating performance for multiple scenarios. TARM is a new program for FY 2003 that arose from new research areas identified in the HTID program. In FY 2003, we are developing intelligent activity and monitoring algorithms that are resident in networked sensors. In FY 2004, TARM plans to develop a prototype system of networked sensors that is scalable and extensible. It will begin to demonstrate and evaluate the prototype system on a series of increasingly challenging scenarios. In FY 2005, we will develop human computer interfaces that are tailored to the demands of different users.

The objective of the **Bio-Event Advanced Leading Indicator Recognition Technology** (Bio-ALIRT) program is to develop the necessary information sources, technologies, and prototypes capable of detecting a covert release of a biological pathogen by monitoring nontraditional data sources, such as animal sentinels, aggregate and anonymized human behavioral indicators, and aggregate and anonymized nondiagnostic and other medical information. The Bio-ALIRT program will dramatically increase the Government's ability to detect a clandestine biological warfare attack, involving both natural and unnatural pathogens, up to two days earlier using existing data sources – in time to respond and to avoid potentially thousands of casualties. Technical challenges include determining the value of each data source, alone and in combination with others, for earlier outbreak detection, correlating/integrating information derived from heterogeneous data sources, development of autonomous signal detection algorithms with high sensitivity and low false alarms, creation of disease models for autonomous detection, and maintaining privacy protection while correlating depersonalized data sources. In FY 2002, Bio-ALIRT identified and characterized approximately 100 nontraditional and "gold standard" data sources. We also developed and evaluated advanced fusion and detection algorithms and disease models, and we detected several disease outbreaks that were then brought to the attention of public health authorities. During FY 2003, we will demonstrate both the ability to detect outbreaks one day earlier with nontraditional data sources, and dynamic privacy protection that could be placed in a medical data system and ensure the anonymity of individual records accessed by the data monitoring software. In FY 2004, we plan to demonstrate the ability of nontraditional data sources to provide an outbreak warning two days before people seek medical care. The corresponding data sources and algorithms will be transitioned to military health authorities for insertion into their medical/syndromic surveillance systems. A prototype Bio-ALIRT system has been constructed for the National Capital Area, and one will be developed for the Norfolk, Virginia, area.

Automated Exploitation of Speech and Text in Multiple Languages

To serve a wide range of critical national security needs, DARPA is developing powerful new human language technology able to exploit huge volumes of speech and text in multiple languages. This technology will dramatically change the way operators and analysts work, substantially improve productivity, and give commanders and decision-makers vital, time-sensitive information.

Much key terrorist threat-related information is currently missed because it is hidden within enormous volumes of terrorist speech and text communications, and because it is often in languages for which the United States has very few skilled personnel. DARPA is changing that situation through several carefully targeted initiatives:

The **Translingual Information Detection, Extraction and Summarization** (TIDES) program is creating powerful new capabilities for finding or discovering needed information, pulling out key facts, substantially condensing what people must read, and translating foreign languages into English. English-speaking analysts will be able to exploit considerably more English language material and (even more significantly) large quantities of foreign language material. In FY 2002, TIDES successfully constructed two text and audio processors by combining several advanced technology components, including automatic event tracking from audio and text sources. In FY 2003, TIDES is enhancing those capabilities and adding several new ones, including first generation Arabic-to-English translation. In FY 2004, TIDES will create an even more powerful unified system, able to process Arabic, Chinese, and English sources.

The **Effective, Affordable, Reusable Speech-To-Text** (EARS) program is creating rich, accurate, automatic transcription technology for broadcasts and conversations in English, Chinese, and Arabic. This will enable automatic detection, extraction, summarization, and translation algorithms to work effectively on audio sources. It will also greatly speed up the laborious analytic process by enabling analysts to read transcripts quickly, instead of listening to recordings slowly. EARS began in the middle of FY 2002. In FY 2003, we are conducting initial tests of new speech-to-text technology. In FY 2004, that technology will be significantly improved and metadata extraction will be added.

The **Global Autonomous Language Exploitation** (GALE) program will develop techniques for discovering critical intelligence by autonomously exploiting enormous volumes of streaming speech and text. GALE will enable machines to: (i) analyze, refine, combine, and package streaming speech and text information; (ii) discover threat-related trends and deviations; (iii) generate critical alerts, reports, and pointers; and (iv) deliver information in actionable form. GALE will build from the successes of both TIDES and EARS. Following a preliminary study in FY 2003, GALE will be launched in FY 2004.

Situation Presentation and Interaction

The **Babylon** program focuses on human-machine interaction, supporting real-time translation and situational awareness. The goal of the program is to develop rapid, two-way, natural-language speech translation interfaces and platforms for users in combat and other field environments. The scope of Babylon is constrained to three military task domains: force protection, refugee processing, and medical triage. Babylon will provide an enabling technology to give language support to the warfighter in deciphering possibly critical language communications during operations in foreign territories. In the first year (FY 2002) of Babylon, the program built and rapidly deployed one-way (English-to- language of interest) speech translation systems in dozens of target languages. The systems were delivered in the form of militarized palm-sized personal digital assistant devices with eight-hour battery endurance. In FY 2003, each of four Babylon two-way translation teams is developing 10 working-domain-constrained natural language translation prototypes on multiple platforms. In FY 2004, 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 noise and accent robustness, thus enhancing the ability of the prototypes to meet practical field requirements. This two-way translation 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-risk languages that will not be supported by any commercial enterprise.

The goal of **Symphony** is to improve human-computer interfaces (e.g., voice commands) by validating the generalizability of the Galaxy English dialog architecture, developed under DARPA's Communicator program. Symphony will evaluate the Galaxy architecture based on specific, selected military applications that may be augmented by a dialog paradigm. We anticipate that dialog-based systems will enhance situational awareness and ease the cognitive load on strategic and tactical decision-makers. Beginning in FY 2003, Symphony will select all target applications, establish Memoranda of Agreement (MOAs) with the Services (to include MOAs with the Army and Navy for participation with the Battlefield Casualty Reporting System program, the F/A-18 program, Sea Shadow program, Movement Tracking System program, and the Battlelab for Vehicle Navigation), and complete feasibility studies. In FY 2004, we plan to complete prototypes at a level of maturity that will establish proof-of-concept and feasibility. We will also assist the Services in mission needs analysis.

The goal of the **Language and Speech Exploitation of Resources Advanced Concept Technology Demonstration** (LASER ACTD) is to demonstrate the potential for inserting new multilingual dialog technology into future military systems. LASER has selected technologies in many categories of communication ranging from handheld translation devices to OCR-based machine translation devices. DARPA is supporting the LASER ACTD by delivering personal digital assistant devices for evaluation and generating target language support prioritized by the LASER advisory team. LASER supports national security by allowing multilingual dialog for civilians and military organizations at the security and force protection level. In FY 2002, the LASER program developed specific languages supporting U.S. Pacific Command: Tagalog, Japanese, and Mandarin. These languages were transitioned to DARPA's Phraselator hardware platform and used in support of the Cobra Gold, Balakitan, and Ulchea Focus Lens exercises. In FY 2003, we anticipate expanding the repertoire to include additional languages in support of Marine forces, and we plan to insert newly developed two-way translation algorithms. In FY 2004, we will emphasize ergonomics, software usability, and requirement validation for potential transition to the services. The primary customer and transition target for ACTD products include the U.S. Pacific Command and U.S. Special Operations Command.

ASSURED USE OF SPACE

The national security community, generally, and the U.S. military in particular, use space to provide warning, intelligence, communications, and navigation. These orbiting assets are one of the great advantages that the U.S. military has over our potential adversaries. And American society relies on space for everything from communications to weather reporting, making space assets a vital element of the U.S. economy and our way of life.

This military advantage and civil dependency have not gone unnoticed by our adversaries, and there is no reason to believe that they will remain unchallenged or untested forever. In FY 2002, the Secretary of Defense directed DARPA to begin an aggressive effort to ensure that the U.S. military retains its preeminence in space by maintaining unhindered U.S. access to space and protecting U.S. space assets from attack. There are five elements in DARPA's space strategic thrust:

- **Access and Infrastructure** is developing technology to provide rapid and affordable access to space;
- **Situational Awareness** will provide us the means for knowing what else is in space and what that "something else" is doing up there;
- **Space Mission Protection** is developing the means to protect U.S. space assets from harm;

- **Space Mission Denial** is working on technologies that will prevent our adversaries from using space to harm the United States or its allies; and
- **Space-Based Engagement** is developing space-based sensing, communications, and navigation technology and methods to support military operations down on earth.

ACCESS AND INFRASTRUCTURE

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. In FY 2002, DARPA selected the Boeing Company team to perform phase II of the Orbital Express Advanced Technology Demonstration. During this 42-month phase, the team will: (i) finalize the design; (ii) develop and fabricate a prototype servicing satellite, the Autonomous Space Transport Robotic Operations satellite, and a surrogate serviceable satellite, NextSat; and (iii) conduct an on-orbit demonstration to validate the technical feasibility and mission utility of autonomous, robotic, on-orbit satellite servicing. Initial efforts will concentrate on the autonomous guidance, navigation, and control software for rendezvous and docking, the highest technical risk area in the program. In FY 2003, DARPA has completed a system-level Preliminary Design Review and will conduct several additional subsystem design reviews. Fabrication and ground test of the two space vehicles will continue through mid- to late FY 2005. Orbital Express was recently manifested as the primary payload on the Air Force Space Test Program MLV-05 mission, a Delta IV Medium launch vehicle, with a launch date of March 2006.

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 microsize 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 micropayload size after transition to the Services. This capability will enable cost-effective use of on-orbit replacement/resupply 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 tradeoff 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 completed system concept definition, demonstration of aircraft propulsion adaptation to first-stage mission requirements, and system requirements and conceptual design reviews. In FY 2003, DARPA conducted system design reviews of the first-stage vehicle and selected the industry teams for conducting the design and risk-reduction phase of the program. In FY 2004, DARPA will begin engine ground tests and conduct the system critical design review.

The **Force Application and Launch from CONUS** (FALCON) program (formerly HyperSoar program) objective is to develop and validate in-flight technologies that will enable a CONUS-based, reusable delivery capability in support of global mobility and power projection. We anticipate that technologies developed by the FALCON program will enable future, low-cost space access concepts as well. A concept of operations for FALCON is to fly at the outer edge of the atmosphere (between 115,000 and 200,000 feet) at hypersonic speeds (between Mach 6-10). A flight demonstration program will be developed to validate both a near-term and a far-term hypersonic air vehicle approach. The near-term global reach capability will be accomplished using a Common Aero Vehicle (CAV) and a new low-cost booster. During these near-term capability tests, technologies relevant to the far-term hypersonic airplane approach will be developed including advanced guidance, navigation and control, long-duration thermal protection systems, and periodic flight mechanics. Far-term global reach technologies, such as high lift-to-drag aerodynamics, high-speed separation dynamics, reusable thermal protection system, leading-edge materials, and advanced propulsion will be demonstrated with a hypersonic technology vehicle using a similar CAV demonstration approach. In FY 2003, a Memorandum of Agreement was signed between DARPA and the Air Force to jointly execute the program. Multiple study contracts will be initiated to develop system concepts, concepts of operations, and technology maturation plans. In FY 2004, DARPA will conduct a downselect for System Definition to start conceptual design of the CAV and new booster development.

SITUATIONAL AWARENESS

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 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, DARPA conducted mission analysis, concept definition, and preliminary design studies for a SPAWN system, and identified the objectives of a proof-of-feasibility prototype demonstration. Based on the results of this phase I effort, in FY 2003 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 is planned to be launched along with the Orbital Express mission to perform a series of on-orbit demonstrations.

The **Space Surveillance Telescope** (SST) 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. The SST program goals for detection sensitivity and search coverage rate represent approximately an order-of-magnitude improvement over current capabilities. In FY 2002, the first year of the program, DARPA completed the design study to determine sensor and optics requirements and a system deployment concept of operations. In FY 2003, the first tile of the sensor focal plane was fabricated, and detailed design of the primary optics has begun. In FY 2004, the first single curved tile wide-field camera will be completed and tested, and optics fabrication will begin.

The **Deep View** program (formerly called Space Object Identification System) 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. In FY 2002, the first year of the program, DARPA completed initial design of the high-power transmitter tubes. In FY 2003, the program fabricated and tested the first transmitter tube and conducted analysis of the sparse-band signal processing system. In FY 2004, development of frequency and power combiners will begin.

The **Coherent Communications, Imaging and Targeting** (CCIT) program could lead to more efficient systems for tracking satellites and communicating with 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 for use on 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, DARPA demonstrated the spatial light modulator devices with scalable architecture. The program is developing three device types, and will assemble the most promising into a laboratory CCIT system, followed by a demonstration at greater than one kilometer range in late FY 2003. In FY 2004, DARPA will select an industry team for additional communications or imaging demonstrations. All three Military Services are potential customers, as CCIT provides capabilities for secure communications.

The **Rapid On-Orbit Anomaly Surveillance and Tracking** (ROAST) program will provide a space-based capability to detect and track on-orbit objects with rapid revisit rates and low latencies. The system will feature a moderate-sensitivity, wide field of view optical telescope hosted in a low-cost, rapid deployment microsatellite constellation. Space-based deployment facilitates event detection with extremely low latency, and low-cost deployment allows sufficient assets to provide global coverage. Key technologies include lightweight mirror technology and dynamic frame read-out charge coupled device sensors to allow adaptive tasking. In FY 2004, DARPA will demonstrate lightweight optics fabrication capability and initiate telescope design.

SPACE MISSION PROTECTION

The objective of the **High Frequency Active Auroral Research Project** (HAARP) instrument completion project is to finish the HAARP Gakona Facility and bring it to its planned performance capability. The Department of the Navy has expressed interest in the potential application of ionospheric interactions in the creation of Extremely Low Frequency (ELF) radiation for submarine communications and other purposes. The Department of the Air Force has expressed interest in the potential applications of ionospheric interaction for ELF, high frequency, and very low frequency communications, over-the-horizon radar, and other purposes. Ionospheric research activities are routinely conducted under a DARPA/Air Force/Navy Memorandum of Agreement with the prototype HAARP system. This program will enable the development and deployment of future systems to provide protection for space-based assets from emergent asymmetric threats, and the investigation and quantification of the use of the HAARP technology to conduct underground facility detection. In FY 2003, the first year of the program, site preparations and antenna manufacture will be completed. In FY 2004, the antenna system will be erected and the power plant upgraded in preparation for transmitter installation.

SPACE-BASED ENGAGEMENT

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), wide band operation, high range-resolution ground moving target indicator modes (approximately one foot resolution), and low minimum detectable velocity. This combination of requirements will drive investments in very large-scale antennas and in novel materials and packaging appropriate to launching and deploying such a system. In FY 2002, we determined the feasibility by developing multiple objective system designs, and we carried out preliminary lab tests on candidate hybrid-polymer materials technologies. In FY 2003, we will develop conceptual demonstration system designs, and we will conduct testing and analysis of complex geometry materials analysis (joints and interfaces). In FY 2004 we will commence detailed demonstration system designs, and we will initiate ground-based scale model proof-of-concept demonstrations.

NETWORKED MANNED AND UNMANNED SYSTEMS

DARPA is working with the Army, Navy, and Air Force toward a vision of filling the battlespace with unmanned systems that are networked with manned systems. The idea is not simply to replace people with machines, but to team people with robots to create a more capable, agile, and cost-effective force that lowers the risk of U.S. casualties. There is an increasing appreciation within the Services that combining unmanned with manned systems can enable new combat capabilities or new ways to perform hazardous missions. Also, improved processors and software permit the major increases in on-board processing needed for unmanned systems to handle ever more complex missions in ever more complicated environments. The research in this strategic thrust can be broadly grouped into aeronautical systems, Future Combat Systems and other land systems, and maritime programs.

AERONAUTICAL 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 lethal and non-lethal 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 effects-based, spiral development program to develop an early operational capability. In FY 2002, the program began flight demonstrations with the X-45A Spiral 0 demonstrators and conducted an initial design review for the Spiral 1 demonstrators. In FY 2003, the program completed the first block of demonstrations and will begin multi-vehicle X-45A coordinated flight tests, continue the preliminary design for the low-observable X-45C for Spiral 1, and begin fabrication of long-lead items. FY2004 activities will include the completion of Block 2 and -3 demonstrations, as well as final design review for the X-45C. In FY2004, the UCAV development will be managed as part of a joint program office.

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's integrated air defense system and high-value targets with relative impunity and 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 FY 2001, Boeing and Northrop Grumman completed analysis and preliminary design of a UCAV-N air system, and began risk reduction activities. In FY 2002, both contractor teams completed initial technology development and were awarded phase IIA agreements to design, develop, and fabricate a UCAV-N Demonstration System to demonstrate the critical and enabling technologies, processes, and system attributes pertaining to operations on-and-around the carrier. In FY 2003, a successful first flight of the Northrop Grumman X-47A Pegasus was completed. Both contractor teams also completed Air OPs demonstrations. Phase II will continue through December 2004. In FY 2004, the UCAV-N development will be managed as part of a joint program office.

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 programs to develop the next generation of autonomous and collaborative mission execution capabilities. UCARs will operate autonomously at low altitude and will execute missions in collaboration with other UCARs, other unmanned systems, and with manned assets. UCAR will leverage 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 UCAR to locate, identify, and prosecute targets farther in front of U.S. and coalition lines, thereby protecting manned and unmanned ground and air systems. In FY 2002, DARPA: (i) awarded phase I agreements to Boeing, Lockheed Martin, Northrop Grumman, and Sikorsky to conduct mission effectiveness and affordability trades to develop their UCAR Objective System conceptual design; (ii) identified critical technologies, processes and system attributes; (iii) completed the conceptual design of a UCAR Objective System (UOS); and (iv) planned a phase II preliminary design effort. In FY 2003, DARPA will move into phase II to: (i) continue to refine the UOS design through mission effectiveness and affordability trades; (ii) conduct risk reduction activities to mature key technologies; (iii) develop the preliminary design of the UCAR Demonstrator System; and (iv) plan a phase III system demonstration effort. The phase II efforts will be completed in FY 2004 and will be used as the basis for the selection of the phase III contractor team.

The **Canard Rotor/Wing** (CRW) 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 vehicle 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 18-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, the program conducted ground testing, including critical full-power restrained testing. Flight testing will be conducted in late FY 2003.

The **Micro-Air Vehicle Advanced Concept Technology Demonstration** (ACTD) program is a joint DARPA/Army ACTD to demonstrate the technical feasibility, military utility, and operational value of a micro-air vehicle (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 program. Those programs demonstrated small (down to six inches in size), unmanned air vehicles and autonomous flight of nine inch to 29 inch ducted fan vehicles, respectively. The ACTD focuses on the small, approximately nine inch diameter, ducted fan vehicle that a single soldier can carry in his/her backpack without displacing anything else. The unique attribute of the system is its ability to fly in hover and/or cruise, enabling positioning to survey areas of interest and, thereby, providing a small unit of action organic improved situational awareness capability. A "perch and stare" capability based on an ability to land and to observe remotely is an objective for military assessment. In FY 2003, the program is developing a core air vehicle system design that meets the needs of the soldier, such as ease of operation and operation on readily available diesel fuel (JP-8). Additional risk reduction platform and systems work will support this effort in FY 2004. Air vehicles will be turned over to the Army for military utility assessment during FY 2004 and FY 2005.

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 **Hypersonics Flight Demonstration** (HyFly) program is developing, and will 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, materials required for extreme thermal conditions, 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, the contractor team: (i) performed preliminary and detailed design efforts and supporting materials/structural demonstrations; and (ii) conducted freejet aero-propulsion testing of the heavyweight vehicle configuration. In FY 2003, DARPA has completed casting of the prototype fuel tank, SLAT Booster nozzle extension testing, and Preliminary Design Review. In FY 2004, DARPA will continue to: (i) conduct ground test verification (static firing) of boosters, captive-carry, drop, boost performance and boost separation flight tests; (ii) conduct sled tests of simulated submunition deployment; and (iii) perform advanced combustion systems proof-of-concept testing on a gun-launched test range. In FY 2005-6, DARPA will conduct various vehicle subsystem tests and integrated vehicle tests. The program will also demonstrate clean supersonic booster and inlet cover separation from a full-scale vehicle at speeds exceeding Mach three.

The **Quiet Supersonic Platform** (QSP) program addresses enabling technologies for long-range supersonic flight that also reduce sonic boom to an acceptable level. In FY 2001, 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, the program validated the aerodynamic performance of these aircraft configurations through wind tunnel testing, and conducted proof-of-concept tests of several key technologies. In FY 2003, DARPA will conduct experiments to demonstrate that a specially shaped aircraft can produce a quieter sonic boom. In FY 2004, DARPA will develop and demonstrate laminar flow control technology to enable efficient cruise performance for swept wing supersonic aircraft.

A key to U.S. warfighting success is control of the air and defeat of enemy ground-based air defenses. While the United States 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 began the development of critical laser, detector, and optical fiber technology for MEDUSA, and we developed 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 we will select a system design for future field demonstrations. In FY 2004, we will build a system and perform laboratory demonstrations of key functions.

The **High Power Fiber Lasers** (HPFL) 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 lasing 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 by 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's phase I, large mode-field area fiber designs, preform fabrication techniques, and coupling of high brightness laser diode pumps are being developed to demonstrate greater than 100 watt single-mode output power from a fiber laser. In FY 2004, DARPA will decide whether to proceed with phase II and selection of designs for combining fiber lasers coherently.

The **High Energy Liquid Laser Area Defense System** (HELLADS) program will design, develop, integrate and demonstrate a High Energy Laser (HEL) weapon system with an order-of-magnitude reduction in cost and weight compared to existing HEL systems. With a goal of less than five kilograms per kilowatt, HELLADS will enable high energy lasers to be integrated with tactical aircraft and unmanned air vehicles. A laser output of 150 kilowatts has been established for the HELLADS program to enable the destruction of rockets and missiles at tactically significant ranges. In FY 2002's phase I, DARPA demonstrated critical elements of the HELLADS laser concept, including the effects of the heterogeneous lasing medium and temperature upon transmission and beam quality. In FY 2003's phase II, a low-power HELLADS laser will be fabricated and demonstrated at a power level greater than 100 watts. In FY 2004's phase III, DARPA will design, fabricate, and demonstrate in a laboratory a subscale HELLADS weapon system at a power level equal to, or exceeding, one kilowatt.

The **Virtual Electromagnetic Test Range** program is substantially improving the process of radar cross section design for DoD air vehicles. The program is developing and bringing to practice fast, accurate, three-dimensional computational electromagnetic prediction codes enabling practical radar cross-section design of full-sized 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, results to-date suggest two orders-of-magnitude reduction in computational expense may be attainable in a variety of important design applications. We ultimately 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 demonstrated the capability for high-fidelity prediction from multisensor apertures and arrays, and we attained significant advances in the prediction of radar scattering from material treatments. In FY 2003, the focus is on transitioning the mathematical developments into standard design practice within the Defense airframe industry. In FY 2004, the program will investigate extensions of the approaches developed to dynamic scattering structures and scenarios in which multiple scattering structures with disparate characteristics are present. Such extensions would support analysis of vibrating bodies, such as aircraft in flight, and highly complex, dynamic situations, such as a ship at sea.

FUTURE COMBAT SYSTEMS AND OTHER LAND 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 with manned and unmanned platforms is the key FCS enabler. 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 mid-May 2003, the Defense Acquisition Executive, Under Secretary of Defense for Acquisition, Technology and Logistics, chaired a Defense Acquisition Board (DAB) Milestone B Review to consider the FCS program readiness to enter System Development and Demonstration (SDD). As a result of this review, the Under Secretary approved FCS to enter SDD as a single Major Defense Acquisition Program (MDAP) as proposed by the Army, and he directed a full Milestone B update in November 2004.

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

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 FCS. 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 an 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 FY 2003, we delivered 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 were selected to build prototype Jigsaw sensors for integration on a helicopter. Extensive laboratory system testing was conducted to validate sensor performance. In FY 2003, contractors will checkout, 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. If successful, an additional effort will start in FY 2003 to ruggedize and miniaturize the Jigsaw sensor for the Army's Future Combat Systems.

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 – 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 fuselage 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 electrooptic devices to detect vehicles or individual soldiers. In FY 2001, we satisfactorily completed initial testing of an OAV candidate, the lift augmented, ducted fan vehicle. Flight control software was developed and autonomous flight tests were performed numerous times. In FY 2002, DARPA continued development of the flight control software to allow for flight in adverse weather. Flight tests were conducted throughout FY 2002, and the autonomous OAV will be evaluated by Future Combat Systems in FY 2003. In FY 2003, DARPA will begin a new program, **Organic Air Vehicles in the Trees**, to develop and test collision avoidance systems for micro-air vehicle (MAV) systems that are capable of reconnaissance and surveillance, to support flight in denied/congested areas. Phase I activities will include evaluation of sensors and design of collision avoidance systems through FY 2004.

The **A160 Hummingbird Warrior** program is revolutionizing the capabilities of helicopters. The program began in FY 1998 to satisfy the Army and the Marine Corps need for an affordable, vertical take-off and landing unmanned air vehicle with a long ferry-range (greater than 2500 nautical miles) and high-endurance capability (greater than 24 to 48 hours) with substantial payloads (300 to 450 lb). Objective missions are C4ISR and logistic support. 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 first flight of the A160 Hummingbird took place on January 29, 2002, and ground and flight testing continued for the balance of FY 2002. In FY 2003, the A160 program development includes: test and evaluation of the new 4 blade rotor, transmission upgrades, engine upgrades, flight control system upgrades, and electronics environmental tests. In late FY 2003 and early FY 2004, the program will evolve from the current technology proof-of-concept stage into a DARPA/Army vehicle maturation stage.

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." In FY 2002, DARPA selected two designs from each payload class for refinement. As a part of this refinement, each team conducted experiments on critical subsystems, e.g., power and suspension systems. All of the designs used hybrid electric drive-trains to accommodate long silent-watch modes and high efficiency. In June 2002, two designs were selected for full prototype fabrication, one from each size class. The prototypes rolled out in February 2003 and will be tested 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. PerceptOR 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. 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. Although PerceptOR contractor teams were expected to accomplish perception development in their own field trials, DARPA also hosted four field experiments in which the robots were operated in an unrehearsed mode in phase II of the program. The first unrehearsed experiment occurred in February 2002 at Fort A.P. Hill, Virginia, for three teams. Further phase II testing was conducted at Yuma Proving Ground, Arizona; USMC Mountain Warfare Training Center, California; and Ft. Polk, Louisiana – locations that had not been seen by the contractor teams. They were conducted both day and night, and in inclement weather. PerceptOR provided 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 onboard perception "context" interpretation. In phase III, two teams were selected for continued field experiments through CY 2003 to evaluate operations in which sensors fail, communications are limited (or fail intermittently) and moving at increased speeds. The results of PerceptOR are expected to provide critical insight into the near-term robotic navigation capabilities available to FCS, and will point the way to continued advancement in ground robot operations under combat conditions.

The **NetFires** program will develop and test a containerized, platform-independent, multimission 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 with 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, multimission 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 FCS. In FY 2002, DARPA completed validation of the launcher system with boost test vehicle launches, refined the seeker concepts with further captive flight tests, and initiated missile launch and navigation and aerodynamics with controlled test vehicle launches. In FY 2003, DARPA continued successful captive flight tests and controlled test vehicle launches at White Sands Missile Range, New Mexico, and Eglin Air Force Base, Florida. Also in FY 2003, extensive transition planning between DARPA and Army program offices has been ongoing. A joint venture/LLC between Raytheon and Lockheed Martin has been finalized and the new team has initiated Pre-System Development and Demonstration activities, including system design studies, risk reduction testing, and Block II technology development. In FY 2004, the program will introduce new concepts of operations for light forces with extensive guided missile flight tests.

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 brassboard test unit through the Joint Surveillance Targeting Attack Radar System. Fabrication of 10 field prototype tag units began in FY 2002, and all subsystem modules are in their final stage of integration and testing. The first prototype will be completed and tested in late FY 2003. Remaining units will be completed and field-tested in partnership with the Army in late FY 2003 and early FY 2004.

Other Land Systems

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 multisensor vehicle to provide battlespace awareness. In FY 2001, the program participated in the Navy Extending the Littoral Battlespace Advanced Concept Technology Demonstration and 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, intelligence/ reconnaissance, surveillance, target acquisition communication and sensor suite digitally linked into the Extending the Littoral Battlespace wide area network architecture. During FY 2002, DARPA completed fabrication of the third and fourth prototype vehicles. Relative to the first two vehicles, the third and fourth vehicles were equipped with improved components and incorporated an enhanced design in the area of battery power conversion, thermal management, and vehicle system control. The vehicles will undergo survivability, automotive, and active suspension performance testing. The program office is currently discussing transition opportunities with U.S. Special Operations Command and the Marine Corps. In FY 2003, the vehicles were integrated with additional mission-specific equipment and will undergo joint limited operational assessment at Yuma Proving Ground, Arizona, in late FY 2003.

The **Antipersonnel Landmine Alternatives** program is developing technologies that provide warfighters with enhanced capabilities that obviate the need for antipersonnel landmines (APLs). One part of the Antipersonnel Landmine Alternatives program, the **Self-Healing Minefield**, seeks to develop and demonstrate an effective battlefield obstacle that does not require antipersonnel submunitions. Current mixed landmine systems, such as the Family of Scatterable Mines, rely on an antipersonnel component to delay enemy attempts to breach fields of antitank landmines. In contrast, the Self-Healing Minefield allows the enemy to breach the antitank landmines, but the remaining antitank landmines have small rocket thrusters that propel them into the breach path, "healing" the breach. Consequently, the desired delay of enemy advance is accomplished without the need for antipersonnel components. Not only does the Self-Healing Minefield remove the antipersonnel component from mixed systems, but battlefield simulations demonstrate that it will provide the warfighter with a new capability to deploy a barrier that is significantly more effective than current systems. In FY 2003, the Self-Healing Minefield program demonstrated scaling to a tactically significant number of nodes. The program is now positioned to transfer into future Army combat systems.

The goal of the **Distributed Robotics** program has been to develop and demonstrate small, mobile robots that can operate collaboratively to satisfy a multitude of military missions. The program developed a number of supporting sensing technologies designed to be incorporated into the robot package. Five different robots were developed with varying mobility capabilities that represent major advances in robot technology for their size range. Examples include a miniature camera-carrying robot that can be fired from a grenade launcher and, upon landing, can propel itself at speeds up to 0.5 meters per second. This robot also incorporates a unique capability to jump up to 30 centimeters over obstacles. We developed a second class of microbots that includes a miniature self-propelled underwater vehicle. A group of these vehicles has been demonstrated to operate in a swarm to detect the source of a spreading underwater chemical plume. Supporting technologies, such as a miniature short-wave infrared camera and an electromagnetic identification system, were also developed and integrated onto the robots. The robots developed in this program have generated considerable interest in the Services, and discussions of transition opportunities with the Army, Navy, and U.S. Special Operations Command are in progress.

The United States 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. After considering many options to counter this threat, it was determined that an interceptor with a low-cost millimeter-wave seeker would provide the best solution. 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 the ESA cost is low enough. Throughout FY 2002, the program explored many options to achieve a low-cost seeker, leading to the award of two contracts for ESA designs based on low-cost, single chip transmit/receive modules in early FY 2003. In FY 2003, the program will undertake fabrication of the low-cost ESA. The Air Force and Army have expressed great interest in this program. DARPA and the Services are negotiating a Memorandum of Agreement to integrate the low-cost seeker and low-cost air vehicle. We plan to have a preliminary design review for a low-cost ESA in mid-2003 and, upon successful completion, a follow-on contract will be awarded. In summer 2003, a form-factored ESA will be initiated, and work will be continued through FY 2004.

MARITIME PROGRAMS

DARPA supports a wide range of maritime technology development programs that span the range of needs for future naval combatants – surface and subsurface, as well as autonomous submersibles operating in the littorals.

Building upon previous DARPA investments in lighting technologies, the **High Efficiency Distributed Lighting** (HEDLight) program seeks to enable significant reductions in platform vulnerability by developing and demonstrating high efficiency "remote source lighting" technologies. The net of electrical wiring necessary to support lighting systems in larger platforms, particularly Navy warships, is a key source of platform vulnerability. Remote source lighting – the distribution of lighting through long-run fiberoptics – can dramatically reduce the density of the electrical wiring network, resulting in significant reductions in platform vulnerability and concomitant improvements in maintainability and damage control. Current remote source lighting systems are relatively inefficient and preclude the general replacement of existing lighting systems. The key enabling technologies for HEDLight are: (i) high efficiency, full-spectrum light sources; (ii) high efficiency fiberoptic luminaires; and (iii) efficient optical systems for coupling the light sources to the fiberoptic cables. The goal of the HEDLight program is a total efficiency of greater than 70 lumens per watt (for comparison, current ruggedized ship-board fluorescent lighting systems are approximately 50 lumens per watt). In FY 2004, DARPA will develop and evaluate the first generation of HEDLight subsystems, targeting subsystem performances that enable an intermediate efficiency goal of 50 lumens per watt for the system as a whole. Technology transition will initially emphasize Navy vessels, and personnel from the U.S. Naval Sea Systems Command and the Philadelphia Naval Shipyard are involved in the program. Ongoing Navy remote-source-lighting efforts, coordinated through the U.S. Naval Sea Systems Command, will provide transition opportunities for successful performers starting in FY 2004.

The **Loki** program seeks to develop the critical system technologies to demonstrate the engineering and technical feasibility of a lethal, stealthy, high-speed maritime "fighter" platform. These technologies include the vortex combustor and related propulsion technologies, materials, structures, and sensing technologies. If successful, Loki will enable aggressive, offensive U.S. military combat operations in littoral regions. With greater speed and access achieved, in part, through the operational flexibility and "combat punch" of these underwater "fighters," meeting joint littoral campaign objectives can be more easily achieved given additional U.S. flexibility in choosing the time and place of engagements. DARPA is developing a test-scale vortex combustor to demonstrate the engineering and technical feasibility of developing a revolutionary propulsion source that could be used in such a lethal, stealthy, high-speed maritime "fighter" undersea platform. Testing of a small-scale vortex combustor began in FY 2002. During FY 2003 and FY 2004, Loki is continuing development of vortex combustor technology and supporting propulsion system components, as well as novel technologies in acoustic and nonacoustic sensors for object detection and avoidance, hull and platform design, and component technologies such as actuators, communication modalities, human-machine interface, and support systems technologies. Loki is in its early stages of analysis and critical technology development, and DARPA will be working with the Navy user community to identify application and transition opportunities as the program matures.

One critical technology to the Loki concept, and other military underwater operations, is the use of a reliable, high energy density power source for propulsion and other purposes. The **Vortex Combustor** program is an innovative effort that seeks to develop a high energy density, 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. Hot testing began in September 2002, and several short-duration tests have achieved successful light-off and self-sustaining operation. Testing underway in FY 2003 is demonstrating the ability of such a device to operate underwater, to be throttled, and to operate for at least an hour. FY 2004 development will include scaling relationship verification, long-term endurance testing, preparation for dynamic testing, propulsion system design, dynamic maneuvering, and material testing. Also in FY 2004, this program will join with the Loki program to better incorporate network-centric warfighting capabilities.

The **Undersea Littoral Warfare** (ULW) program is developing antisubmarine and countermine technologies focused on the near-land littoral region, an ocean area characterized by high traffic density, complex oceanographic environments, quiet diesel submarines, and potentially numerous floating, moored, and buried mines. The five primary efforts being conducted under the ULW program are:

- The **Piranha** effort will enable submarines to engage elusive maneuvering land and sea targets by exploiting emerging battlefield intelligence, surveillance and reconnaissance (ISR) sensors; wide band networked communications; real-time exploitation targeting algorithms; and existing/planned submarine strike weapon systems. This effort will develop key technologies that enable attack-and-cruise missile submarines to play a wider role in responding to time-urgent maneuvering targets from a forward-deployed position. Piranha will focus on the following key technology areas that enable submarine applications: continuous asymmetric connectivity to sensors and weapons while at depth, ISR sensor data exploitation for targeting (e.g., sensor-to-weapon handoff, georeference algorithms), and organic delivery of ground and surface ISR sensors. The effort will pursue a progression of more realistic demonstrations, culminating in closed-loop submarine engagement of moving ground surface vehicles.

- The **Long-Range Mine Detection** program seeks to develop and demonstrate technologies that provide long-range discrimination of naval mines in the littorals. Preliminary limited testing results indicate that the technology and phenomenology are reliable and robust. If successful, this program, in conjunction with the Navy, will deliver radical new mine detection technologies for warships operating in littoral waters. During FY 2003 and FY 2004, the Long-Range Mine Detection program will collect data and assess system performance in complex environments. This effort is being coordinated with the Office of Naval Research and the Navy's Mine and Undersea Warfare offices.

- The **Smart Actuators and Marine ProjectS demonstratiON** (SAMPSON) program seeks to develop and demonstrate an advanced control system for smart materials-based actuators compatible with submarine requirements. Actuators that provide adaptable stealth technology for the control or reduction in submarine signatures will significantly enhance a submarine's ability to remain undetected. This program seeks to leverage the successes of smart material actuator technology efforts to-date and incorporate additional active control and stealth technologies. During FY 2003, DARPA developed the test program, developed and fabricated a test-scale actuator, and explored performance in identified signature regimes. This technology will transition to the Navy with U.S. Naval Sea Systems Command as the transition partner. Current plans are to transition SAMSON to the Large Scale Vehicle, with long-term goal transition to VIRGINIA class submarines, if successful, at the end of FY 2003.

- The **Littoral Naval Architecture Study** will explore future concepts to help develop and define a notional architecture and concept of operations for naval operations in the littoral region. As part of expeditionary force operations, future naval forces require access to littoral waters and the ability to project power ashore. These forces must conduct operations in the presence of naval mines, numbers of small craft, and diesel submarine threats, and enable access for follow-on joint expeditionary forces. During FY 2003, this effort will identify the individual and collective technologies necessary for successful operation in areas defended by forces ashore, mines, submarines, small craft, and antiship missiles, and define the desirable and achievable performance characteristics of various manned and unmanned systems useable in a littoral naval force.

- In the **Submarine Design Study**, DARPA and the Navy are initiating a program effort to explore innovative and affordable submarine design concepts that can accommodate novel payload and sensor concepts. The proposed effort is intended to foster innovation and to push technological limits by attempting to maintain VIRGINIA class nuclear powered attack submarine capabilities in notional submarine concepts with significantly lower displacement, coupled with the potential for decreased acquisition costs. DARPA hypothesizes that this cannot be done without a radical departure from current design practice.

The goal of the **Robust Passive Sonar** (RPS) program is to significantly improve the capability of tactical towed sonar systems to detect and track elusive diesel-electric submarine targets operating in challenging littoral environments. This will be accomplished by canceling surface-shipping noise, which is the primary cause of interference in these environments. In addition, the program will provide new capabilities for target detection and tracking: (i) while the receive array is maneuvering by compensating for array shape; and (ii) in the forward direction by suppressing noise from the receiver tow platform. The RPS program accomplishes surface-shipping noise cancellation by incorporating into the sonar processing architecture adaptive signal array processing techniques, high-fidelity acoustic propagation models, and accurate models of sonar array dynamics. The program will couple this advanced processing architecture with multidimensional receive arrays that provide acoustic measurements that are better matched to the acoustic propagation phenomena inherent in littoral environments. Net system performance gains against surface-shipping noise are expected to be 10 to 20 decibels, and we expect this system will motivate future array and acoustic sensor field designs. During FY 2003 and FY 2004, DARPA will implement the RPS algorithms into a real-time passive acoustic processing system that greatly improves our capability to operate in the littorals against submarine threats in dense shipping traffic areas. In FY 2003, DARPA will complete and demonstrate preliminary development of the processing system via a non-real-time laboratory evaluation against the RPS performance objectives using the RPS experimental data. In FY 2004, development of a field-deployable real-time system will be completed, and the system will be demonstrated on an appropriate Navy fleet platform operating in an at-sea exercise. Transition is planned to the U.S. Naval Sea Systems Command Advanced Rapid Commercial Off-the-Shelf Insertion program for the AN/BQQ-10 sonar system.

The **Friction Drag Reduction** program established two goals to address the practical barriers to full-scale implementation of friction drag reduction. The first goal was to tackle the fundamental physics, and the second was to develop a multiscale modeling capability that would lead to large-scale design models that incorporate sufficient physics such that they are truly predictive in nature. Such a capability would allow researchers to run full-scale experiments on a computer, thereby enabling them to narrow the full-scale experimental test matrix to something feasible. Significant progress on both of these goals was achieved during FY 2002. Computational techniques that leveraged massively parallel computer architectures showed the existence of two distinct drag-reducing regimes with fundamentally different flow structures and direct evidence of the stretching of polymers in regions of high vorticity. In addition, modeling of bubbles in turbulent flow indicated that small spherical bubbles can produce drag reduction, even at low void fractions. Significant advances in experimental techniques included Particle Image Velocimetry, which was used to achieve unprecedented resolution of velocity and vorticity fields in polymer experiments. A unique imaging method suggested that polymers that organize into sheets or filaments produce dramatically enhanced drag reduction. Small-scale experiments with 30 micron bubbles clearly demonstrated that, like polymers, bubbles must be located within a very thin layer near the wall to be effective. In developing the multiscale modeling capability, large-scale modelers worked to develop approximations to enable modeling at realistic scales, while ensuring that the approximations still captured enough of the physics so the codes could be used to make accurate predictions. At the end of phase I of the program, the codes demonstrated good qualitative agreement with first-principles results and experimental data. In addition, a large scale experimental capability was constructed at the Large Cavitation Channel in Memphis, Tennessee, to provide high-quality data at large scales to validate the computational models being developed in the program. A transition agreement with the Hydrodynamics Technology Center (HTC) at Naval Surface Warfare Center, Carderock Division, was established during FY 2002, whereby HTC will receive all the codes developed during the first phase of the program, which ends in late FY 2003. The second phase of the program, which will begin during the fourth quarter FY 2003, will build upon the multiscale modeling capabilities developed during phase I to create large-scale design codes that demonstrate quantitative and qualitative agreement with experimental data. Such data will be generated using the large-scale experimental testbed constructed during the first phase of the program.

ROBUST, SELF-FORMING NETWORKS

The Department of Defense is in the middle of a transformation to what is often termed “network-centric warfare.” In simplest terms, the promise of network-centric warfare is that networked military systems will change the terms of any conflict to favor the U.S. military. It will allow the United States and our allies to go beyond a correlation of local forces by providing them better information and letting them plan and coordinate attacks far more quickly and effectively than our adversaries.

At the heart of this concept are survivable, assured communications at strategic and tactical levels. The goal of this work is a network that degrades softly under attack, while always providing a critical level of service. At DARPA, we are conducting research in areas including self-forming networks, software programmable radios, spectrum management, low probability of detection/intercept/exploitation communications, and information assurance and survivability.

SELF-FORMING NETWORKS, SPECTRUM MANAGEMENT, AND SECURE COMMUNICATIONS

The **Networking in Extreme Environments** program seeks to create a wireless networking technology for the warfighter that enables robust connectivity in operational environments and can be integrated into new, emerging sensor and communications systems. DARPA is developing a system that takes advantage of the unique properties of ultra wide band (UWB) devices that enable them to function in a dense multipath environment to very accurately resolve range and to act as sensor and communications devices. During FY 2003, DARPA completed laboratory electromagnetic interference testing on 20 military receivers that were selected to best represent the range of military systems in use today. DARPA will integrate the physical testing results with the modeling efforts to identify a broad range of modes of UWB operation that do not cause harmful interference to other military systems. During FY 2004, DARPA will use the information gained from the modeling and testing efforts to develop initial designs for a UWB physical layer that will improve the signal-to-interferer ratio by more than 20 decibels, increase receiver sensitivity code gain by more than 20 decibels, and examine opportunities to reduce the power requirements and physical size of the UWB devices. DARPA will develop *ad hoc* networking and multiple access protocols to integrate into an operational UWB system. During FY 2005, DARPA will conduct a series of experiments to demonstrate the ability of UWB systems to provide reliable communications in dense urban terrain and other harsh electromagnetic environments. These experiments will demonstrate the military utility of UWB sensor and communication systems and support their inclusion in ongoing communications programs

The **Airborne Communications Node** (ACN) program will enable an affordable, autonomous communications infrastructure that simultaneously provides assured communications, situational awareness, and signals intelligence (SIGINT). ACN payloads could be integrated on platforms ranging from high altitude endurance (HAE) unmanned airborne platforms (e.g., Global Hawk) to vessels at sea to ground vehicles. The ACN system will be scalable, enabling payloads for various platforms to be constructed from a core set of common circuit boards and chassis. The ACN on a HAE unmanned airborne platform will provide wide-area wireless communications and SIGINT services over the theater of operation for joint and multinational forces by establishing an early, robust, airborne infrastructure for intra-theater line-of-site and reachback beyond line-of-site without the need for large, in-theater assets. ACN will augment and enhance the battlefield communications infrastructure to adapt communications, situational awareness, and SIGINT services to the flow of battle. Therefore, the ACN system needs to be adaptable, interoperable, robust, secure, and affordable within the size, weight, and power constraints of the intended platforms. In addition, the ACN architecture allows for implementing technologies and subsystems that can adapt the various wireless command and control tiers that will exist in the future network-centric battlesphere. The ACN system operational utility will be assessed by U.S. Joint Forces Command as part of a Joint Advanced Concept Technology Demonstration (ACTD), the Adaptive Joint C4ISR Node, which began in FY 2003 and will be complete in FY 2005, with an extended user evaluation in FY 2006 to FY 2007. The ACTD, which will be jointly funded by DARPA, Army, Air Force, U.S. Joint Forces Command, and the Office of the Secretary of Defense, will integrate ACN payloads onboard Air Force and Army aircraft.

The **Next Generation Communications** (XG) program was initiated to provide both a mechanism for rapid and efficient utilization of the shrinking military bandwidth in the dynamic environment of the 21st century and a viable solution to commercial carriers' demands for additional spectrum. The goal is to demonstrate for the DoD the enabling technologies and system concepts to improve spectral utilization of military radio frequency emitters by a factor of 20. The premise for XG challenges conventional wisdom about the spectrum, since, in most discussions, it is assumed that spectrum demand overwhelms the fixed supply. By looking at "spectrum" from a different perspective, DARPA validated a dynamic system in which spectrum use changes constantly. Initial measurements show, on average, less than two percent of the spectrum is actually in use in the United States at any given moment, even though most of the spectrum is allocated. The key technology question becomes whether the unused spectrum can be exploited for DoD purposes, while ensuring that other systems do not interfere with military needs, and that DoD usage does not interfere with those other systems. The XG program is developing four key technologies to answer that question: (i) compact spectrum sensing; (ii) spectrum characterization; (iii) ability to react; and (iv) adapting to spectrum changes. XG is completing its first year of research, but, already – based on initial findings and confidence in current and future technology – DARPA is starting to change senior decision-makers' perspectives of spectrum management. Our preliminary analyses are building confidence in the ability to efficiently and effectively operate in military and civilian spectrum domains with a vast increase in communication capability, given the finite spectrum that is available. This adaptive thinking is seen in both our Defense research program, and civil activities, such as the recent Federal Communications Commission Spectrum Management Policy Task Force report. There is much more XG research to accomplish. DARPA has started to develop the techniques and preliminary system designs to demonstrate this capability under controlled conditions. DARPA will build and demonstrate a selected design in a field test by FY 2006. DARPA has already begun working with the Services in planning the transition of XG technologies into the development efforts of current and future systems, leveraging the Department's investment in digital radio technology. DARPA is confident that this revolutionary way to manage spectrum will be in use in the near future.

DARPA completed the **Situational Awareness System** (SAS) program (formerly the Small Unit Operations – Situational Awareness System program) in December 2002 and transitioned the technology to the Army. The SAS program addressed command, control and communications issues that can plague dismounted soldiers. DARPA developed cutting-edge technologies in stealthy, small unit communications, mobile *ad hoc* networking, land navigation, Blue (i.e., friendly) Force tracking, and distributed information management. Each technology is, by itself, an outstanding technological achievement. The radio frequency component of SAS is the most advanced featureless waveform in existence. It autonomously adapts frequency and power output to ensure connectivity in any environment, while countering detection, interference, and jamming. The SAS network is a self-forming, self-healing, peer-to-peer network that can scale autonomously from a couple of nodes to thousands of nodes. The self-regulating network can adjust data at rates from 10 kbps to 4 Mbps as it provides point-to-point, multicast, and unicast voice, video, and data. The SAS navigation system integrates a suite of sensors and ranging algorithms to provide accurate location and elevation, even in the absence of Global Positioning System signals, such as in buildings and tunnels. The distributed information management application, specifically developed for SAS, is effective in aggregating the Blue Force and threat data, reducing the data set by 90 percent, and smartly distributing that information to each member of the network as is necessary or relevant to their unique location, organization, and mission. The SAS leap-ahead technologies provide the awareness and connectivity that is essential for the network-centric warfighting principles of Joint Vision 2020. DARPA built 76 prototype radios in FY 2002 to test the system's performance in realistic conditions. A final demonstration was conducted at the McKenna Range Military Operations in Urban Terrain site at Fort Benning, Georgia, in October 2002. The event showcased the system's radio, networking, navigational, and situational awareness capabilities through an operational military scenario reminiscent of the events in Mogadishu, 1993. As DARPA closed out this effort, we seamlessly transitioned the SAS technology to the U.S. Army Communications-Electronics Command, (CECOM). In addition to integrating SAS technology into Soldier System's Objective Force Warrior for use by dismounted soldiers, CECOM is leveraging the radio and networking technologies to accelerate the development of networked fires, unattended sensors, intelligent munitions, communications relay, and robotic systems. While the success of SAS represents a leap-ahead capability for mounted and dismounted warfighters, it has served to springboard other programs, to ensure their success in supporting the Army vision for Objective Force Warrior, Future Combat Systems, and other network-centric warfighting concepts.

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 2002, we demonstrated in the field that the beamformer antennas can protect the pseudolite itself from jamming and allow the pseudolite to provide precision navigation. In FY 2003, we will demonstrate a full system of four airborne pseudolites that provides precision navigation for GPS-guided weapons. Transition of the capability to the Adaptive Joint C4ISR Node and the High Altitude Airship programs are being investigated, as well as to a C-130 roll-on, roll-off package. This program ends in FY 2003, although the demonstration may continue into FY 2004.

WolfPack is an unmanned system that will provide a robust, self-forming network to detect and identify targets. It provides an autonomous, networked, stand-in electronic surveillance/ electronic-attack/electronic-protect capability with multiple delivery options. WolfPack is now entering phase IV, prototype evaluation and testing, the goal of which is to integrate technologies that enable unique functions for detection, networking, and situational awareness, and determining directed response for radio frequency communications, radars, and information systems. WolfPack will use miniaturized components to relay critical information for precision targeting or provide sophisticated electronic attack, either autonomously or by commander direction. In the first three phases of WolfPack research, DARPA identified emerging technologies, algorithms, antenna design, and microcomponents. This work showed that WolfPack can enable accurate geographic location of threats and can perform sophisticated tactical jamming with minimal collateral damage. WolfPack phase IV is a two-year effort that will meet the following objectives: (i) architecture analysis; (ii) integration of the antenna, networking, deployment, and signal classification; and (iii) system development and demonstration of signal processing, software-defined radios, antenna, and command and control functions. In FY 2003, DARPA investigated concepts for an accelerated WolfPack capability. Early development of technologies that could lead to a rudimentary near-real-time geolocation of our enemy's radio communications using both military and commercial systems, and surgical denial of those communication systems through the use of a precise coordinated response WolfPack-like system were analyzed. Potentially used as a distributive suppression of enemy air defense asset, these rudimentary, close-proximity WolfPack systems could permit nonlethal disruption of enemy radar systems, including possible terrorist reuse of civilian platforms. DARPA is developing long-term plans with the U.S. Army for deployment via airborne and deep-launch devices, and is working with the Air Force in a distributed suppression of enemy air defense role. Initial discussion with the Navy is taking place for littoral and force protection missions.

The **Tera Hertz Operational Reachback** (THOR) 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 up to 2.5 gigabits per second over a 1000 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 THOR program will exploit the installed global terrestrial fiber infrastructure by placing a fiber access point near the theater and 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: (i) technology-push (phase I); (ii) subsystem prototyping and demonstration (phase II); and (iii) end-to-end system prototyping and demonstration (phase III). During FY 2003, performers will develop large-angle electronic beam steering, high-power laser transmitters, small/compact sensitive optical receivers, and mobile free-space optical networking protocols. DARPA prototyped and demonstrated subsystems built on this critical core technology in a variety of laboratory environments. These demonstrations addressed individual link (air-to-air, air-to-ground) performance. Also in FY 2003, DARPA selected system integrator contractors for phase II, which will focus on the integration of the component technologies into an operational system. Initial steps will be an overall architecture and design with simulations, modeling, and system demonstrations. In FY 2004 and FY 2005, we anticipate demonstrating ground and airborne components of this architecture showing free-space optical capabilities. In FY 2005, we plan to enter phase III, which will include final development of the THOR capability. This phase will culminate in an end-to-end demonstration of architecture, airborne and ground nodes to meet the threshold objectives. Our transition targets are the Air Force, Army, Navy, and intelligence community.

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** 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 glottal excitation 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 glottal excitation, which provide a potentially unique and powerful set of physiological metrics. In FY 2003, DARPA will collect direct measurements of glottal excitation and begin developing processing algorithms for noise suppression using these measurements in conjunction with acoustic data. In FY 2004, DARPA 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. In FY 2005, the Advanced Speech Encoding technology will be integrated into an appropriate military communications system and evaluated. Transition candidates are the National Security Agency, U.S. Army Communications-Electronics Command, and U.S. Naval Sea Systems Command.

INFORMATION ASSURANCE AND SURVIVABILITY PROGRAMS

The Department of Defense has a critical and growing dependence upon the information systems that are crucial to the future vision of network-centric warfare. Additionally, our critical infrastructures and the economic success of our nation similarly depend on such technology, and the poor state of security in those networks and systems is a well-recognized national vulnerability. 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** (IA&S) suite of programs are creating technologies and systems to raise strong barriers to cyber attack, making the adversary work much harder, while providing commanders the technology to see, counter, tolerate, and survive sophisticated cyber attacks.

- The **Cyber Panel** program goal is to develop technologies for monitoring networked information systems for signs of cyber attacks and responding rapidly to avert or defend against them. Additionally, Cyber Panel is developing methods and software tools to compute the impact of an attack inflicted on an information system and how much the attack can degrade the functions the system performs and determine, by mathematical, game theoretic, or adversarial planning methods, the defensive response that best stops the attack and recovers to acceptable levels. Several technologies from Cyber Panel have been commercialized over the past year, most notably the products known as Hawkeye from System Detection Inc. and EMERALD from SRI International.

- 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. These technologies include capabilities for ensuring the fault tolerance and secure survivability of critical network services, 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), and capabilities to trace and contain attacks as close to the source as possible. During the past year, numerous technologies have been transitioned, including transition into the Future Combat Systems program for detection of and defense against network denial-of-service attacks. Several projects have started commercializing the technology, most notably Peakflow™ DOS and Traffic with Arbor Networks.

- The **Dynamic Coalitions** program goal is to develop technologies for establishing distributed coalitions of joint 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). Some policy management technology has been transitioned to the Future Combat Systems program, and several projects have started commercializing the technology, most notably Secure Spread, a secure group communications technology, from Johns Hopkins University.

- The **Composable High Assurance Trusted Systems** (CHATS) program is developing high assurance operating system technologies to protect DoD systems from constant attack. These technologies are being developed in concert with the unclassified open-source operating system development community and will have broad sweeping applicability to many programs within DARPA and the DoD. During the past year, the major open-source operating systems, i.e., Linux, OpenBSD, and FreeBSD, released new versions of their respective operating systems with significant security and assurance improvements developed in the CHATS program. In addition, CHATS has made available an open-source X.509 public key infrastructure technology and an open-source secure computer boot technology to ensure systems cannot be comprised during initial startup.

- The **Organically Assured and Survivable Information Systems** (OASIS) program changes the current mindset of preventing information system intrusions at all costs to a strategy of employing effective safeguards so 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 tradeoffs between system functionality and performance and system security. The OASIS program has demonstrated: (i) effective techniques to protect systems from malicious code attached to e-mails 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 demonstrated achievements in certificate authority, survivable servers and clients, real-time execution monitors, mobile agent protection, and 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.

- In FY 2003, several OASIS, Fault Tolerant Networks, and Dynamic Coalitions technologies were evaluated for their effectiveness in tolerating cyber intrusions and attacks, and their performance will be characterized as part of the **Organically Assured and Survivable Information Systems Demonstration/ Validation** (PE 0603760E, Project CCC-01) program. The program will culminate in a working prototype of a military mission critical system that will show the feasibility of developing highly dependable systems and supporting networks. The Air Force Joint Battlespace Infosphere (JBI) information systems, responsible for producing Air Tasking Orders, will be fortified with IA&S technologies. The demonstration will consist of continued production, real-time modification, and execution of Air Tasking Orders, even while many of the JBI information systems are under a sustained cyber attack by a well-resourced red team. The demonstration is in partnership with the Air Force Research Laboratory, Rome, New York, and is planned for the end of FY 2004.

- The **Operational Partners in Experimentation** (OPX) program goal is to put advanced information assurance technology into the warfighter's hands for accelerated transition to the operational community and improved feedback to the research community. Over the last year, DARPA accelerated the maturation and fielding of our anomaly-based intrusion detection technology. In tests on real-world Air Force data, these systems were able to keep up with data streams that swamp existing systems and find hundred-fold greater instances of suspicious activity than current systems. Moreover, they did this while keeping the number of false alarms negligible. These DARPA systems are under final testing at Lackland Air Force Base, with a prototype bound for U.S. Special Operations Command during FY 2003.

- The **Coalition Networking Experimentation** (CoNE) program is a follow-on to the OPX program for additional operational experimentation with Dynamic Coalitions, Fault Tolerant Networks, and Cyber Panel technologies. Specifically, CoNE is transitioning technology through participation in the Fleet Battle Experiment Kilo and the Joint Warrior Interoperability Demonstration 2003. The CoNE program is inserting various technologies into operational components, namely, transitioning Identity-Based Encryption technology to U.S. Northern Command, transitioning Secure Domain Name System technology to the Marines at the Marine Information Technology Network Operations Center, and transitioning several technologies to the U.S. Pacific Command.

- The goal of the **Dynamic Quarantine of Worms in Military Enterprise Networks** project, under the **Malicious Code Analysis** program is to develop dynamic quarantine defenses for U.S. military networks against large-scale malicious code attacks such as computer-based worms. The ever-growing sophistication of the malicious code threat has surpassed the ability of commercial industry to address this problem. As the U.S. military pushes forward with network-centric warfare, terrorists and other nation-states are likely to develop and employ malicious code to impede our ability to fight wars. This project will develop the capability to automatically detect and respond to worm-based attacks against military networks, provide advanced warning to other DoD enterprise networks, and study and determine the worm's propagation and behavior.

Additional DARPA research programs in computer and network security and survivability include:

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 the performance and vulnerabilities of DoD networks, including mixed wired and wireless nets with potentially millions of nodes and a variety of flow mechanisms and applications traffic. New and validated models derived from complex systems theory and simulation tools will provide online, autonomous, and semi-autonomous network control capability (reducing human intervention), as well as rapid planning and design of mission-specific networks. In FY 2002, these models were the first to identify the global routing instability vulnerability in the core Internet due to *Code Red* and *Nimda* virus attacks. Potential techniques for reducing the vulnerability were analyzed and reported to the Defense Information Systems Agency. The program also demonstrated fast simulation techniques for online analysis of a Navy reconfigurable land-based tactical network with hundreds of nodes and links, ranging from routers onboard ships to satellite links and soldier radios. In FY 2003, the program will enable faster-than-real-time simulation and analysis by enabling the dynamic selection of parameters to influence routing and quality-of-service in mixed wired and wireless nets, and will enable fast design of networks of thousands of nodes. In FY 2004, the program will develop methods for prediction, control, and design that can scale to tens of thousands of nodes and demonstrate online network control, as well as transition technologies to DISA, the Navy, and other DoD agencies.

The **Visibly-Controllable Computing** (VCC) program will develop a new class of security-enhanced computer workstation technologies that will provide users with practical tools for understanding and managing workstation security postures, and for understanding anomalous software behaviors caused by resource unavailability, error, or attack. Leveraging research conducted under DARPA's Cyber Panel and other DARPA programs, the VCC program will develop a new class of general-purpose systems that display important system states and activities to users, allow users to smoothly guide system behavior, and ultimately allow the system to explain its states and behaviors in terms most appropriate for human consumption. By reducing uncertainty about system states and behaviors, visibly-controllable systems will empower users to protect their cyber-assets, reduce the total cost of ownership, and provide a safe haven for Internet-connected cognitive software. In addition to protecting cognitive software, visibly-controllable systems may also use cognitive software: they will apply artificial intelligence techniques (e.g., reasoning and learning), as appropriate, to generate intuitive, user-centered explanations of system state and behavior. A key hypothesis of the VCC program is that system-level structure information (e.g., strongly enforced walls, communications choke points, and dependency analysis) can be exploited to establish baseline properties that can be leveraged "up" into explanations of system state and behavior. Current systems contain very little strongly enforced structure and almost no dependency analysis. In FY 2003, the VCC program will demonstrate techniques that identify and express dependency relations between software components. In FY 2004, the VCC program will: (i) develop a series of prototype systems that establish strongly enforced structure; (ii) evaluate the feasibility of the added structure to overall system operation; and (iii) measure the extent to which the added structure can enable coherent observations of system states and behaviors and, thus, the extent to which such behaviors can then be guided, and the expressiveness of the explanations that can be derived from it.

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 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 2002, the program focused on expanding the logistics information system's capability to detect threats and change system-state dynamically in response to those threats. The program underwent large-scale evaluation and assessment, including red team attacks of the logistics information system during a representative small scale contingency scenario. A high-strength security model was implemented into the software agent architecture, and the military concept of "ThreatCon" as a control mechanism to support enhanced survivability. Agent-based fault tolerance and sensor-based adaptivity was demonstrated through experiments involving infrastructure loss and computing degradation. An extensive, automated, script-based experimentation and assessment environment was built to capture performance measures. 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. More challenging assessments of the performance of the UltraLog system in a more demanding and harsh wartime environment will continue in FY 2003 and FY 2004. The UltraLog "society" will be scaled up to 500 agents in FY 2003, with a program completion goal of 1000 medium-complexity agents in FY 2004.

DETECT, IDENTIFY, TRACK, AND DESTROY ELUSIVE SURFACE TARGETS

The Department of Defense has steadily improved its ability to conduct precision strike for many years. As a result, in the words of the Chairman of the Joint Chiefs, "... the bomb is no longer solely an area weapon, but is going to be used like bullets from a rifle, aimed precisely and individually."[1] Timely, accurate, and precise delivery of bombs and missiles has helped the United States overthrow hostile regimes in short order with very few American or unintended casualties. Yet, our experience has also shown that major challenges remain in target detection, identification, and tracking. It is still difficult to strike targets that are hiding, moving, or require a rapid reaction by U.S. forces in order to be destroyed.

To provide a focused response to these challenges, DARPA established the Information Exploitation Office (IXO) to assemble the sensors, exploitation tools, command systems, and information technologies needed to rapidly find and destroy ground targets in any terrain, in any weather, moving or not, at any time, with minimum accidental damage or casualties. We are working to seamlessly meld sensor tasking with strike operations, leveraging the development of platforms that carry both capable sensors and effective weapons. Of course, this implies blurring or even erasing barriers between the intelligence and the operations functions at all levels of command. This is a difficult technical challenge that requires a joint approach with potentially large implications for U.S. military doctrine and organizations – truly a DARPA-hard problem.

The research includes four general areas:

- **Sensors** to find targets;
- **Sensor exploitation systems** to identify and track targets;
- **Command and control systems** to plan and manage the use of sensors, platforms, and weapons throughout the battlespace; and
- **Information technology** to tie it all together and ensure the effective dissemination of information.

---

1 General Richard Myers, Chairman of the Joint Chiefs of Staff, Oral Testimony before the Senate Armed Services Committee, February 5, 2002.

SENSORS TO FIND TARGETS

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 staying "on the air" for short intervals, which make them challenging targets for current capabilities. The AT3 concept employs nondedicated platforms (e.g., tactical fighters, reconnaissance aircraft, unmanned air vehicles, and 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 – hence the AT3 motto, "One squawk and you're dead." In FY 2002, the AT3 technology was built and tested extensively in ground and preliminary flight tests. In FY 2003, strenuous flight-testing will be completed against real threats. Also in FY 2003, significant progress is being made toward transition of the technology into the next generation of radar warning receivers.

The goal of the DARPA **Counter Camouflage, Concealment, and Deception** (CCCD) 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 exists for this large class of concealed targets. Targets of interest include tanks, rocket artillery systems, tactical ballistic missiles, mobile surface-to-air missile (SAM) systems, supply vehicles, guerrilla bases, river transportation craft, and drug laboratories. In data collected during FY 2001 at Camp Navajo, Arizona, the DARPA FOPEN SAR demonstrated excellent image quality at 15 kilometer standoff ranges, and the 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 at multiple locations, the DARPA FOPEN SAR system was characterized in all modes and was 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, employing camouflage, and in various imaging geometries. DARPA demonstrated the capability of the system to detect other targets, including drug laboratories and SAM launchers hidden in foliage. FY 2002 was the last year of the DARPA-funded Advanced Technology Demonstration program. The Army and Air Force will also employ the FOPEN SAR Advanced Technology Demonstration system in user demonstrations to support transition of this capability to the Services, and will continue terrain characterization flights in support of the Army's Future Combat Systems program.

The **Symbiotic Communications** (SYCO) 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 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 indication (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, day or night and in all weather, without putting themselves at the additional risk of employing a sensor that must radiate to obtain its data, thereby giving away its presence and location. In FY 2003, DARPA continued to conduct flight tests with a DeHaviland Twin Otter aircraft using SYCO transmitters and a passive airborne receiver to produce interferometric synthetic aperture radar (SAR), dual-polarization images of vehicles, and GMTI. Successful completion of early flight tests in FY 2003 demonstrated this passive, all-weather capability operating in non-real-time and producing SAR, moving target indication, and NIMA level three terrain elevation data. In FY 2004, the demonstration system will be designed and built to achieve level four accuracy and demonstrate real-time processing and terrain characterization. In FY 2005, the demonstration system will be used to participate in Service exercises with the Air Force to demonstrate operational utility. Transition to the Air Force is planned, and discussions are underway with the U.S. Air Combat Command and with U.S. Special Operations Command to develop SYCO system concepts of operation.

The goal of the **Eyeball** program is to develop and demonstrate novel concepts for precision target identification of moving and stationary tactical targets from standoff platforms utilizing electrooptical sensors. This program is motivated by the expectation that, while future radar assets will have the capability to perform target detection, location and tracking – and even some forms of target classification – target identification performance will be insufficient to allow targeting and allocation of attack assets due to radar and signature limitations. The Eyeball sensor will exploit the benefits of combining spatial, spectral, and polarimetric signatures from sparse or filled apertures to enable real-time, precision identification of critical, tactical targets. The critical aspect of this program is understanding what is required in terms of combined spatial, spectral, and polarimetric signatures and resolution trades across the sensing domains to realize the required target identification performance. In FY 2000, a contract was awarded to Raytheon Systems Company to execute a multiphase program. The first phase included a phenomenology assessment, modeling, and architecture trades. Based on FY 2001 results, Raytheon designed and built a testbed sensor in FY 2002, which has been used in FY 2003 in a ground-based experiment to quantify the requirements for achieving a precision identification capability. Also in FY 2003, Raytheon is developing a preliminary design for an airborne sensor that could be deployed on an unmanned air vehicle. If the design shows that technical, cost, and installation goals can be achieved, an additional effort will start in FY 2004 to develop a prototype deployable sensor.

The objective of the **Foliage Penetration Reconnaissance, Surveillance, Tracking and Engagement Radar** (FORESTER) program is to detect and track both dismounted troops and vehicles maneuvering under tree cover, thus denying this form of sanctuary to the enemy. To achieve foliage penetration, let alone being able to detect groups of soldiers, an operating frequency in the ultra-high-frequency band has been selected. To detect walking people with FORESTER, it is necessary that the platform velocity be nearly zero. Hence, deployment on a nearly-stationary platform, such as a hovering helicopter like the A160 Hummingbird unmanned air vehicle, is required. A FORESTER design study will be performed in FY 2003 by two competing contractor teams led by Northrop Grumman (Baltimore, Maryland) and Syracuse Research Corporation (Syracuse, New York). Based on an independent evaluation of these competing designs, a single team will be selected to build a brassboard system for tower/mountaintop testing in FY 2004 to 2005, complete with a mock-up of the helicopter (including rotating blades). If performance goals are met, a preproduction prototype system will be flown on an A160 (or, possibly, a Black Hawk helicopter testbed) in FY 2006.

The DARPA **Tactical Sensors** program is developing an end-to-end, turnkey system of integrated acoustic and seismic sensors, multilayer and multisensor fusion algorithms, networks, and fielded hardware to provide warfighters with a capability to detect, track, classify, and identify mobile time-critical targets, civilian vehicles typically used by nontraditional combatants, and personnel in denied enemy areas. The inherently high confidence levels and precision will allow warfighters to employ unattended ground sensors for indirect fire weapon targeting, remote scouting, perimeter defense and augmentation, or cueing of other C^4ISR systems. The program has successfully ported laboratory-designed hardware and software into a 120 millimeter form factor compatible with the fielded emplacement systems for Family of Scatterable Mines and developed an emplacement decision aid (EDA) that factors meteorological, topographical, and tactical parameters into sensor placement recommendations. The EDA is incorporated into an operator console that receives and displays sensor reports and continuously updates vehicle status.

In FY 2002, two clusters of four sensors were hand-emplaced at the Naval Air Warfare Center, China Lake, California, to demonstrate detection of high-value targets (such as tactical mobile missile launchers), target cueing to overhead assets, and connection to a command and control network in support of the Navy's Fleet Battle Exercise Juliet. In late FY 2003, a helicopter deployment demonstration is planned to showcase the system's ability for remote autonomous deployment and the enhanced algorithm's capability to identify and track multiple simultaneous targets. Transitions to the Army, Marine Corps, and U.S. Special Operations Command are being explored.

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 (e.g., 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 with: (i) each other; (ii) unmanned air vehicles; (iii) intelligence, surveillance, and reconnaissance platforms; and (iv) ground stations. These communications support essential targeting and sensor-to-shooter coordination. 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; (v) no central points of failure; (vi) ease of use; (vii) suitability for future air platforms; and (viii) complete coexistence with existing tactical data links, such as Link 16. The current common data link for most air, sea, and critical ground platforms, Link 16 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. TTNT complements Link 16's outstanding capabilities to provide shared situational awareness. TTNT will enable emerging targeting systems, such as Affordable Mobile Surface Target Engagement and Advanced Tactical Targeting Technologies, to achieve their full capabilities. In FY 2002, TTNT's focus narrowed to provide a high performance, robust networked communications capability within the Joint Tactical Radio System (JTRS) architecture. The first flight tests of breadboard implementations of the technology will take place in FY 2003. The groundwork is being laid to assure rapid transition of this technology to the Air Force, following successful completion of all testing in FY 2003 to 2005. The second area of work in the TTNT program applies novel antenna technology to bring common data link capabilities to small air vehicles; antenna testing will take place in summer 2003.

The **Synthetic Aperture Ladar for Tactical Imaging** (SALTI) program will combine the long-range day and night availability of radar, the natural interpretability of optical imaging, and the military exploitability of three-dimensional (3-D) data into a single sensor package capable of being fielded on a long-range unmanned air vehicle (UAV), such as the Global Hawk. The SALTI sensor will use a laser illuminator with a wide bandwidth waveform transmitted from a medium altitude aircraft to form an optical synthetic aperture to produce high resolution synthetic aperture radar imagery at stand-off ranges substantially longer than those enabled by traditional ladar systems. Conventional long-range ground moving target indication (GMTI) radar provides accurate target location estimates in range, but they rely on tracking based on multiple target detections to develop accurate target location estimates in angle. Because the angle measurements provided by a ladar are significantly more accurate than those afforded by conventional radars, ladar GMTI offers the possibility of provided accurate estimates of target range and angle simultaneously based on a single target detection, i.e., from a single view. An additional goal of the program is to demonstrate this single-view ladar GMTI capability. Since the system uses an active laser transmitter, SALTI imagery will be available day or night. The program will also use interferometric techniques to produce high-resolution 3-D imagery on a single pass with the sensor. In FY 2003, the program began development of critical laser, receiver, and image formation algorithm technology. In FY 2004, initial laser and receiver subsystem developments will be completed. A short-range demonstration of a synthetic aperture ladar sensor will be completed in FY 2005 in collaboration with the program agent, the Air Force Research Laboratory, Wright-Patterson Air Force Base. A high-altitude long-range demonstration with the Air Force will be completed in FY 2007. Early discussion is planned with the U.S. Air Combat Command to develop SALTI system concepts of operations. A follow-on Advanced Technology Demonstration by the Air Force Research Laboratory to transition SALTI to a UAV platform is under consideration.

The **Integrated Sensing and Processing** program is developing algorithms that will substantially improve both design and operational methodologies to enhance the performance of broad classes of DoD sensor systems and networks. 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. The Integrated Sensing and Processing program 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. These advances are expected to enable order-of-magnitude performance improvement in detection sensitivity and target classification accuracy, with no change in computational cost, in applications ranging from surveillance to weapon guidance and involving radar, sonar, optical, and other sensing modalities. During FY 2002, the program pioneered new mathematical frameworks for global optimization of design and operation of several different types of sensor systems. It also started implementation of software prototypes of the new methodology in testbed 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. In FY 2004, the program will select a few DoD-specific focus applications for larger scale demonstration and evaluation of the Integrated Sensing and Processing concept.

SENSOR EXPLOITATION SYSTEMS

The **Affordable Moving Surface Target Engagement** (AMSTE) program is developing technologies to make it feasible and practical for the warfighter to precisely, rapidly, and affordably engage individual moving surface vehicles in all weather and from long ranges. AMSTE integrates multiple standoff radars and long-range weapons into an integrated, networked engagement system, permitting standoff fighters and surveillance systems to direct low-cost Global Positioning System (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 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. A series of FY 2002 developmental flight experiments culminated in the delivery of multiple GPS-guided precision weapons against moving vehicles with increasing complexity in both target densities and target dynamics. These demonstrations included the simultaneous launch of two AMSTE Joint Direct Attack Munitions (JDAMs) against two separate targets in a convoy, as well as the launch from 35 miles away of an AMSTE Joint Standoff Weapon, that scored a direct hit on a moving M-60 tank. In FY 2003, the AMSTE program is continuing experimentation with the AMSTE system. A series of FY 2003 developmental flight experiments include live JDAM drops, continued development and demonstration of AMSTE long-term track maintenance capabilities, and plans to 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. AMSTE has been undeniably successful in demonstrating the technical capability to kill moving targets, so FY 2003 will see considerable negotiation with transition partners to develop a transition strategy.

The **Dynamic Tactical Targeting** (DTT) program is developing new sensor control and data fusion technologies that will enable the warfighter to find, identify, and track mobile, time-critical targets in a 30 kilometer-by-30 kilometer area. The DTT program will design, build, and demonstrate a process to efficiently manage multisensor surveillance of large areas and large numbers of objects, and to extract moving targets of high interest for handoff to precision engagement systems. 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 sources for timely access to critical data; (ii) dynamically task unattended ground sensors, unmanned air vehicle sensors, and human intelligence to fill ISR coverage gaps and provide relevant sensor observation in areas of tactical interest; (iii) fuse 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 progressively complex technology demonstrations in the testbed at the Air Force Research Laboratory, Wright-Patterson Air Force Base, followed by insertion of the technology into an operational system in conjunction with one or more of the Services (Army Space Program Office, Air Force Research Laboratory, and/or the U.S. 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 developed models of tactical sensors to enable fusion with national and theater sensor data. It also prototyped technology to adaptively allocate ISR sensor resources on efficient search profiles, deployment of additional tactical sensors to fill coverage gaps, and track maintenance of objects/targets in the battlespace. In FY 2003, it is building a laboratory testbed for the DTT system at the Air Force Research Laboratory.

The **Standoff Precision Identification in Three Dimensions** (SPI 3-D) project will develop and demonstrate the ability to provide high-resolution 3-D images using an affordable sensor package composed primarily of commercially available components. It will be capable of providing confirmatory identification at long range, "radar standoff with optical quality," and will have the ability to overcome weapons effects obscuration and penetrate foliage, camouflage and cloud layers. Just as the human eye labels every resolution element within its field of view with three colors (red, green, and blue), this system will label every pixel it sees with three pieces of data (intensity, range, and polarization). We will conduct a series of ground, air, and unmanned air vehicle demonstrations of standoff 3-D ladar precision identification and track fusion techniques that provide for: (i) rapid acquisition; (ii) polarization exploitation; (iii) intensity mapping; and (iv) high range resolution to obtain precise identification of enemy ground moving targets. These demonstrations will employ existing commercial, off-the-shelf optics, focal plane arrays, and gimbals, combined with a novel polarization to range mapping technique. Long-range 2-D laser imaging on test ranges has shown that the atmosphere supports standoff active imaging. Once fully integrated, SPI-3D could lead to further demonstrations involving multispectral imaging and clutter suppression by FY 2006. In FY 2002, a preliminary feasibility analysis showed the potential for use of Pockel cell technology to achieve these goals. In FY 2003, we will fabricate a prototype for laboratory and early flight tests. In FY 2004, we will pursue packaging and hardening for transition to a Predator-class platform.

The **Exploitation of 3-D Data** (E3D) program is focused on achieving confident identification of surface targets by making use of 3-D data that will be supplied by new generations of sensors. The E3D program is organized into three technical components: target recognition, target acquisition, and modeling. Both the recognition and acquisition areas are developing key, component technologies that will attempt to exploit the unique features of 3-D data. The recognition area addresses identification and classification of targets by components and will address the desire to "fingerprint" targets using their precise 3-D shapes. Targets include: (i) modeled targets, whose shape and structure have been assessed well in advance; (ii) generic target classes, such as trucks, tanks, and flatbeds; and (iii) on-the-fly targets and target classes that have just been observed by a 3-D sensor. Performers in the acquisition area are investigating local area 3-D search and clutter rejection. The component technologies rely on accurate 3-D target models built from 3-D sensor data. The program includes efforts to develop and supply data for testing and an effort to evaluate performance of the developing technology. The program goal is to demonstrate that the 3-D shape and structure of targets, together with 3-D information about the context of the targets, can permit confident identification that will be demonstrated over broad ranges of obscuration, configuration variation, and environment complexity. The program will also identify requirements for 3-D resolution and target features in order to be able to perform "fingerprinting" of targets according to 3-D features. In FY 2002, we collected test data and began algorithm development. In FY 2003, we have been evaluating preliminary identification algorithms against a stable of 120 targets. In FY 2004, we will extend the acquisition and identification algorithms to more complex environments. In FY 2005, we will tailor the algorithms for insertion into the ground stations or exploitation sites that will receive data from sensors such as Jigsaw and Standoff Precision Identification in Three Dimensions.

The **National/Tactical Exploitation** (NTEX) project is developing technologies to locate and identify enemy air defense units, using multisource imagery and data from both national reconnaissance systems and tactical assets that provide sensor data. Based on a Memorandum of Agreement with the National Imagery and Mapping Agency (NIMA), the project will place researchers into facilities with access to data and analysts managed by the Geospatial Intelligence Advancement Testbed (GIAT) project at NIMA. One key challenge is that air defense targets and their signatures are highly variable, due to articulations, variants, and expedients (e.g., "home brew" targets, such as missiles bolted to flat bed trucks). Some target signatures are unknown because there are no captured targets or because we have never modeled the target. Furthermore, previous exploitation tools were generally built around a single sensor or a few fixed sources, whereas the NTEX project will integrate information from many multiple-information sources, including electrooptical (EO) sensors, infrared sensors, and synthetic aperture radar, with cues from the environment. In the NTEX project, computer models are being built interactively based on multiple EO images, adaptively refining and validating models with subsequent views from other sensors. A key idea is the use of cues, such as noncoherent change detection and terrain delimitation methods, to limit the search and improve recognition performance. The project is employing a unifying information-combining approach, specifically Bayesian networks, with an approach that recognizes targets by components in order to identify enemy air defense units. Transition of technologies into operational use will be facilitated by the proximity of GIAT facilities to operational cells. FY 2002 saw the installation of baseline hardware and software in the GIAT. In FY 2003, we have been evaluating that capability on emerging air defense systems. In FY 2004, we will demonstrate enhanced capability provided by the Bayesian network technology.

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 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 restrikes can be avoided. The project will use synthetic aperture radar (SAR) systems, coordinated with weapons delivery, to image the targets during the strike to enable damage assessment within seconds. In FY 2001, instrumented data collections were conducted using airborne sensors and military vehicles (e.g., trucks, air defense vehicles, howitzers, and armed personnel carriers), and 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 was refined and evaluated using focused data collections emphasizing through-strike sensing. Both soft and hard targets underwent hits and near-misses by a range of munitions. This data allowed us to develop and mature an algorithm suite called the Target Impact Indicator (TII). The TII was used to analyze data from a number of operational sensors, including the advanced SAR system in the U-2 and the intended Joint Strike Fighter radar in a BAC1-11 aircraft. Our goal is to determine when a target is hit with a 98 percent detection rate, rejecting 99 percent of the near-misses as no-kills. Final program activities in FY 2003 will promote insertion of TII capability into tactical air strike platforms.

The **Sensor Information Technology** (SensIT) program extended research and development activities in both software and networking to enable geographically distributed microsensor networks. The software technologies are applicable to a variety of sensor nets, on the ground and in the air, on buildings, and on bodies, and will be capable of performing multiple missions. The networked embedded systems retain only supervisory control, while automating traditional "in-the-loop" tasks. The sensor tasking, data collection, integration and analysis must be fully automated to enable operation within time constraints far shorter than can be achieved by human operators. In FY 2001, SensIT researchers teamed with the Marine Corps to deploy an 80-node sensor network in an operational environment. Autonomous, remotely deployed sensors collected information, communicated the data, and displayed the results to soldiers stationed at rear area safe havens. In FY 2002, a SensIT network was deployed in a Marine Corps live-fire exercise to use seismic and acoustic mode sensors to autonomously trigger an imager and send the resulting image to a command post in rear areas. Also in FY 2002, SensIT researchers demonstrated integrated technology developed in SensIT and conducted experiments and demonstrations at researcher sites around the country to show the possibilities of advanced sensing and remote information display, including tracking and classification of moving vehicles, the utility of nested queries, and the efficiency of new routing algorithms appropriate for sensor networks. SensIT technologies are now being incorporated in other DoD research and development and procurement programs, such as the Navy's Expeditionary Sensor Grid, the Marine Corps ground sensors, and Special Operations sensors.

COMMAND AND CONTROL SYSTEMS

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 U.S. 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 geospatial 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 used 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. Also in FY 2003, U.S. Special Operations Command (SOCOM) created a program to transition command and control software developed by DARPA to all SOF attached to theater commands. DARPA supported the transition by providing initial training to Special Operations Center, U.S. Pacific Command; U.S. Space and Naval Warfare Systems Command; and U.S. Joint Forces Command, which are supporting SOCOM with training and deployment assistance.

The **Autonomous Negotiation Teams** (ANTS) program 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 pilot's flight times, and overall combat readiness level of an entire squadron. In FY 2001, ANTS demonstrated the ability of software agents to approximate behavior tradeoffs and to use negotiation in advanced logistics scenarios of 1000 components and a three-second-response requirement. This ANTS capability is being transitioned through an Advanced Concept Technology Demonstration and deployment in Marine Air Group Harrier squadrons and to the Joint Strike Fighter. This was extended to cooperative flight scheduling and maintenance planning and to prototype implementations in mission planning for unmanned combat air vehicle operations. This effort will culminate in FY 2003 with demonstrations of resolving conflicts under time limits by renegotiating plans or modifying goals, and extending the planning horizon for mission and maintenance scheduling to an unprecedented period of an entire year. The latter capability will make the ANTS tools effective components of long-term planning and decision support tools. In late FY 2002, ANTS achieved a milestone with its Marine air transition partner: it produced the first entirely computer-generated Air Tasking Order for training missions that was approved without change by the Marine Air Group Commander. FY 2003 will see the delivery of final ANTS tools to the Marine Corps.

The **Command Post of the Future** (CPOF) program has developed tools that radically improve a commander's understanding of the tactical situation on the ground. This improved understanding leads to better tactical decisions and faster decision times, which, in turn, leads 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. This improved situation understanding has been demonstrated to improve targeting and fires by 400 percent. 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 Army Stryker Brigade Combat Teams. Component technologies (collaborative planning, visualization, and multimodal interfaces) will transition individually to the Army and Marine Corps through insertion into programs of record.

The **Mixed Initiative Control of Automa-Teams** (MICA) project is developing technologies that will enable one, or a few, warfighter(s) to manage many teams of unmanned air vehicles (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 to enable 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 are developing 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 is emphasized during the mixed initiative dialogue between the human and the UAVs. In FY 2002, the program built 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 is being expanded to evaluate cooperative management of two to five teams of five-to-10 UAVs with an operator-in-the-loop in FY 2003. Military operators are participating 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. FY 2003 will see early transition of selected technologies to the Unmanned Combat Air Vehicle program. Our activities in FY 2004 will include intense evaluation of an entire MICA system against an extended simulation and selected hardware-in-the-loop experiments.

Microsensors equipped with processors and radio transceivers offer fine-grained control using information and physical processing at the most basic level, thus blurring the separation among computation, sensing, and actuation in the physical world. The **Networked Embedded Systems Technology** (NEST) program is developing robust coordination services for networks of such devices. NEST 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 emphasize: (i) Special Operations Forces intelligence gathering, surveillance, target tracking; and (ii) tagging red and blue forces by the use of randomly deployed, netted sensors. In FY 2001, the program initiated the development of essential coordination services, such as synchronizing clocks, forming consensus when data values disagree, and electing a single node as a leader. In FY 2002, NEST built upon these services to obtain memory-, power-, and communication-efficient services that can be used at design time in a plug-and-play manner to tailor them to specific applications. A spectrum of applications will be demonstrated in FY 2003, ranging from Special Operations Forces-specific applications, such as red force tagging and monitoring, to active damping in launch vehicles. Other applications include urban warfare coordinate grid formation for situational awareness and single-shooter localization through coordinated action of netted sensors. In FY 2004, we will demonstrate extreme scaling of these applications to hundreds of thousands of sensors covering large areas and the tools to custom design and visualize such applications from mission requirements and sensor platform specifications.

The **Software Enabled Control** (SEC) program exploits 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 2002, we developed adaptive hybrid control services to ensure stable operation and extend the control design to support highly coordinated control of multiple platforms. Advanced low-level flight controls were demonstrated on several scaled-down fixed and rotary wing platforms. Initial flight tests were performed that featured an Open Control Platform, based on Common Object Request Broker Architecture, which hosted an initial set of SEC technologies. In FY 2003, we are testing controls technologies with hardware-in-the-loop simulations and conducting test flights with scaled-down rotary- and fixed-wing aircraft. We are integrating select controls technologies from multiple researchers onto the Open Control Platform, and we are developing run-time optimizations and flight platform support functions within the Open Control Platform. In FY 2004, we will assess the integrated SEC technologies hosted on the Open Control Platform in more complex, operationally relevant scenarios.

INFORMATION TECHNOLOGY INFRASTRUCTURE

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, both in command and control and in intelligence applications. The focus of the DAML program shifted in FY 2002 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 was deployed on an operational intelligence network node, and selected DAML tools were 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 now being employed by the U.S. 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 overflight 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. The U.S. Navy Warfare Development Command intends to evaluate the use of DAML technologies in its Expeditionary Sensor Grid program, a multitiered, warfighter-centered architecture of numerous and heterogeneous battlespace sensors that complement current and planned national and theatre systems. U.S. Joint Forces Command is interested in DAML in support of its Operational Net Assessment function, which is focused on assisting the Joint Force Commander in deriving targeting objectives. Additionally, in FY 2003 a draft specification for rules to be used in conjunction with the DAML language will be submitted to the World Wide Web Consortium.

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 onto formal expressions of the system's requirements. MoBIES does this with symbolic representations from which automated performance, safety, and correctness can be performed, and which can be automatically refined into executable program code. In FY 2002, we developed individual design tools, along with standard interchange formats and behavioral specifications, so we can create large, complex systems using collections of smaller, specialized tool components. We also developed correct-by-construction automatic code generators so we can translate formal system models into executable programs with guarantees that the resulting code will meet safety criteria. In FY 2003, we are integrating the tools and design technologies into application-specific design environments, so we can test the resulting toolset for scalability, composability (a measure of modularity), and efficiency. We are also developing technologies for customizing the embedded computing platform based on software designs. In FY 2004, we will augment design environments with analysis and verification tools and assess the performance of integrated toolsets to challenge problems in avionics or software radio. The 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 generate efficient, error-free software. MoBIES technology will eliminate manual steps in embedded software development, verification, and validation, so 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.

As the DoD is faced with new environmental, economic, terrorist, and information warfare threats, platform-centric DoD weapons systems must transition to systems that are 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. In FY 2002, PCES technology developed and applied intermediate representations and mechanisms for code composition and transformation that automatically generated aspect-oriented software. This concept allows programmers to implement mission functions, error management, memory management, and other aspects of a system independently, then "weaves" the separate aspects into conventional code. It is being applied to control and enhance the quality of surveillance and reconnaissance missions performed by operational avionics mission computing systems at Boeing Phantom Works (St. Louis, Missouri). In FY 2003, the PCES program is developing and demonstrating techniques for simultaneously enforcing real-time and fault-tolerant behavior of weapons-targeting algorithms in unmanned combat air vehicle systems, such as the Boeing X-45 Unmanned Combat Air Vehicle platform. In FY 2004, the PCES program will integrate its highly flexible, dependable, and efficient aspect-oriented software technologies into advanced sensor-to-decision-maker-to-shooter weapon systems. We will also demonstrate how these technologies significantly improve the prosecution of time-critical mobile land targets.

Today's complex military problem-solving tasks are performed either 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 enter knowledge directly 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 focused on knowledge entry for a militarily significant challenge problem: creation of a battlefield situation course of action (COA) reasoner in a force-on-force scenario. This challenge problem tested combined RKF tools in an integrated knowledge base development system using mixed development teams of multiple logic and domain experts, and demonstrated a rate of 50,000 axioms per month from the domain experts. RKF tools developed and expanded during the challenge problem will be enhanced, refined, and hardened in FY 2003, and a substantial, reusable knowledge base will be created to support continuing DoD programs and DARPA research. The final FY 2003 demonstrations will be guided by subject matter experts to exercise the knowledge base and tools and verify the rate of knowledge entry, the fidelity of the COA analysis and simulation, and the ruggedness and utility of the tools. RKF technology is being inserted into applications for U.S. Strategic Command and the Army War College.

CHARACTERIZATION OF UNDERGROUND STRUCTURES

Many potential U.S. adversaries are well aware of the U.S. military's sophisticated intelligence, surveillance, and reconnaissance capabilities and global reach, so they have been building deeply buried underground facilities to hide what they are doing and to harden themselves against attack. Such installations can be used for a variety of purposes, including ballistic missiles, leadership protection, command and control, and the production of weapons of mass destruction.

The **Counter-Underground Facility** (CUGF) program is developing and assessing the technology for sensors and systems to enhance DoD's capabilities to characterize the functionality of adversaries' underground facilities and/or enable and verify the functional or physical defeat of such a facility. Underground facilities are a serious and growing asymmetric threat to national security and to the operational dominance of the U.S. military. The functional capabilities and intentions of many such facilities are unknown, as are their physical layout, equipment complement, and construction details. Successful planning and attack of such facilities requires enough knowledge regarding these unknowns to achieve military objectives and, for facilities engaged in the storage or manufacture of weapons of mass destruction, to minimize collateral damage. This program began in FY 2000 with a science-based program to define exploitable seismic, acoustic, electromagnetic, and effluent signals emanating from such facilities. Specifically, the CUGF program has evaluated the potential to exploit effluent signatures to characterize a facility's operational status and internal processes, to localize external facility vulnerabilities such as vents, and to evaluate a facility post-strike. Initial studies and testing within the program developed validated models for the expected observable signature. A number of potential methodologies for exploitation of the effluent observable were evaluated including ground-based chemical point sensors, ground-based chemical detection LIDAR systems, airborne and ground-based LWIR imagers, and UAV-based mobile chemical sensors. Continued research in FY 2003 will evaluate an aerosol mapping LIDAR system for the detection of exhaust gas particulates.

In FY 2002, the CUGF program initiated two technology demonstrations. One will demonstrate a functional (non-form-factored) sensor system capability for monitoring critical activities and target localization in support of facility attack. The second will demonstrate innovative new sensors, improved signal coupling to sensors, and related communication technologies. The design and fabrication will occur in FY 2003, and the demonstrations will be accomplished in FY 2004.

BIO-REVOLUTION

DARPA's strategic thrust in the life sciences, dubbed "Bio-Revolution," is a comprehensive effort to harness the insights and power of biology to make U.S. warfighters and their equipment stronger, safer, and more effective.

Over the last decade and beyond, the United States has made an enormous investment in the life sciences – so much so that we frequently hear that we are entering a "golden age" of biology. DARPA is mining these new discoveries for concepts and applications that could enhance U.S. national security in revolutionary ways. There has been a growing recognition of synergies among biology, information technology, and micro/nano technology. Advances in any one area often benefit the other two, and DARPA has been active in information technology and microelectronics for many years.

DARPA's bio-revolution thrust has four broad elements:

- **Protecting Human Assets** refers to the Biological Warfare Defense work described above in the "Counter-terrorism" strategic thrust;
- **Enhanced System Performance** is developing new systems with the autonomy and adaptability of living things by developing biologically-inspired materials, processes, and devices;

- **Enhanced Human Performance** is aimed at preventing humans from becoming the weakest link in the U.S. military by exploiting the life sciences to make the individual warfighter stronger, more alert, more endurant, and better able to heal; and
- **Tools** are the variety of techniques and insights on which the other three areas rest.

ENHANCED SYSTEM PERFORMANCE

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. In FY 2002, we began to define the performance of honeybees being trained to detect explosives and locate targets placed in the field. Targets containing explosive compounds were placed in the field 10 to 100 yards from hives. The numbers of bees over target, blanks, or controls were identified, and a dose response and receiver operator curve were generated. The results indicate that bees are able to detect part-per-billion concentrations of explosives 100 yards from the hive with very high-fidelity and accuracy.

We continued our efforts to understand how to use endemic insects as collectors of environmental information. We created a key insect database system, which allows a collector to rapidly identify insects from a trap and, based on what is adsorbed on them, determine from taxonomy and natural history the source of the agent of interest. We collected significant background insect biomass data from a number of important climates in order to provide background information for this application. In FY 2003, we will test this endemic insect system in key operational demonstrations here and abroad.

Another thrust area in the Controlled Biological and Biomimetic Systems program is to mimic the locomotive and sensory capabilities of animals in hardware systems. We have continued to mine advances in insect vision in order to create synthetic sensors that can provide autonomous navigation and control. Using optical flow, we have shown the ability of small unmanned air vehicles (fixed-wing and helicopter) to follow terrains close to the ground, avoid obstacles, and recover from unstable aerodynamics. We have continued to show, in low Reynolds Number aerodynamic flight, the ability of small, flapping wings to provide stable locomotion. The micromechanical flying insect, a one centimeter robotic bee, took its first flight in FY 2002.

In ground platform development, in FY 2002 we showed that a small hexapod called RHex can increase its mobility capabilities using legs and can perform unlike any other wheeled or tracked vehicles. RHex jumped one body length and demonstrated stair and hill climbing (45 degrees) in FY 2002. In FY 2003, RHex will begin the process of transitioning to Service application programs. In FY 2004, we will expand this effort in our **Biodynotics** (Biologically Based Dynamic Robots) program to provide increased robotic capabilities including jumping, wall climbing, and grasping – all based on biomimetic dynamics and control.

The last component of the program examined the interface of living and nonliving systems. In FY 2002, we demonstrated that a rat can be controlled remotely from a laptop as it maneuvers through a series of complex environments. Future efforts will demonstrate that we can monitor remotely other brain regions in the rat, including the olfactory centers enabling the ability to remotely detect what the rat is smelling. In FY 2003 and FY 2004, our **Robolife** program will begin to quantify the performance of rats, birds and insects in performing missions of interest to DoD, such as exploration of caves or covert deposition of sensors.

Impressive autonomy and adaptability are well-known attributes of biological systems. The major emphasis of our Bioderived Materials activity 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 that demonstrates a level of performance beyond today's standard optics, but with reduced size and complexity. This program will develop novel synthesis routes to fabricating materials having extreme optical and electrooptical properties by emulating the elegant structure that nature uses in the lenses of animals such as fish. This program began in late FY 2002 with efforts that range from new material concepts mimicking the multilayer lenses in biological vision systems to microfluidic-based concepts that enable significant changes in performance. In FY 2003, our goal is to demonstrate the materials necessary for a dynamically controlled-index lens with a field of view approaching 120 degrees that will enable, with a single set of optics, the ability to scan a broad area and focus on a specific target when required. To do this with today's technology requires a very complicated set of lenses that are heavy, difficult to manipulate, and expensive. In FY 2004, we will demonstrate the use of self-assembly processes to synthetically reproduce materials with a variable reflection in the visual to near-infrared that performs as a wavelength variable bandpass filter. Success in this program will yield a single lens that can switch between a wide and a narrow field of view within a frame rate, thus allowing significantly improved sensors. Defense sensor system manufacturers are part of the program to ensure successful transitions to such applications as low-cost, variable field of view seekers for missiles.

ENHANCED HUMAN PERFORMANCE

The **Brain Machine Interface** program is exploring 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 devices or system operations. Areas addressed in this program include: (i) extraction of neural codes for movement, senses, and for memory; (ii) use of neural codes to control of a robot or prosthetic; (iii) determination of required inputs for closed-loop communication; (iv) new methods, processes, and instrumentation for accessing neural codes noninvasively; and (v) new materials and device design and fabrication that embody compliance and elastic principles and integrate mechanical systems with neural control commands.

Our progress in FY 2002 and early FY 2003 shows recording and telemetric transmission of neuronal code information from greater numbers of cellular information centers (or neurons) in neuronal network ensembles. These have enabled, for the first time, the ability of a monkey to control a cursor or virtual joystick with neuronal activity without moving its arm. Progress was made in extracting the signals from the brain and sending them wirelessly to a working prosthetic robotic arm that recapitulated the motion from the brain signals. Modeling the dynamics of neuronal networks in specific regions of the brain responsible for memory (hippocampus) has enabled the creation of very large-scale integration (VLSI) microchips that have onboard mimicked memory circuitry. Initial experiments in FY 2003 identified key circuitry in a behavioral monkey model that will be used to test whether the artificial circuit can integrate into the living circuit to restore or augment memory. We explored new brain machine interface designs that include positional capabilities of the microwire used to record from the brain, and material (ceramic) and surface modifications to explore long-term stabilization of the interface for chronic implantation.

In FY 2003 and FY 2004, our plans include further expansion of high-density interconnects with these regions in order to provide measurement and stimulation of distributed neuronal ensemble recording in different regions of the brain and stimulation for brain-to-brain communication devices and input/output of information directly to the central nervous system from a peripheral robotic device or platform. We will explore stimulation paradigms that represent relevant experience for closed feedback control (visual, auditory). We will also examine the control of a freely moving hexapod robot utilizing the same strategy of direct brain control. Noninvasive techniques will be explored that may also enable the noninvasive extraction of neuronal ensemble codes for similar prosthetic and robotic control. Further focus on device compatibility with brain tissue will also be important in the next phase of the program.

The **Continuous Assisted Performance** (CAP) program is developing a wide range of technical approaches to extend the capabilities of soldiers to perform their duties for up to seven days without sleep. Unlike existing brain stimulators, such as caffeine or amphetamines, CAP will develop techniques that maintain cognitive function during long periods of sleep deprivation. This program began in FY 2002 with a portfolio of efforts that include: (i) magnetic brain stimulation; (ii) understanding individual differences in resistance to sleep deprivation; (iii) effects of exercise and diet on resistance to sleep deprivation; and (iv) 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 performance will be expanded, and their activities accelerated. In FY 2003, the program is identifying technology to successfully reverse the effects of sleep deprivation on executive function. In addition, the program is expanding approaches that enhance neurogenesis as a protection against the effects of sleep deprivation, and we are beginning to transition some of the more mature efforts to the Army Soldier Center (Objective Force Warrior), the Air Force, and the Navy SEALs. In FY 2004, promising projects will be advanced to phase II funding and will be targeted at the development of effective candidate drugs or prototype devices that prevent or reverse the degradation of cognitive performance by extended sleep deprivation.

The vision of the **Persistence in Combat** program is to empower the warfighter with medical care during an intense engagement with the adversary and enable him to remain physically functional in the battlefield. 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. The objective of the program is immediate stabilization of acute blood loss within five minutes, controlling acute pain within five minutes, and repairing human tissue within four days. The immediate application of medical care by the individual will impact national security by dramatically reducing medical logistics, decreasing long-term disability, and ensuring that warriors can return to duty to accomplish their mission. In FY 2002, the program successfully demonstrated accelerated retinal repair after exposure to chemical injury in an animal model, resulting in restoration of vision. A handheld biophotomodulation device in the near-infrared spectrum was developed for retinal eye repair. In FY 2002, we also demonstrated a relationship among the nervous system and endothelial cells and the immune system through nervous system stimulation, which regulates specific biomarkers related to controlling bleeding. In FY 2003, we will demonstrate a relationship in small animal trauma models between the nervous system and the coagulation system to control bleeding. Finally, we will develop a specific human protein to block acute pain after traumatic injury. In FY 2004, we will demonstrate the effects of external stimulation of nerves to control bleeding, arrest pain within five minutes in an animal pain model, and demonstrate at least 50 percent visual restoration in a nonhuman primate model, compared to traditional therapy, after weapons-grade laser eye injury. Together, these projects will help make great strides toward enabling a self-sustaining warrior on the battlefield.

In FY 2003, we will begin the **Metabolic Dominance** program. The goal of this program is to enable superior human physical and physiological performance by reducing or removing the current limitations on maintaining peak physical performance. We will pursue several technical thrusts to overcome these limitations, including: (i) developing an improved ability to control nutrient availability to the muscles; (ii) increasing the training potential of soldiers by controlling body temperature; (iii) increasing the number and efficiency of the mitochondria in muscles to increase energy production in muscle; and (iv) identifying the cause of fatigue, which degrades short- and long-term performance. During late FY 2003 and FY 2004, proof-of-principle efforts will begin with a focus on the control of energy metabolism by induced switching from metabolizing carbohydrates to the breaking down of fat (lipolysis). In addition, we will develop a prototype device for controlling core body temperature and will establish new methods for increasing mitochondrial numbers and efficiency and for controlling muscle phenotype. Finally, we will develop an understanding of the molecular control mechanisms associated with fatigue.

The objective of the **Metabolic Engineering for Cellular Stasis** program is to understand nature's mechanisms for protecting cells from environmental stress, such as dehydration, and implement that understanding in cells and tissues of interest to DoD. This includes developing desiccated platelets, red blood cells, and stem cells with minimal storage and transportation requirements and an extended shelf life to reduce the logistics burden for their use during critical periods of need. Two additional goals are to identify how stem cells can be controlled within the body to facilitate healing, and how naturally occurring hypometabolic states, such as hibernation, can be used to reduce mortality following injury.

In FY 2002, this program demonstrated that blood platelets can be stored, desiccated, up to 12 months and, after rehydration, remain metabolically active. By contrast, fresh platelets have a shelf life of about six days in a clinical setting and, thus, are not viable for battlefield use. This breakthrough is likely to lead to FDA testing for the clinical use of desiccated platelets in humans. The program began evaluating the potential for developing stem cells that can be used in multiple recipients without the need for typing. Hibernators were begun as models for stabilizing organs to identify targets applicable to the whole organism. In FY 2003, the program will continue to develop preservation methods for three cell types: platelets, red blood cells and stem cells.

We will demonstrate 24 months of storage for platelets and focus on transitioning these desiccated platelets to clinical trials. Red cells and stem cells will be moved to *in vivo* animal tests. The first set of studies is complete, and monocarboxylate transporters have been identified as essential for inducing hypoxic tolerance. Our next studies will determine whether protection occurs during hemorrhagic and/or hypovolemic shock.

The **Training Superiority** program will create new approaches to training our warriors to win in the high-technology, complicated, and often isolated environment of future conflicts. We will do this in two ways. First, we will create, in areas of high military importance, new kinds of cognitive training systems that will include elements of human-tutor interactions and the emotional involvement of computer games coupled with feedback of Combat Training Center learning. The second thrust will, using the example of commercial, persistent, massive multiplayer online games, link these new training approaches with existing Service and Joint training systems into a self-sustaining architecture, allowing continuous on-demand training anywhere, anytime, for everyone. Together, these two thrusts will initiate the training revolution that must occur if the ongoing DoD thrust for transformation is to succeed. In FY 2003, the program will competitively determine how to create and implement the on-demand warfare training architecture. We will also initiate the creation of training systems such as a "seabag-sized" air mission trainer for use by the Air Force and Navy, rapid tactical language instruction for the "brain behind each trigger finger" for the Marines and Army, and a way to capture training courses electronically such that they teach far better than the best teacher and may save the DoD several billion dollars per year in training costs. In FY 2004, we will deliver three initial electronic tutoring systems to military users and demonstrate an initial capability to link them with other systems.

TOOLS

The **Bio/Info/Micro Sciences** program, which began in FY 2001, is DARPA's fundamental research effort at the intersection of biology, information technology, and the physical sciences. The goal of the Bio/Info/Micro Sciences 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 protect the warfighter and enhance human performance for 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 to stimulate the development of a new generation of scientists and engineers performing science and technology at the intersection of biology, information technology, and microsystems technology. This approach will yield a new cadre of scientific and technical talent 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 Sciences 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.

Research highlights for FY 2002 include: (i) decoding of electrical signals from the cortex of a monkey and demonstrating that the neural code can be used directly to move a cursor on a computer screen just by the monkey's thinking about it; (ii) development of a new process for manufacturing nanoscale devices that enable visualization of single molecules; (iii) design of an electrolysis-based actuator for use as a moveable probe in living brain tissue; (iv) demonstration of a microcantilever that can detect 100 to 1000 molecules carrying a specific DNA sequence; and (v) imaging the spatial distribution of protein molecules in living bacterial cells.

In FY 2003, we will continue device development, including: (i) miniaturization of moveable microelectrodes and the development of carbon nanotube arrays as nerve cell electrodes; (ii) manufacture of nanodevices that can be used to detect single biomolecules interacting with each other; and (iii) demonstration of a new spectroscopic technique and signal processing algorithm 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 2004, we anticipate that developments that enhance warfighter performance will begin to emerge from this phase of the program and will feed technologies directly into other, more applied technology programs at DARPA. For example, many of the techniques for measuring and understanding neural codes are being transitioned to – and exploited by – the Brain-Machine Interface program.

The goal of the **Biological Input/Output Systems** basic research program is to demonstrate specific, measurable state changes (e.g., color) in plants and microbes in response to chemicals of interest to the DoD (e.g., biological warfare and chemical warfare agents, fuels, explosives, and chemical precursors). There is currently no stand-off capability for monitoring the chemical environment quantitatively with high specificity. The basic investigations under this program 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, and 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. In FY 2002, this program began to design genetic regulatory pathways, 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 are constructing and characterizing a variety of designed regulatory and metabolic pathways that can be used in combination to construct sentinel organisms. In FY 2004, we will demonstrate simultaneous detection of multiple chemical analytes (e.g., explosives and chemicals related to their manufacture) by engineered sentinel organisms.

The **Deception Detection** program will develop and demonstrate techniques and sensors to detect deceptive intent in a range of Defense applications (e.g., personnel screening for intelligence and law enforcement agencies). The program will also explore new approaches to develop a scientific basis for understanding human deceptive processes, which may lead the way to broad range deception detection applications. Current screening techniques are flawed, enabling many deceivers to avoid detection and falsely accusing large numbers of innocent people. An effective method to assess intent will decrease both the missed detections and the false alarms. In FY 2003, we will initiate an experiment to determine if deceptive behavior can be detected in a checkpoint environment by searching for unique, identifiable characteristics of individuals who, with knowledge of and consent to the checkpoint interrogation, try to perpetrate high-stakes deceptions that they believe have been authorized by some higher authority. We will also initiate efforts to develop insight into the brain/body processes of deception by exploring deep brain processes that may be associated with deception and potential conditioned responses in deceptive situations. In FY 2004, we will complete our initial experiments and, if they are successful in identifying clear measures diagnostic of deceptive behavior, we will expand the research to explore their utility in the presence of clutter over a wider range of subjects and real-life confounders.

The **Molecular Observation, Spectroscopy, and Imaging using Cantilevers** program is developing new instrumentation, computational tools, and algorithms for real-time, atomic-level resolution, three-dimensional, 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 also provide a detailed knowledge of doping profiles and defects in nanoscale electronic devices – information critical to 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. This program started in FY 2002, and we have already made progress in understanding the major sources of noise in this instrument. Moreover, we have determined that these noise sources will not prevent us from reaching our near-term goal of single-electron-spin sensitivity. In FY 2003, we will demonstrate that this instrument is indeed capable of detecting a single electron spin, enabling us to study spin-labeled, single macromolecular complexes in their native functional state. In FY 2004, we will demonstrate that this instrument is capable of defect profiling in semiconducting nanostructures and determining conformations of spin-labeled proteins.

The **Simulation of Bio-Molecular Microsystems** (SIMBIOSYS) program is developing innovative interfaces between molecular-scale processes in chemistry/biology and micro/nanoengineering (electronics, optics, microelectromechanical systems (MEMS)) through experimental and theoretical analyses. The goal is to develop smart biological/chemical sensors that detect molecular targets in extremely small concentrations (high-sensitivity, single-molecule detection) with extremely high selectivity (i.e., no false positives), all in an order of minutes to seconds. The technologies developed under this program will enable widely distributed, remote sensors that are capable of reporting back in real-time about biological/chemical events, providing detailed information on location, agent identification and agent concentration. These capabilities are crucial for soldier protection and homeland defense.

In FY 2002, we developed 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 for bio-fluidic transport processes in microsystems. We also developed 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 demonstrated the use of MEMS and nanoelectromechanical systems (NEMS) 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: (i) solid-state nanopores for single-molecule DNA sequencing; (ii) solid-state nanocantilevers as single-molecule readers in real-time; and (iii) engineered biological proteins as sensors for high-sensitivity detection of chemical agents.

In FY 2003, we are designing working devices that incorporate biological components into sensors, actuators, and computational devices. We are developing 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.

In FY 2004, the sensor systems will be tested to quantify performance metrics in terms of sensitivity, selectivity, and speed. The computational models developed during the program will be integrated into existing microfluidic system simulation software to produce design tools for integrated biological/ chemical sensor systems.

The **Bio-Magnetic Interfacing Concepts** (BioMagnetICs) program will develop novel capabilities for integrating nanomagnetics with biology, and will demonstrate the advantages of magnetics as a powerful new tool for manipulation and functional control of large numbers of cells and biomolecules. The novel capabilities being targeted by the BioMagnetICs program will have a pervasive impact on future applications of biotechnology, including chem-bio detection, therapeutics, and medical diagnostics. Specific examples of new capabilities being targeted by this program include: (i) portable, high-sensitivity DNA detection and readout; (ii) noninvasive, nondestructive imaging of intracellular activity; (iii) remotely addressable, magnetics-based bio-chemical sensors; (iv) cellular manipulation and magnetically actuated, on/off control of cellular functions; and (v) magnetic filtration of biotoxins from humans.

The BioMagnetICs program was initiated in FY 2002. Efforts during the first year focused on developing improved magnetic nanoparticles and sensors for magnetic labeling and magnetic detection of cells and bio-molecules. These efforts are continuing in FY 2003 and are now focused on the integration of novel magnetic nanoparticles and magnetic sensors with biology and proof-of-concept demonstrations for achieving the targeted chem-bio detection, therapeutic, and diagnostic capabilities listed above. In FY 2004, the emphasis of the BioMagnetICs program will continue to be on providing proof-of-concept demonstrations for using nanomagnetics to enable important new applications of biotechnology for the DoD. Some program milestones include: (i) continued demonstration of improved magnetic nanoparticles; (ii) demonstration of magnetic sensors with improved sensitivity; (iii) demonstration of efficient magnetic filtering of toxins in fluid samples; and (iv) demonstration of magnetically actuated intracellular functions.

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 nano- to macro-scale devices for Defense applications. We will explore 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 nanomotors and tissues could lead to revolutionary systems with unparalleled performance for Defense applications. These include enabling a new generation of hybrid biological/mechanical machines that efficiently actuate materials and fluids at many scales and, thus, could enable new classes of sorting and sensor 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, and hybrid actuators or power sources for robotic, microelectromechanical systems, drug delivery, and other devices. *In vivo* applications might include perpetual physiological monitoring, drug delivery, tissue regeneration and repair, and prosthetic devices.

In FY 2002, early work on bio-molecular motor characterization began. Potential device designs incorporating bio-molecular motors were formulated. In FY 2003, we are investigating the mechanism of motor function, motor performance, and efficiency for several types of biomolecular motors as the basis for device designs. Performance metrics will be modeled, measured, and quantified. In FY 2004, biomolecular motors will be integrated into systems and demonstrated on applications requiring nanoscale power sources and transducers, actuators, sensors and drug delivery systems (*in vitro* and *in vivo*).

DARPA's **Microelectronic Bioprocesses** program seeks to enable revolutionary advances in bio-computing, synthetic biomaterials, and adaptable bio-assay systems through the development of microscale chemistry, large-scale parallelized oligonucleotide synthesis technology. Key technical advances include the development of microfluidic microscale synthesis chemistry, the assembly of multiple chains of oligonucleotides made in parallel into a long molecule, and real-time microliter-scale polymerase chain reaction. Microscale chemical processing has inherent advantages in thermodynamic and kinetic efficiencies, and the program is further integrating the synthesis processes onto electronic chips, which provides for the direct integration with existing silicon-based fabrication infrastructures. This allows rapid manufacture of potentially long oligonucleotides of arbitrary sequence, packaged alongside silicon-based components. The goal of the Microelectronic Bioprocesses program is the synthesis of pico-molar quantities of "data-grade" (greater than 50 percent confidence of zero errors), 10,000-element-long oligonucleotides from a bench-top system in less than 24 hours. During FY 2003, we demonstrated error-free assembly of 1000-element chains, and FY 2004 will conclude with the demonstration of data-grade 10,000 element synthesis.

The **BioComputational Systems** program is exploring and developing computational methods and models at the bio-molecular and cellular levels for 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 provide innovative capabilities in the prediction and control of 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 2002, we developed the architecture for BioSPICE, a simulation program for intra-cell evaluation, that, based on spatial-temporal mathematical models, permits biologists to perform *in silico* analysis, discovery of internal processes hitherto unknown, and the design of sophisticated cell experiments based on analysis of vast amounts of data. BioSPICE is being developed with progressive sophistication and experimental validation; in FY 2002, we released BioSPICE version 2.0. A suite of models of biochemical gene-protein reactions was developed for BioSPICE and was used to characterize cellular processes, such as cell cycle, and bacterial processes, such as formation of spores. In FY 2002, the program also made significant advances in DNA computing. DNA sequences were manipulated in a massively parallel way to solve an instance of a class (satisfiability problem) of complex computational problems, which involved finding the correct solution from a million possibilities (20-variable satisfiability). In FY 2003, the program will: (i) continue to develop scalable, DNA-based computing and storage; (ii) investigate self-assembly of engineered DNA nanostructures; (iii) develop computational models that capture the behavior of mechanisms in living cells underlying pathogenesis and rhythms that are common to many organisms; and (iv) release more sophisticated versions of BioSPICE that include spatial models and simulation tools. In FY 2004, the program will demonstrate the effectiveness of modeling in predicting cellular dynamics in applications such as cell cycle control and bacterial spore control, and we will identify key intracell mechanisms that might be potential targets of interventions in bio-defense contexts. We will also demonstrate applications of DNA-based computing, including design of 3-D nanostructures that can potentially enable highly reliable crystallography and layouts for molecular electronics. Agencies that we expect will implement BioSPICE, and use DNA computing, include the Defense Intelligence Agency, Central Intelligence Agency, National Institute of Allergy and Infectious Diseases, Centers for Disease Control and Prevention, U.S. Soldier Biological and Chemical Command, and Walter Reed Army Medical Center. Applications include antiterrorism initiatives and/or biopharmaceutical target discovery.

COGNITIVE COMPUTING

Many elements of the information technology revolution that have vastly increased the effectiveness of the U.S. military and transformed American society – time-sharing, interactive computing, the ideas behind the personal computer, the Internet – were spurred by the vision of a scientist at DARPA in the 1960s and 1970s, J. C. R. Licklider, whose vision was of people and computers working together symbiotically. His concept was of computers seamlessly adapting to people as partners that handle routine information processing tasks. This frees people to focus on what they do best – think analytically and creatively – and, thereby, greatly extends the powers of their minds, i.e., what they can know, understand, and do.

Despite the enormous and continuing progress in information technology over the years, it is clear that we are still quite short of Licklider's vision. While current information systems are critical to U.S. national defense, they remain exceedingly complex, expensive to create and debug, unable to easily work well together, insecure, and prone to failure. They still require the user to adapt to them, rather than the other way around. Computers have grown ever faster, but remain fundamentally unintelligent and difficult to use. Something dramatically different is needed.

In response, DARPA's Information Processing Technology Office (IPTO) is returning to its "roots" to take on Licklider's vision again in a strategic thrust called "Cognitive Computing." Cognitive computers can be thought of as systems that know what they are doing. Cognitive computing systems will have the ability to reason about their environment (including other systems), their goals, and their own capabilities. They will be able to "learn" both from experience and by being taught. They will be capable of natural interactions with users and will be able to "explain" their reasoning in natural terms. They will be robust in the face of surprises and avoid the brittleness and fragility of previous expert systems.

To meet this challenge and opportunity, DARPA will focus on five core research areas over the next few years: computational perception; representation and reasoning; learning, communications and interaction; dynamic coordinated teams of cognitive systems; and robust software and hardware infrastructure for cognitive systems. The theoretical work in these areas will be focused by emphasizing several specific, but different, applications. The Cognitive Computing strategic thrust will also serve as a template to reshape DARPA's enduring foundational work in information technology.

The **Perceptive Assistant that Learns** (PAL) program will develop technology for a new class of integrated, highly functional cognitive systems. These systems will act as personalized executive-style assistants to knowledge workers and decision-makers, including military commanders. Initially we will strive to create assistant programs that will display basic competencies, including: (i) basic conversational interaction with people and other assistant programs in a normal operational environment; (ii) sending and receiving information in a human-like manner; (iii) relating information and activities in different media; (iv) observing the assistant's user and inferring preferences for accomplishing daily tasks; and (v) accepting advice and guidance expressed in natural language. Such systems will push the limits of technology for formal reasoning, learning, and computational perception, integrated in a unified multitasking, mixed-initiative architecture. A unique feature of the PAL program will be the creation of technology for LifeLogs, ontology-based systems that capture, store, and make accessible the flow of one person's experience in and interactions with the world. LifeLogs will integrate data capture and manual/user-assisted metadata generation capabilities, data storage, and a search engine interface to implement a baseline LifeLog capability. The effort will also develop knowledge-engineered representations and abstractions, and incorporate learning techniques to minimize need for user annotation and to automatically extend the abstraction hierarchy.

The program will demonstrate cognitive systems that make use of experience and knowledge to help them understand and seek perceptual input, resulting in systems that do *purposeful perception* (i.e. sensor information will be filtered and processed in the context of specific, high-level goals). Methods for processing raw data will be learned in a way that optimizes performance of the entire system. Our initial systems will focus on observing human partners with the goal of determining the partners' preferences and learning to anticipate the partners' actions. The systems will also be able to alert their partners if usual procedures are not followed. As the cognitive systems become more sophisticated, they will be able to carry out various tasks that they have learned from the partners for the partners' benefit. In FY 2003, the PAL program will develop the advanced machine learning and reasoning techniques needed to build a personalized assistant. In FY 2004, we will conduct a test of these new learning and reasoning techniques to assess their effectiveness to adjust and focus on PAL research.

The **Adaptive Networking** program will create information and communication networks that possess significant degrees of network self-reliance and responsibility for their own behavior and survival. This includes the following capabilities: (i) self-diagnosis; (ii) automatic adaptation to changing and hostile environments; (iii) reconfiguration in response to changes in environment; (iv) intelligent negotiation for tasks and resources; and (v) robustness under attack. The project will produce a potentially radical new design for distributed computer and device networks and the software that manages them and will have considerable ability to adapt to unforeseen changes. Initial efforts will focus on the identification and characterization of the major components of an adaptive cognitive network, especially modeling, reasoning, and learning capabilities. In FY 2003, the Adaptive Networking program will establish a basic architecture for sensing and controlling a network from an external centralized point of view, in what we might call a "knowledge plane." The core requirements for representation, reasoning, and learning in the knowledge plane will also be established. In FY 2004, the program will develop a plan to implement specific adaptive, self-diagnostic, and reconfiguration network capabilities using the knowledge plane model. Efforts will also be initiated to design and develop the initial network protocols.

The **Real-World Learning Technology** program will investigate advanced machine learning techniques and will design and develop practical technologies to allow cognitive computing systems to improve their performance and understanding over time. The program will determine which types of learning (e.g., learning by example, learning by analogy, statistical learning from training data, and explanation-based learning) are most effective when applied to challenging problems of importance to the military. It will drive the design and implementation of new, hybrid learning technologies that allow cognitive systems to learn in a wider variety of situations. These new methods will, for example, combine statistical learning techniques with knowledge-based techniques that take into account background knowledge and prior experience. We will develop technologies that allow enduring systems to learn continuously over long periods of time. Application of this technology will have a dramatic effect on the adaptivity and effectiveness of cognitive systems and their ability to perform better over time. In FY 2003, the program will focus on identifying critical problems and scenarios to challenge machine learning technology in ways that will produce fundamentally new learning techniques needed to enable robust cognitive computing systems. We will also initiate research to categorize a broad variety of problems into classes that best address different types of learning technology and techniques. In FY 2004, the program will design and develop hybrid learning systems that allow cognitive systems to adapt to a wide variety of naturally-occurring situations and perform better over time against challenges similar to those to which they have been exposed in the past.

The goal of the **Augmented Cognition** (AugCog) program is to enhance the warfighter's cognitive capacity and capability under complex operational and stressful conditions. Specifically, AugCog has developed the means to measure a subject's cognitive state in real-time and is now developing methods to manipulate that state noninvasively in order to greatly improve the performance of various functions in the human-machine interface. The program is developing the technology to integrate new digital devices that support memory, perception, and thinking, and link that support with the user's context state information to directly improve the overall cognitive performance of the warfighter. By accessing the cognitive state of the individual in real-time, automated computational systems will be able to use that information to provide appropriate information and displays to help modify and mediate the user's cognition. The online processing and analysis of cognitive state will allow computers to provide operational data in a manner specifically targeted to the user – and in a way that will not disrupt the user's current functions. In essence, AugCog will make it possible for computational systems to adapt to the user, rather than forcing the user to adapt to the computational systems. The program will culminate in the development of a closed-loop, human-computer interaction capability, with the computer able to anticipate, predict, and augment the performance of the user. In FY 2002, the AugCog program developed robust, noninvasive, real-time, cognitive state detection technology for measuring the cognitive processing state of the user. In FY 2003, AugCog is integrating multiple cognitive sensor technologies into a comprehensive cognitive assessment environment that will permit manipulation of the human state. In FY 2004, the cognitive state sensing and manipulation technologies will be integrated into complex and operationally relevant prototype closed-loop environments for testing and evaluation. The AugCog program moves beyond merely redesigning human-computer interfaces into completely recreating them with the state of the human as an integral component.

The **Collaborative Cognition** program will develop technologies to enable the design and implementation of collaborative agents in dynamic, multiagent environments. Agents will be able to cope with limited and/or noisy sensor information; limited communication capabilities; changing and unforeseen environments and other agents; and limited *a priori* knowledge of each other's capabilities. In contrast to most current systems that address collaboration and teamwork, the Collaborative Cognition program will develop software for controlling agents capable of interacting with both friendly and adversarial agents, while operating in multiple domains and/or varying scenarios within the same domain. In particular, the software will be adept at controlling agents under previously unseen or unknown conditions. By building on previous DARPA work, such as Control of Agent-Based Systems, the program can quickly and efficiently explore the application of innovative cognitive and behavior modeling approaches to intelligent agent systems. In FY 2003, Collaborative Cognition is exploring a strategic control language to specify the behaviors of individual agents and teams of agents regardless of their low-level implementations. In FY 2004, Collaborative Cognition will enable agent learning to improve performance against a team of adversaries after observing the team's behavior over an extended time, assuming constant adversary behavior (i.e., the adversary does not adapt its behavior). Success will revolutionize concepts for applying distributed agent technology – first to modeling and simulation systems, with eventual application to operational environments.

The **Self-Aware Peer-to-Peer Networks** program will develop resilient, scalable sensor computation networks with decentralized control. This technology will support battlespace awareness by enabling the self-formation of large, *ad hoc* networks of sensors and computational elements within the severely resource-constrained environment (e.g., power, bandwidth, and stealth) of military operations, while enabling networks to survive component failure, network intrusion, and the subversion of elements. This "self-aware" network of sensors and communication will provide a lifeline to the warfighter in the support of effective operations, while automating the burdensome and distracting tasks of network deployment, configuration, and management.

In this program, high-level languages will be developed to map the user's mission plans, including, possibly, geographical constraints and direct control of individual sensors into network control actions. A sensor network will function as a distributed cognitive system that dynamically controls resources and renders implicit knowledge of itself and its environment. The cognitive system will provide on-demand sensing, imaging, and tracking with a prediction/planning capability to estimate the state and trustworthiness of network elements and communication links. Therefore, as elements fail or are subverted, the Self-Aware Peer-to-Peer Network will provide control for realistic sensing and prediction tasks. Application of this technology will play a dramatic role in the detection and defeat of terrorist networks and will support a variety of networks of manned and unmanned systems. In FY 2003, the Self-Aware Peer-to-Peer Networks program will define an overall static architecture for distributed sensing networks that can achieve cognitive capabilities. In FY 2004, the program will define cognitive representations, distributed agent coordination technologies, information fusion algorithms, network control language, and network benchmarks. It will also seek to develop a dynamic architecture that demonstrates a robust, extensible network, yielding the advantages of a centralized network in a decentralized implementation.

The **Self-Regenerative Systems** (SRS) program will conceive, design, develop, implement, demonstrate, and validate architectures, tools, and techniques to field systems that are capable of adapting to novel threats, unanticipated workloads, and evolving system configurations. We will employ higher level cognitive functions such as reasoning, deliberation, and reflection. These technologies will allow future information systems to be dramatically more robust, survivable, and trustworthy than today's systems. Beyond graceful degradation capabilities provided by fault- and intrusion-tolerance mechanisms, SRS-enabled systems will be able to reconstitute their full functional and performance capabilities after experiencing an accidental component failure, software error, or even an intentional cyber attack. They will maintain their robustness and trustworthiness attributes even as they undergo growth and evolution in functionality and performance over time. Such a system will learn from its experience so it performs better tomorrow than it did today. In FY 2003, SRS will identify novel attacks, and will generalize and learn from specific attack events to form a defense against a general set of cyber attacks and failures. In FY 2004, SRS will develop technologies to diagnose and assess damage, and repair and recover from damage caused by accidental faults, software aging, or malicious activities. This development work will lead to follow-on technologies that will allow a system to automatically heal itself. In addition, this research will contribute to systems that will predictively adapt their security posture to anticipated threat conditions, and adaptively balance performance and functionality with security.

The **Computer Exploitation and Human Collaboration** program is exploring innovative information processing approaches that will enable users to interact with computers in a highly intuitive fashion, and enable collaborations and intelligent exchange of information in a seamless manner. This research supports new cognitive models and interfaces, and adaptive techniques for processing information presented in multiple sensory modalities (visual, verbal, tactile). It will explore new man-machine interaction paradigms, based on implicit interaction where the human's intent and capability is inferred. This technology will address information overload and improve the decision-making performance of the warfighter by providing concise, salient information to improve perception, comprehension, retention, and inference. The radically new analysis of emergent collaborative and competitive behavior will push the envelope of "deep reasoning" in decision-making by systematically incorporating the interaction and intent for high-performance human-computer interfaces.

In order to create a cognitive system – one we could truly describe as "knowing what it was doing" – we need to develop technology that would allow such a system to remember what it knew and to manipulate that knowledge to determine its implications. This latter process we call "reasoning," and it is one of the cornerstones of our Computer Exploitation and Human Collaboration agenda. Cognitive systems would need to reason as well as humans, for instance, in making plans for future activities, and adapting those plans as circumstances changed – or in making good guesses as to the causes of observed events, even without definitive information.

In FY 2003, the program will focus on real-world reasoning research that is at the core of practical cognitive systems, such as an agent that assists a military commander, soldier, or an analyst. Real-world reasoning will create new techniques for machine reasoning that enables: (i) accurate reasoning in large knowledge bases; (ii) hybrid reasoning methods, such as deduction and inference in dynamic and uncertain information environments, and strategic reasoning in environments containing cooperative, competitive, and hostile elements, such as in the battlefield; and (iii) rapid incorporation of information from multiple sources into the reasoning process. In addition, adaptive, multimodal interfaces will provide a new, empirically validated approach and technology base for designing high-performance human-computer interfaces. The FY 2004 effort will integrate reasoning tools that aid decision-making and overcome shortfalls in current reasoning techniques. The program will also demonstrate a significant performance improvement over current reasoning techniques and evaluate alternative methods for dynamic hybrid reasoning with multiple parallel reasoners that collaborate dynamically. Technology will be developed in the context of the commander's operational environment, wargaming scenarios, and logistics. In addition, multiple efforts focusing on visual and auditory pathways will enhance delivery and presentation of information to the warfighter. Success will substantially improve the decision-making process.

The **Architectures for Cognitive Information Processing** (ACIP) program is developing a new class of cognitive computing techniques to efficiently enable and implement cognitive information processing. ACIP will enable innovative and truly robust real-time cognitive computing for DoD applications involving the element of surprise by developing: (i) fundamentals, framework, and development environments; (ii) algorithms and architectures; and (iii) implementations. Current intelligent processing implementations depend on the use of existing, numerically-based architectures and, therefore, are implemented via algorithms and processing architectures that are ill-suited to cognitive processes. The ACIP program will establish cognitive computing capabilities that significantly advance the state of the art at all cognitive processing levels to support efficient, real-time implementations. ACIP will develop cognitive computing implementations that will span the areas of cognitive architectures, alternate representations, composite run-time systems, active processing and retrieval hardware, and living framework. These capabilities will support new classes of cognitive information processing applications that will enable the overall goal of "systems that know what they are doing." Early identification and evaluation of candidate cognitive algorithms and kernels will be performed in FY 2003. FY 2004 activities will focus on in-context mission analysis and test suites on which ACIP development would be based and evaluated, as well as cognitive architectural research and common cognitive framework development. We will also establish in-context application performance baselines.

The **Network-Centric Infrastructure for Command, Control and Intelligence** (NICCI) program will develop the software infrastructure (e.g., libraries of components, and design tools) that enables groups of people, applications, and devices to be rapidly brought together to perform a task predictably and efficiently based on external "contextual" factors (e.g., threat level, time-critical constraints). The program will construct "habitats" that automatically provide context information to teams of components (i.e., software systems, objects or agents, and humans) based on knowledge of the task and roles of the participants. The habitats will include business and interaction rules as an integral part of the system. Embedding executable rules and process specifications supports dynamic automatic acquisition, monitoring of changes, rule enforcement, sharing of services, and controlling membership. In FY 2003, NICCI will demonstrate use of logical policy specifications to control tasking, resource allocation, and access privileges. In FY 2004, we will focus on policy and workflow management that effectively operates and adapts to changes in policies, doctrine, or situational context in a dynamic, multilayered, system-of-systems environment.

The **Knowledge Based Systems** program will develop the critical technologies needed to enable computers to understand and reason with large amounts of human knowledge. Imagine the possibilities if we could create computing systems that really understood and could reason about the sum total of human knowledge – in science, in technology, in military tactics and strategy. Banks of such computing systems could work 24 hours a day to reason over, or "think" about that knowledge – to answer any imaginable question, make new scientific discoveries, invent new technology, discover new medical cures, analyze world situations, identify national vulnerabilities, or plan military operations. These systems could be large banks of strategic scientific and technical knowledge, or small, individual knowledge bases. Building such systems requires that knowledge be expressed in formal knowledge representation languages that allow computers to reason about the knowledge, consider its implications, imagine possible future scenarios, and discuss with the human user all aspects of the information. The significant challenges are centered on the fact that critical knowledge involves temporal information, complex belief structures, and uncertainty. Current representation technology does not seem adequate to capture such information. The FY 2004 program plans are to develop the core knowledge base kernels and basic knowledge entry techniques needed to create the first generation of computer-understandable knowledge systems.

The goal of the **Advisable Systems** program is to design and build systems that users can control in natural and flexible ways – not via menus or by programming them, but by exchanging advice and instructions with them. The program will accommodate a range of advice levels, including high-level goals and policy, preferred strategies and constraints on system behavior, and specific direction. Users will be able to express this advice in natural English and engage in a dialogue with the system to clarify/elaborate the general advice. Based on this dialogue, the system will translate the user's intent into an executable plan and start behaving as if it were originally programmed for that function. As Advisable Systems mature, this behavior will increase in complexity from configuration of existing capabilities to the automated acquisition or generation of new capabilities. Advisable systems will allow commanders and other decision-makers more natural and more productive access to, and control over, a wide range of software capabilities in a variety of mission-critical areas, including command and control, intelligence, and logistics. Advisable Systems will be evaluated in terms of the complexity of advice handled, the speed and accuracy of implementing that advice, and system performance improvement observed when executing the advice. In FY 2003, languages for representing advice will be defined in the context of one or two mission domains. These languages will have precise operational and declarative semantics and will be translatable into executable plans or parameterized configurations of existing software modules. In FY 2004, tools will be developed for applying different levels of advice (e.g., policy, preferences, and constraints) and mediating conflicts among them.

Autonomous Software for Intelligent Control will program a variety of autonomous mobile robots to independently perform military tasks in a diverse spectrum of complex, dynamic environments. The goal is to achieve near-human performance in the tasks of perception-based autonomous vehicle navigation, and effective interaction of robots with humans. Representations of tasks, goals, plans, common-sense knowledge, and perceived environmental features, including the behaviors of humans, are core to this effort. These representations, at multiple layers of abstraction, provide the key infrastructure necessary to support reasoning about the world and tasking modalities natural to the human user. Several alternative approaches are being pursued to augment preprogrammed activities and responses with powerful learning-derived competencies for perception and control analogous to those of biological systems. This software will enable autonomous systems to effectively reason about real-world situations in order to appropriately modify their behaviors. Integrated perception, including fusion of data from multiple sensor and multiple processing modalities of the same data, will reduce operator intervention and achieve semi-autonomous operation. The result will be highly capable robots that can learn new tasks and adapt quickly to new environments with minimal programming effort, with numerous applications in the battlespace of the future. In FY 2003, the program will demonstrate a trainable, perception-based, autonomous, indoor navigation capability, and multisensor outdoor navigation for urban environments. In FY 2004, the program will develop an on-road driving system capable of safely operating in the proximity of humans and other vehicles, distributed perception-based autonomous navigation behaviors for unmanned surface vessels, and infrastructure and tools to seamlessly integrate communications, control, and perception capabilities to implement a networked team of air and ground unmanned vehicles for reconnaissance and area patrol. The program will demonstrate human-supervised and autonomous behavior modes on a humanoid robot platform using perceptual, behavioral, and natural interactive capabilities, and adjustable operator interaction modes on cognitively compatible teams of semi-autonomous, semi-independent robots. During FY 2004, the perception-based technologies will continue to be implemented on robotic platforms and incorporated into the Army Research Laboratory's Robotic Collaborative Technology Alliance unmanned ground vehicle initiatives.

DARPA's Enduring Foundations

While DARPA's eight strategic thrusts are strongly driven by national security threats and opportunities, a major portion of DARPA's research emphasizes areas largely independent of current strategic circumstances. These "Enduring Foundations" are the investments in fundamentally new technologies, particularly at the component level, that historically have been the technological feedstocks enabling quantum leaps in U.S. military capabilities. DARPA is sponsoring research in *materials*, *microsystems*, *information technology* and other technologies that may have far-reaching military consequences. These technologies often form enabling chains. Advanced materials have enabled new generations of microelectronics, which, in turn, have enabled new generations of information technology. And information technology is the enabling technology for network-centric warfare, discussed above.

DARPA's support of these enduring foundations naturally flows into its eight strategic thrusts with a fair amount of productive overlap. For example, some of the work under the *Bio-Revolution* thrust could also be considered part of the *Materials* work and the *Information Technology* work is being reshaped by the *Cognitive Computing* thrust. With this in mind, over 40 percent of DARPA's budget is devoted to high-risk, high-payoff component technologies. This figure is consistent with a goal established by the Undersecretary of Defense (Acquisition, Technology and Logistics) that at least 40 percent of DARPA's research be for "core technologies."

MATERIALS

The importance of materials technology to Defense systems is often underestimated. In fact, many fundamental changes in warfighting capabilities have sprung from new or improved materials. The breadth of this impact is large, ranging from stealth technology, which succeeds partly because materials can be designed with specific responses to electromagnetic radiation, to information technology, which has been enabled by advances in materials for computation and memory.

In keeping with this broad impact, DARPA has maintained a robust and evolving materials program. DARPA's approach is to push those new materials opportunities and discoveries that might change the way the military operates. In the past, DARPA's work in materials has led to such technology revolutions as new capabilities in high-temperature structural materials for aircraft and aircraft engines, and the building blocks for the world's microelectronics industry. The materials work DARPA is supporting today is building on this heritage of major contributions.

DARPA's current work in materials includes the following areas:

- **Structural Materials** are low-cost, ultra-lightweight structural materials and materials designed to accomplish multiple performance objectives in a single system;
- **Functional Materials** are materials with a nonstructural function, such as advanced materials for semiconductors, photonics, magnetics, and other electronic materials;
- **Smart Materials and Structures** are materials that can sense and respond to their environment; and
- **Power and Water** involves materials that: (i) enable novel ways to generate and store electric power (e.g., advanced fuel cells and materials to extract energy from the environment); and (ii) can be used for air or water purification and harvesting water from the environment.

STRUCTURAL MATERIALS

The **Multifunctional Materials** program explores materials that combine the function of structure with a separate system function (e.g., power, repair, and ballistic protection). In FY 2002, we designed, built, and flew the first micro-air vehicle (MAV) in which the structural fibers of the aircraft's wings were also its batteries. On its maiden flight, the vehicle (named "Wasp") flew for over 100 minutes, surpassing the previous flying time record by a MAV by more than a factor of three. With a 13 inch wing span, Wasp weighs only 4.2 ounces and is designed to carry a variety of miniature sensors. We also demonstrated massively actuating, damage-tolerant structures capable of very large shape changes (suitable for morphing applications and space structures) and materials with unique electromagnetic properties.

In FY 2003, we will demonstrate multifunctional, self-consuming ("autophagous") structures that generate thrust for altitude control and end-of-life operations of satellites by consuming the structure that was required for launch into space, but which has no purpose once *in* space. This previously jettisoned mass is now used for on-demand, controllable thrust. During FY 2003, we are also pursuing acoustically tuned multifunctional structures that provide structural capability concomitant with noise and vibration suppression.

In FY 2004 the Multifunctional Materials program will focus on developing synthetic malleable/flexible materials that emulate the capability and complexity of natural materials, while incorporating structural, sensing, actuating, and self-repairing elements. These material systems are inspired by natural systems, e.g., animal appendages containing bones, nerve endings, and muscles. These complex materials will be critical to fully realize the potential of bio-inspired robots that walk on land, fly through the air, and/or swim through the water. Finally, a major limitation on the performance of all hypersonic and space-access vehicles is the "thermal load" on the vehicles due to frictional heating as the airframe moves through the atmosphere. We plan to explore ultra-light material systems that use embedded magnetic filaments to create plasma-repelling fields for hypersonic vehicle directional control and reduced thermal load on the vehicles.

The **Structural Amorphous Metals** program exploits the truly unique properties (toughness, strength, ballistic properties) of structural amorphous metals for critical Defense applications, such as ballistically resistant ship structures, and as a replacement for depleted uranium in antiarmor projectiles. In this program, we demonstrated iron-based amorphous metals (which won an R&D 100 Award[2]) 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, and developed approaches for predicting compositions likely to form amorphous metals. In FY 2002, we used these approaches to develop more stable amorphous alloys. We have also synthesized the first nonmagnetic, iron-based amorphous alloys for Naval applications, which we have been able to cast in six-millimeter thick sections – orders-of-magnitude thicker than previous state of the art. We have also developed iron-based amorphous coatings that are being evaluated under a Navy demonstration program for transition to Navy helicopter engine components. As part of our effort to develop potential replacements for depleted uranium rounds, we have developed new high-density nickel-based amorphous alloys as matrices for second-generation tungsten-reinforced antiarmor penetrators. The Army Research Laboratory evaluation of the first-generation penetrators has provided promising preliminary results, and this evaluation is continuing in FY 2003. In FY 2003, we are evaluating the properties of structural amorphous metals in the context of making significant improvements for Defense applications, i.e., we are developing processes for a number of product forms such as sheet (for Naval applications) and complex-shaped parts for airframe (F-22/F-119) and space-based applications. We are developing a materials property database that will enable military platform designers to exploit the unique properties of structural amorphous metals. In FY 2004, we will continue development of approaches for processing these advanced materials in bulk at reasonable cost. We plan more complete evaluation of properties (e.g., structural, corrosion, and ballistic) and the demonstration of prototype components, including, F-22 wing structural members/components, F-135 stators, and C-17 control surfaces.

The goal of the **Prognosis** program is to manage military equipment by determining remaining usable life, and quantitatively and reliably predicting future operating capability. A major limitation in the readiness of combat systems is the lengthy component and structure inspection process, with "go/no-go" operational decisions made very conservatively in order to avoid the failure of materials in critical components, such as the power plant. As a result of Prognosis, 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 initiated 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 modified facilities at Patuxent Naval Air Station and initiated a series of spin-pit tests to investigate: (i) novel methods for

2 R&D 100 Awards are presented annually by Research and Development magazine to the innovators of the 100 most technologically significant new products of the year.

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, multiscale models of the damage accumulation processes and their cascading effect on future performance. In FY 2003, we are continuing the spin tests using both actual F404/F414 (the engines in the F/A-18) turbine disk components and subscale F100 (the engine used in the F-16) mini disks. For FY 2004, we plan a series of increasingly complex mission profile tests with appropriate fracture model and sensor data fusion protocols. We plan expansion of the Prognosis concept to other, critical (non–engine) components in military platforms that impact system readiness and asset availability.

The **DARPA Titanium** initiative is starting in FY 2003 to exploit revolutionary new processes for the production of titanium that should enable new low-cost and previously impossible-to-fabricate titanium alloys. These are likely to be unique, previously unattainable alloys with microstructures and properties – i.e., high-quality (low-impurity) materials with excellent uniformity throughout their cross sections – that enable *new high performance* capabilities for air, space, and other DoD applications. Additionally, the new processes promise high-volume, *low-cost*, environmentally benign production methodologies. Achieving our goal of $4 per pound for titanium powder would enable the use of titanium in place of steel, a revolutionary approach for ships and armored vehicles. In FY 2004, we plan to establish a prototype U.S.-based production capability to demonstrate the technical efficacy and reproducibility of new titanium extraction processes and to demonstrate their utility in DoD platforms.

In FY 2002, DARPA initiated a program in **Friction Stir Processing** (FSP). The FSP process offers a revolutionary capability to modify the local microstructure in metallic components and weldments at any location. This is accomplished using a nonconsumable rotating tool to create a localized column of hot, plasticized ("worked") metal that provides the ability to tailor and significantly enhance properties for specific, structural needs at very specific locations. For example, FSP can be used as a means to selectively improve properties during component fabrication such that, once in service, the structure will survive better in its environment. FSP can also be used as a field repair technique to immediately repair battle damage and return a structure to military action with minimum outage time. In FY 2002, we demonstrated, in cast nickel-aluminum bronze, that FSP resulted in greater than 100 percent increase in yield strength and greater than 65 percent increase in tensile strength, while increasing damage tolerance (ductility). One of the first applications from this DARPA program will be to use FSP to fabricate ships' propellers. By the end of the program in FY 2005, we will demonstrate that FSP can both significantly accelerate the propeller fabrication process, with substantial cost savings, and improve propeller strength to accommodate faster ship speeds.

A second application for DARPA FSP is enhancing the formability of thick-plate 2519 aluminum (used on the Marine Corps Advanced Amphibious Assault Vehicle). In FY 2002, we demonstrated enhanced formability of thick-section components over the baseline non-FSP material. During FY 2002, we also demonstrated that FSP could increase the ductility in A356 aluminum castings by a factor of 10 (from three percent to 31 percent), while simultaneously increasing yield strength by 13 percent and tensile strength by 43 percent. Using a helicopter component as the demonstration article, we demonstrated the ability to superplastically form 0.2 inch thick FSP 7475 aluminum plate at a rate seven times faster than non-FSP material. We note that complete part-forming was not even possible without the aid of FSP.

During FY 2003, we are continuing the processes and tool development tasks to identify practical processing windows for shop floor practices. We are also establishing facilities and practices at the Naval Surface Warfare Center, Carderock Division, and at the Navy's propeller manufacturing facility in Philadelphia to enable rapid transition to the Fleet. In FY 2004, we plan to establish a properties database for the materials of interest and to extend the technology to stainless steels (the candidate material for future Navy vessels). In another Navy application, we plan development of processes for weldment improvement in both conventional steels and the newly developed stainless steels.

FUNCTIONAL MATERIALS

The **Functional Materials** program is developing nonstructural materials and devices that enable significant advances in communications, sensing, and computation for the military. Examples include: (i) magnetic materials for high-sensitivity, magnetic field sensors and nonvolatile, radiation-hardened magnetic memories; (ii) light-emitting polymers for flexible displays; and (iii) frequency-agile materials based on ferrite and ferroelectric oxides for high-sensitivity, compact, tuned filters, oscillators, and antennas. It also includes a major thrust in "metamaterials," which are engineered composites that promise materials performance beyond that found in nature. In addition, this program features the development of new approaches for creating electronic circuits on conformal surfaces (see Mesoscopic Integrated Conformal Electronics, below).

In FY 2002, the Functional Materials program demonstrated fully radiation-hard, magnetic nonvolatile random access memory (MRAM) that is competitive with conventional memories. Currently these memories are faster than dynamic random access memories (DRAM), are much faster than FLASH, and are approaching the speed of static random access memories. They are as dense as DRAM but are still limited in size because they are not yet a fully mature technology. Because they have fewer masking steps and layers than DRAM, they should be cheaper when the technology is fully mature. These nonvolatile memories will replace some, if not *all*, of the existing random access semiconductor memories – particularly flash memory. (Flash memory is the only widely used, nonvolatile memory today, but it has limited cyclability, in contrast with the infinite cyclability of MRAM). This memory technology has been transitioning to the Defense Threat Reduction Agency and the Navy Trident program, and it is beginning to generate a significant amount of commercial investment. Finally in FY 2002, flexible, near-infrared emitters based on both organic and inorganic emission sources were synthesized and processed as thin films. Through variations in the chemistry, these systems can be tuned to emit light with wavelength ranging from 900 nanometers to 1500 nanometers for such applications as: (i) flexible, near-infrared emitters for friend/foe identification applications; (ii) infrared scene generators; and (iii) wound healing bandages.

In FY 2003, the Functional Materials program is exploring the understanding and exploitation of material properties at the surface that may dramatically differ from the bulk. As dimensions approach the molecular level, material properties are dominated by the surface. These properties can include: (i) a thermal function (e.g., phonon interaction and heat transfer); (ii) a biocidal function (i.e., antimicrobial, antispore); and (iii) an energy function (photon traps and energy conversion). Of high interest is the exploitation of interface engineering for various functions that are surface-dominated. For example, a goal of interface engineering includes the manipulation of phonons at the interface between two materials. This can be exploited to significantly increase the thermal conductivity of insulating, high dielectric strength organics without increasing electrical conductivity. All-electric ships, electric guns, and laser weapons would all benefit from this advancement in materials, since thermal management is the limiting materials problem in each of these applications. Another example is the role of the interface in biocidal coatings, where materials chemistry can be used to discover new ways to treat common surfaces to provide an active deterrent to bacteria and innovative ways to activate and kill spores on a surface. The interaction of photons with a variety of surfaces leads one to think about an energy function where new molecules can be synthesized with properties that enable photon capture and conversion within the same molecule at a surface. This approach involves molecular engineering at the surface for self assembly on a surface. This program has evolved from two small studies investigating how one can manipulate the surface to directly impact materials with surface-dominated properties for DoD applications.

In FY 2003, the Functional Materials program also yielded a significant improvement in the state of the art of field-tunable materials for frequency-agile filters and antennas, and voltage-variable phase-shifters for a host of applications ranging from communications to remote sensing. Varactors made from these materials have lower losses than semiconductor varactors and comparable losses to microelectromechanical systems (MEMS) radio frequency switches, but they offer continuous rather than stepwise tunability. Moreover, field-tunable materials offer the added potential for significantly lower cost than either varactors or MEMS due to the ease of manufacture, their inherent reliability, and lack of a requirement for sophisticated packaging. The program is currently transitioning to several important DoD applications in the U.S. Army

Communications-Electronics Command, including electronically steered antennas for communication on-the-move and tunable, conformal satellite communications ultra-high-frequency patch antennas for airborne and covert applications, where conventional antennas either adversely effect the platform aerodynamics or are very conspicuous.

The objective of the DARPA **Metamaterials** program is to develop, fabricate, and implement new, bulk metamaterials that will fill the tremendous voids in the design space for a number of important military applications. Metamaterials are engineered composites that exhibit superior properties not observed in the constituent materials or in nature. 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 2002, several breakthroughs in metamaterials were achieved, including the demonstration of nanocomposite magnets with record strength and the confirmation of negative refraction of radio frequency energy in "left-handed," or "negative index" metamaterials. In FY 2003, we are emphasizing optimization of metamaterial performance and implementation of 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. In FY 2004, our emphasis will be on achieving prototype demonstrations of metamaterial applications. Specific examples of prototype demonstrations being pursued include: (i) a small, low-profile, ultra-high-frequency antenna for satellite communications; (ii) novel lightweight lenses for beam steering in radar applications; and (iii) high-temperature magnetic bearings capable of operating in turbine environments.

The objective of the **Mesoscopic Integrated Conformal Electronics** (MICE) program is to create electronic circuits and materials on any surface. 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 has developed 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. MICE tools 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 include: (i) the demonstration of printed zinc-air batteries that have four times more volumetric power density than commercial batteries; (ii) the demonstration of direct-write fractal antennas; and (iii) the demonstration of direct-write solar cells. With these demonstrations in-hand, MICE contractors continue to move forward with commercialization strategies that will facilitate the transition of MICE tools to the electronics industry. In FY 2002, MICE contractors continued 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, beginning in FY 2002 and continuing into FY 2003, MICE contractors began working together to establish a "virtual" MICE Center of Excellence in order to educate potential military and commercial users about MICE technologies. This thrust in our Functional Materials program ends in FY 2003, but the MICE techniques will be exploited in FY 2004 in other Functional Materials activities.

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. For example, if successful we will provide orders-of-magnitude more flexibility to our remote sensing assets. The program has already demonstrated: (i) long-lived electron spin coherence in semiconductors, which translates to very long spin-propagation distances; (ii) spin information easily propagates across boundaries between very different semiconductors in a complex heterostructure without any loss of spin information; and (iii) a spin light emitting diode (spin-LED) that emitted more than 85 percent circularly polarized light. In FY 2002, we discovered several new and technologically important ferromagnetic semiconductors with transition temperatures above room temperature. Also in FY 2002, we demonstrated very high-speed optical switching using spin precession to control the optical polarization, and a metal-oxide-semiconductor spin transistor. In FY 2003, we plan to demonstrate a terahertz-speed spin resonant tunneling device that operates at or near room temperature. In FY 2004, we plan to demonstrate a scalable, spin-based implementation for a quantum logic gate based on phase coherence and control, which will operate at frequencies well above 10 gigahertz.

SMART MATERIALS AND STRUCTURES

The broad, but strongly interdisciplinary field of **Smart Structures and Materials** seeks to apply multifunctional 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 and then the brain processes the information, causing a muscle (actuator) to respond. The Smart Materials and Structures program has applied existing smart materials (e.g., piezoelectrics) to reduce noise and vibration and to achieve aerodynamic and hydrodynamic flow control in such a way that allows a paradigm shift in the design of undersea vehicles and torpedoes, engine inlets, aircraft wings, and helicopter rotor blades. For example, 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 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 and the successful fatigue testing of the smart X-frame actuators for the Smart Rotor effort is complete. A whirl tower test of the active blades, with a limited-authority, independent blade control capability, is planned for July 2003 to demonstrate the reduced vibration that smart materials will provide. The program will end in September 2003. We anticipate that the Army, which funded the building of the rotor blades used in the system test, will likely transition the program into wind tunnel test and flight test using improved smart actuator designs emerging from this program.

The **Piezoelectric Single Crystals** program exploits the discovery of a class of materials that provide a revolutionary improvement in converting an electrical signal into a mechanical motion. Under electric stimulus, these rock-hard materials are able to change their shape over 10 times more than conventional materials. In the Defense sector, these materials offer the potential for 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, areas of major impact include medical ultrasonic diagnostic imaging, optical switches in telecommunications, and precision machine tool control. The materials development task of this thrust has already led to three materials manufacturers that are producing material in prototype quantities, at a cost suitable for device demonstrations. Current efforts focus on demonstrating the enhanced device performance characteristics these materials afford. For example, in laboratory tests an innovative torpedo homing transducer element, which is three-tenths the size of present devices, has shown increased bandwidth, allowing substantially increased torpedo targeting range. Realistic field demonstrations of device performance began in FY 2002 and will be completed in FY 2003. Transition of these technologies to the services, especially the Navy, is a critical next step, and efforts are underway to develop transition programs for the most promising Naval applications, ranging from torpedo countermeasures through torpedo homing to mine classification.

Compact Hybrid Actuators is exploring novel ways to employ smart material driving elements to create a new class of efficient, high energy density actuators in packages that are 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 they could have applications to the control of new types of hypersonic missiles. In FY 2002, researchers developed bench-top prototypes of novel compact actuators that included micromachined teeth and ratcheting mechanisms for adaptive optics applications, a thin-film shape-memory, alloy-driven hydraulic pump for missile guidance and control, and nonmechanical valves for smart material-driven hydraulics. The program plans further integrated prototype actuator device tests in FY 2003. Prototype actuators are being evaluated for the flight controls of the UCAV, steering of a kinetic energy antitank missile, and position control in adaptive optical systems. Final, application-oriented system tests are scheduled for FY 2004.

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, particularly 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 mechanical-assist robotic systems that integrate closely with the soldier and help him/her carry and maneuver large and heavy loads. The program is addressing key technology developments, including: (i) energy-efficient actuation schemes and power sources with a relevant operational life; (ii) active-control approaches that sense and enhance human motion; (iii) biomechanics and human-machine interfaces; and (iv) system design and integration. In FY 2002, researchers developed and evaluated exoskeleton structures and power sources. In FY 2003, prototype lower-body exoskeleton systems consisting of an "exostructure," power source, actuators, and control systems are being fabricated and evaluated in the laboratory. In 2003, evaluations began at the U.S. Army Natick Soldier Center to determine the utility of the exoskeleton for Special Forces tasks, such as carrying heavy loads over extremely rough terrain for extended periods. Powered, load-bearing locomotion demonstrations are currently planned for FY 2004 in coordination with our military advisors.

The **Morphing Aircraft Structures** program will create adaptive aerospace structural systems that will enable an air vehicle to change shape ("morph") in flight in much the same way that birds change their body configuration to match their flight profile. These adaptive structures will enable a single, autonomous, military air vehicle to perform missions with a multitude of diverse, conflicting roles, such as dwelling over a target for long periods and then morphing into a maneuverable, high-speed attack configuration to destroy ground targets it identifies, or engaging air threats for self-protection. Morphing aircraft represent a new capability for the creation of agile cruise missiles and hunter/killer platforms that will be particularly effective in prosecuting elusive targets, such as mobile missile launchers. In FY 2003, the Morphing Aircraft Structures program is designing, fabricating, and testing actuators, mechanisms, components, and subsystems for a full adaptive wing structure. In FY 2004, the subsystems and components for the adaptive wing will be fully integrated into a prototype for wind tunnel testing.

POWER AND WATER

It has long been 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: (i) direct oxidation fuel cells, including solid oxide fuel cells; (ii) extremely compact fuel processors for integration with proton exchange membrane fuel cells; (iii) novel small engines; (iv) new approaches to solid-state thermionic emission and thermoelectrics coupled to advanced miniature combustion systems; and (v) advanced materials and materials processing. In FY 2002, we demonstrated fuel cells that operated via direct electrochemical oxidation of hydrocarbons, such as diesel fuels. In addition, record high specific power was demonstrated in a solid oxide fuel cell operating on methanol fuel. In FY 2003, hand-held 20 watt systems operating on methanol fuel are being delivered for field testing to the Air Force and Army. In FY 2004, we will demonstrate the first-generation prototypes of 20 watt solid oxide fuel cell stacks operating on hydrocarbon fuels, including military logistic fuels. There are several interested military transition customers, including U.S. Special Operations Command, U.S. Army Communications-Electronics Command, U.S. Army Soldier Systems Center, and the Marine Corps.

The objective of DARPA's **Water Harvesting** program is to ensure sustainable water supplies to maintain agility and length of deployment for the Army's Objective Force. The program will include approaches to harvesting water from any available source to eliminate 50 percent 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 as 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 started to examine a variety of technical approaches to achieve these goals. In FY 2003, for each project we are conducting model experiments designed to overcome the most difficult technological hurdles standing in the way of prototype development scheduled for FY 2004 and FY 2005. This program is being conducted with the help of U.S. Army Tank and Automotive Command and U.S. Special Operations Command to assure successful transition of these technologies to the Army, Marine Corps, and Special Forces.

MICROSYSTEMS

Microsystems – microelectronics, photonics, and microelectromechanical systems (MEMS) – are key technologies for the U.S. military, enabling it to see farther and with greater clarity, and better communicate information in a timely manner.

DARPA is building on these accomplishments by shrinking ever-more-complex systems into chip-scale packages – integrating the three core hardware technologies of the information age into "systems-on-a-chip." It is at the intersection of microelectronics, photonics, and MEMS that some of the greatest challenges and opportunities for DoD arise. Examples include integrating MEMS with radio frequency electronics and photonics; integrating photonics with digital and analog circuits; and integrating radio frequency and digital electronics to create mixed signal circuits.

The model for this integration is the spectacular reduction in transistor circuit size under Moore's Law: electronics that once occupied entire equipment racks now fit onto a single chip containing millions of transistors. As successful as this progress has been, the future lies in increasing the level of integration among a variety of technologies to create still-more-complex capabilities. DARPA envisions intelligent microsystems that enable systems with enhanced radio frequency and optical sensing, more versatile signal processors for extracting signals in the face of noise and intense enemy jamming, high-performance communication links with assured bandwidth, and intelligent chips that allow a user to convert data into actionable information in near-real-time.

Taken together, these capabilities will allow the U.S. military to think and react more quickly than the enemy and create information superiority by improving how warfighters collect, process, and manage information.

MICROELECTRONICS

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 they 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 has investigated components and architectures of quantum information processing systems, along with algorithms and protocols to be implemented on those systems. In a major early milestone, QuIST researchers demonstrated the world's first implementation of quantum factoring, which has applications in encryption and security. In FY 2002, the program demonstrated techniques for fault-tolerant computation and secure communication, and has demonstrated robust single-photon sources and detectors that are being installed in quantum communication testbeds. 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. Moreover, we will demonstrate the first solid-state quantum dot two-qubit gates (five qubits is equal to 32 conventional bits). We will also demonstrate a small quantum memory of three to five quantum bits. This is enough to demonstrate a quantum repeater, the first practical application of quantum processing. In FY 2004, we will develop robust architectures for multiple-node solid-state quantum computers with at least two qubits per node. We will also demonstrate at least one multiple-site quantum communication testbed operating over commercial fiber. This will be the first time that quantum information is sent over a commercial fiber with other traffic, rather than just in a laboratory testbed.

The **Polymorphous Computing Architectures** (PCA) program is developing a revolutionary approach to implementing embedded computing systems that support reactive, multimission, multisensor, and in-flight retargetable missions. The approach reduces 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. The program identified reactive mission computing requirements and dynamic mission operational constraints required to support future dynamic mission scenarios. In FY 2002, the program developed candidate polymorphous computing architectures, initial morphware standards, and mission-based constraint implementations. In FY 2003, the program will demonstrate the viability of this technology through initial proof-of-concept demonstrations incorporating an early PCA prototype chip. In FY 2004, the continued design, evaluation, and implementation of PCA designs established in FY 2003 will be pursued toward a final set of PCA device implementations and demonstrations in the FY 2005 timeframe. 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 and in-scenario evolving mission. In addition, we anticipate DoD embedded computing platform life cycle cost reductions of up to 45 percent over current technology.

The goal of the **Advanced Lithography** program is to reduce technical barriers to the development of advanced lithographic technologies for the fabrication of a broad range of microelectronic devices and structures. Innovative research in pattern generation and transfer, imaging materials, new processing techniques, and metrology will provide alternatives beyond current evolutionary trends. Maskless approaches will address the low volume needs of military systems. The program will investigate technologies for the creation of highly complex patterns at sub-0.05 micron resolution over field areas in excess of 1000 square-millimeters. Applications with larger geometries will be explored for innovative devices and structures beyond microelectronics, including photonics and bio-arrays. In FY 2002, the program developed key tool components, materials, and processing for both maskless and projection approaches for lithography at 0.05 microns, and we are fabricating prototype devices for military applications with features at 0.1 micron. In FY 2003, the **Sub-0.1 Micron Lithographies** program will: (i) develop and demonstrate key subsystems for both maskless and projection approaches for lithography technologies that will extend to 0.05 microns and below; (ii) fabricate prototype tools for the fabrication of devices with 0.07 micron features; and (iii) explore nanolithography with features down to the range of 10 nanometers. Also in FY 2003, the program will develop mask technology (writing, inspection, and repair) and resists and metrology for lithography for 0.05 micron and below, and exploit advances from longer-term developments in direct write-on-wafer projects. In FY 2004, the program will deliver a commercial imprint lithography tool and reduce technical risks in key areas of components, materials and processing.

The objective of the **Clockless Logic, Analysis, Synthesis, and Systems** (CLASS) program is to develop clockless integrated circuit design techniques that overcome fundamental limitations of today's dominant clocked design methodology so that we may achieve increased circuit density and speed, while minimizing design time. The clock is a crystal oscillator in most integrated circuits that orchestrates the operation of the circuit. It dictates the updating of data in registers, whether internal or for input and output, and the amount of computation that can be performed between clock ticks on the most recent register data. The advantages of removing the clock in logic implementations include: (i) virtual elimination of clock signal distribution problems as circuit feature sizes decrease below 100 nanometers and transistor densities increase into the millions-per-chip; (ii) greatly reduced power consumption (improved energy utilization); and (iii) greatly reduced electromagnetic noise, which can seriously interfere with nearby analog circuits. Clockless design advantages also include improved circuit operating characteristics (the ability to function over a wide range of power and speed operating points) and increased robustness (against voltage and manufacturing process variations) compared to corresponding clocked implementations. An evaluation and design infrastructure will be developed and used to demonstrate these advantages and, equally important, to achieve drastically reduced design effort. The program will be initiated in FY 2004 with a study/evaluation phase to identify the most promising clockless logic design methods and a review of potential applications where the technology could have the most significant impact. In FY 2004, we will initiate design of a complex integrated circuit chip using the most promising clockless design methods. In FY 2005, the chip will be fabricated, and we will compare its performance and design time to the comparable design based on the standard, clocked design method.

The goal of the **High Frequency Wide Band Gap Semiconductor Electronics Technology** program is to exploit the material properties of silicon carbide and gallium nitride alloys to enable the next generation of high-power, high-frequency monolithic microwave integrated circuits (MMICs) capable of operating at frequencies up to 40 gigahertz. These advanced MMIC components will enable extended functionalities in future radar, communication, and counter-measure systems for space-, airborne-, maritime-, and ground-based platforms.

The Navy's June 2000 report to the Congressional defense committees on the Surface Navy Radar Roadmap identified increased demands on radar performance and performance goals for meeting the operational requirements projected for 2015 that cannot be practically met with conventional technologies. The report cited advances in wide band gap semiconductor materials, such as silicon carbide and gallium nitride, as essential to meeting the required increases in range, advanced discrimination, and signal-processing capabilities for advanced theater ballistic missile defense radars. The subsequent March 2001 Technology Assessment for the Surface Navy Radar Roadmap concluded that, to achieve the projected capabilities in fiscal year 2009, consistent with meeting a 2015 operational capability, requires a generational change in high-power amplifiers, device and array thermal management, digital radar, processing algorithms, and processor-independent system software. The report identified advances in wide band gap semiconductor materials and devices as key to that technology development.

The material properties of wide band gap semiconductors will allow microwave amplifiers to achieve 10 times the power density than conventional gallium arsenide or silicon amplifiers at microwave- and millimeter-wave frequencies. In addition, these MMICs will be capable of operating at higher temperatures than current technologies, resulting in a reduction in component size, cooling requirements, and system size, weight, and cost.

In FY 2002, the program initiated development activities focused on solving fundamental material issues that will enable the future fabrication of high-frequency MMICs with high manufacturing yields and low cost. The FY 2002 thrusts included: (i) developing low-defect-density, high resistivity silicon carbide substrates suitable for production of microwave- and millimeter-wave integrated circuits; (ii) exploring alternate-substrate concepts, mainly gallium nitride and aluminum nitride, to potentially improve the electrical and thermal performance of high-frequency, high-power MMICs; and (iii) developing innovative epitaxial material fabrication processes for the optimization of efficient, high-frequency MMICs. In FY 2003, the program is: (i) improving substrate resistivity by stoichiometry control; (ii) expanding substrate-usable area from 50 millimeters to 100 millimeters, while reducing defects and dislocations; (iii) improving the uniformity of epitaxial films to less than ± 3 percent sigma deviation over 90 percent of substrate usable area; and (iv) validating the material quality with suitable device characterization. In FY 2004, the program will conduct an assessment of wide band gap substrates and the epitaxial material technologies. The decision criteria for substrate technology will be the contractor's ability to produce large-area substrates (100 millimeters in diameter) with the required electrical properties for radio frequency devices: (i) high resistivity (exceeding 10^7 ohm-centimeter); (ii) low micropipe (MP) density SiC substrates (less than 10 MP per square centimeter); and (iii) alternate substrates with low defects per square area (10^7 per square centimeter).

For epitaxial material technologies, the DARPA decision criteria will be based on the contractor's ability to demonstrate epitaxial materials with ± 3 percent uniformity in composition, thickness, and doping concentration over 75 millimeter substrates

(90 percent usable area). The activities under this effort will accelerate the development and transition of wide band gap semiconductor materials, devices, and component technologies for radio frequency/microwave devices and to reduce the technical risk and expedite insertions into military systems. This program is being carried out collaboratively by the Director, Defense Research and Engineering, the Secretary of the Navy, DARPA, and other elements of the Department of Defense.

The goal of the **High Power Wide Band Gap Semiconductor Electronics Technology** program is to develop components and electronic integration technologies for high-power, high-frequency microsystem applications based on wide band gap semiconductors. 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 Ship, More Electric Aircraft, and Electric Combat Vehicle require extensive power control and distribution electronics. 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 developed: (i) three inch conducting, wide band gap semiconductor substrates with a 10-fold reduction in defect density; (ii) epitaxial growth techniques for 100 micron-thick, lightly doped blocking layers; and (iii) processing techniques for 10 kilovolt-class wide band gap switches and diodes. In FY 2003, the program will: (i) demonstrate three inch diameter, wide band gap substrates with less than one defect per cubic centimeter; (ii) demonstrate low on-state resistance for 10 kilovolt-class devices; (iii) demonstrate process reproducibility and minimization of yielding limiting factors; and (iv) establish device characterization for very high-power, solid-state switches and diodes. In FY 2004, the program will: (i) demonstrate high-current (100 ampere), high-voltage (10 kilovolt) switches and diodes with operation up to 100 kilohertz; (ii) demonstrate high-power-density packaging for greater than 10 kilovolt operation; and (iii) develop integrated power control logic compatible with high temperature and power silicon carbide power devices.

In a revolutionary departure from today's painstaking circuit fabrication methods, the **Moletronics** (Molecular Electronics) program is pursuing the construction of circuits using nanoscale components, such as molecules and inexpensive chemical self-assembly processes. These chemically assembled systems will have high device density (scaleable to 10^{11} devices per square centimeter, more than 100 times that of current silicon integrated circuits) and low power. The requirements for electrical power now drive much of our information-age infrastructure, placing ever greater need to obtain low-power electronic systems. In FY 2002, Moletronics demonstrated that nanowires have conductivities near that of bulk metal and quantified the defect-tolerance required for a molecular-based computer to function within the required error tolerance level. Moletronics also optimized the performance of several classes of molecular devices, demonstrated a molecular-scale gain device, increased device density, and developed innovative architectures that exploit the unique properties of switching on the molecular-scale. In FY 2003, Moletronics will: (i) develop hierarchically directed assembly processes to assemble molecular devices, wires, and interconnects; (ii) demonstrate efficient defect-search algorithms; and (iii) model the scalability of molecular circuit architectures to high counts and high device densities. Further, demonstrations of new and refined prototype memory arrays are planned, as is a demonstration of a self-assembled adder circuit. In FY 2004, the Moletronics program will demonstrate functionality, e.g., 16 kilobit memory or logic circuit of corresponding device count, comprised of defect- and fault-tolerant molecular based circuits (i.e., including molecules, nanotubes, and nanowires) fabricated using hierarchical assembly processes at a density equivalent to 10^{11} devices per square centimeter.

The objective for the **Vertically Interconnected Sensor Arrays** (VISA) program is to develop and demonstrate imaging readout technology that will result in revolutionary improvement in the performance of a wide range of defense imaging systems, e.g., missile seekers, forward-looking infrared devices, ladars, and photoreconnaissance satellite imagers. This will be accomplished through the development and implementation of novel three-dimensional imaging readout architectures and circuits, which emulate the visual process in some animals (e.g., the fly). In FY 2003, the VISA program will implement highly parallel, densely interconnected architectures with micron-size "vias" that penetrate stacks of detectors, analog, mixed-signal, and digital circuits. In FY 2004, the program will demonstrate stacking with cryo-cycling compatibility and will demonstrate proper functionality and greater than 16-bit dynamic range. Additionally, the program will demonstrate extended-geometry "via" technology and proper functionality, with subnanosecond time resolution.

The **Ultra Wide Band Array Antenna** program develops array antenna and beamforming technology to support steering from 10 to 100 independent beams with instantaneous bandwidths in excess of 100-to-one from an array antenna. Frequency ranges of interest are: 20 megahertz to three gigahertz, 100 megahertz to 20 gigahertz, and 500 megahertz to 50 gigahertz. In FY 2003, the program will: (i) begin component design and simulation of radiating elements, low-noise amplifiers, and beamformers to support a 33-to-one bandwidth; (ii) explore initial designs to support 100-to-one instantaneous bandwidth; and (iii) validate performance by simulation. In FY 2004, the program will: (i) complete the phase I design efforts and extensions to 100-to-one bandwidth; (ii) down-select component and architecture approaches; and (iii) begin component fabrication.

The objective of the **Acoustic Micro-Sensors** program was to develop and demonstrate: (i) miniature sensors exploiting the mechanical properties of microelectromechanical devices heterogeneously integrated with advanced analog/digital electronics; and (ii) innovative circuit architectures to demonstrate sensors that require low power, are capable of operating for very long period of times in harsh environments, and which can be manufactured with standard semiconductor fabrication processes at a low cost. A key goal was for the sensor to be capable of locating, tracking, and identifying sound sources of interest in the presence of high levels of background noise. We have demonstrated several broad-band (10 to 20,000 hertz) acoustic microsensor unit concepts capable of localizing sources of interest within two degrees of bearing accuracy, and capable of unattended operation with conventional batteries for more than 300 days. This performance is achieved in a sensor volume less than one cubic inch. In addition, this effort demonstrated robust directional and omnidirectional microphone concepts (microphone area less than 10 square millimeters) with sensitivity performance similar to the best commercially available microphone (signal-to-noise ratio greater than 62 decibel per pascal per hertz) at less than 1/10,000 the manufacturing cost. These new microphone concepts will enable the proliferation of low-cost, long-endurance, unattended acoustic sensor networks for DoD applications.

The objective of the **Steered Agile Laser Beams** (STAB) program is to develop small, lightweight laser beam scanning technologies to replace large, heavy, gimbaled mirror systems, thereby enabling compact, lightweight steered laser beam modules for free-space optical communications, infrared countermeasures, and target designation systems. New solid state/microcomponent technologies, such as optical microelectromechanical systems, patterned liquid crystals, photonic band gap crystals, and diffractive microoptics, are being used to build small, ultra-light, rapidly steered laser beam subsystems. Compared to conventional methods of beam steering, this program will achieve: (i) a 30-fold reduction in volume; (ii) a 65-fold reduction in weight; and (iii) greater than a 10-fold increase in throughput. The STAB program has already successfully demonstrated the world's first all-electronic wide-angle laser beam steering in a very compact form factor. A prototype system was demonstrated and delivered to DARPA in the second quarter of FY 2003. This prototype has a field-of-regard (FOR) limited to less than 15 degrees in azimuth and elevation, and a steering efficiency of less than 40 percent. At the conclusion of the program (fourth quarter of FY 2003), the FOR will be extended to greater than 25 degrees, with steering efficiency greater than 70 percent. To-date, multiple technical approaches to accomplish the STAB program goals have been demonstrated, thereby greatly reducing risk in our transition plan.

STAB technologies are transitioning into two system-level programs at DARPA. DARPA's Tera Hertz Operational Reachback program (p. 30) is using STAB beam steering technology as the critical enabler for long-haul free-space optical communications links. Likewise, DARPA's Multifunction Electro-Optics for Defense of U.S. Aircraft program (p. 19) is using STAB beam steering technology for laser targeting control. In addition, the STAB program is transitioning technology to the Air Force Research Laboratory for testing in infrared countermeasures applications, and to the U.S. Army Communications-Electronics Command for development of a tactical battlespace free-space optical network.

The **Reconfigurable Aperture** program (RECAP) has developed two new areas of antenna and aperture capability. The RECAP program's original goal was to develop an aperture capable of achieving ultra-wide bandwidth performance (10-to-one bandwidth) by reconfiguring through a number of narrower bands. Many designs achieved this goal. Two approaches were able to achieve instantaneous, ultra-wide bandwidth without the need for reconfiguration, opening up many new applications for wide-band scanning arrays. The RECAP teams further developed several new core technologies, including radio-frequency microelectromechanical switches, high-impedance ground planes, and artificial magnetic materials. RECAP technologies will allow multiple functions to share an antenna, reducing the number of antennas needed on masts of ships, and the program has produced technologies that will enable extremely thin, conformal apertures for airborne use. The RECAP program ended in FY 2002, and RECAP apertures are being fielded for prototype communication systems within the Future Combat Systems program.

The most capable military radars have active-array antennas, capable of rapid electronic steering of the radar beam without any physical antenna movement. This agile beam capability is critical during tactical engagements. The electronics in a conventional active-array include thousands of microwave integrated circuits constructed from individual elements that must be diced, tested, packaged, and assembled. This process is expensive and slow. The **Highly Integrated Millimeter Wave Electronically Scanned Array** program will enable wafer fabrication lines to produce complete and fully integrated wafer-size active-array electronics. These integrated wafers will include microwave circuitry, digital control circuitry, beamformers, and radiators, and have the capability to tolerate imperfect production yields. The integrated wafer is packaged as a single component. Low-cost active-array electronics produced on automated semiconductor fabrication lines will have two major military payoffs. First, the cost of systems that use active-arrays will drop significantly. Since the integrated wafer diameter is matched in size to a typical millimeter-wave electronically steered array, it serves as the complete active-array electronics. For larger applications, the integrated wafers will be used as tiles to create much larger inexpensive active-arrays. The second major payoff is that active-arrays will be enabled for use in applications where the agile beam is necessary but conventional cost is prohibitive. This includes disposable applications, such as smart munitions, seekers, and also a variety of high-bandwidth tactical communications. Current communications systems must choose between high bandwidth, using fixed-dish antennas, or mobility, using low-bandwidth (voice) antennas. The agile beam of an active array antenna enables both mobility and high bandwidth (video, sensor data) mobile communications. In FY 2004, emerging millimeter wave integrated circuit technologies will be surveyed, optimum electronically scanned array architectures for wafer arrays will be developed, and proof-of-principal test structures will be fabricated.

The objectives of the **Uncooled Integrated Sensors** program were: (i) to develop and demonstrate, in large-format, high-density uncooled infrared arrays, new thermal nanostructures and materials to realize uncooled infrared imaging arrays approaching the thermal sensitivity limit; and (ii) demonstrate integrated, high performance arrays in extremely small, low-power packages suitable for unmanned vehicle applications to demonstrate viability of uncooled infrared sensors for novel applications. This program has demonstrated low-stress microbridge, infrared-sensitive materials with high optical absorption deposited over large area substrates, and processed to achieve a 480-by-640 element, uncooled infrared array with pixel dimensions as small as 20 microns. Electronic design and packaging innovations contributed to the realization of a sensor weighing less than one pound, two-to-three times less than the typical large-format sensor packages. With a field of view of greater than 50 degrees, and sensitivity within a factor of seven of the theoretical limit, these arrays have demonstrated that excellent infrared imaging can be obtained in a micro air vehicle without sacrificing imaging quality. These arrays provide the potential for remote vehicles to locate targets in complex environments.

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 of providing a 10-fold increase in ASIC processing capability over currently available ASICs in minimum design time. MSP enables new military missions and will help ensure that the United States 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, DARPA identified potential methods for obtaining the 10-fold increase in sensor data processing capability of ASICs in minimum design time, and also identified military applications to demonstrate this increase. In FY 2002, the program conducted experiments through fabrication of test structures to verify the 10-fold increase in sensor data processing capability. In FY 2003, DARPA selected two phase II contractors to fabricate full-scale ASICs based on both the most promising methods from phase I and support from DoD programs looking to benefit from the MSP technology. Demonstration of the 10-fold increase in military sensor data processing applications are planned for FY 2004, including testbed demonstrations of actual-use scenarios.

PHOTONICS

The goal of the **Analog Optical Signal Processing** (AOSP) program is to significantly enhance the performance of, and enable entirely new capabilities and architectures for, tactical and strategic radio frequency systems. Our approach is to expand 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. In FY 2002, the AOSP program completed the analysis of advanced optical signal processing architectures and algorithms, and the potential system impact of inserting the optical processing technology in system front-ends. Specific items accomplished include: (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; and (iv) evaluating signal processing algorithms and photonic component performance requirements. In FY 2003, the program is designing, fabricating, and testing individual photonic components capable of meeting military radio frequency signal processing requirements. We will determine the most promising approaches for developing integrated, chip-scale components using new materials and processing technology, and we will determine the interface requirements. After we evaluate the suitability of the new components for use in prototype modules, the most promising approaches will be selected and prototype module assembly and construction will begin. Existing system testbeds will be exploited to fully characterize the photonic-based radio frequency signal processing components. An example integration opportunity that would provide significantly enhanced survivability might be in the radar warning receiver in tactical aircraft: AOSP technology would enable detection of antiaircraft fire control radars that have low-power, advanced modulations. In FY 2004, the program will develop the three AOSP modules with at least 10 gigahertz bandwidth and 100 decibel dynamic range (72 decibel for the waveform generator); we will demonstrate AOSP performance in a system context.

The goal of the **Adaptive Focal Plane Array** (AFPA) program is to develop reconfigurable infrared (IR) focal plane arrays (FPA) that are capable of "hyperspectral imaging on a chip." A key deliverable will be demonstrating hyperspectral and multispectral imaging in a standard, forward-looking infrared package. These AFPAs will be electrically programmable on a pixel-by-pixel basis, thus enabling the real-time reconfiguration of the array to maximize either spectral coverage or spatial resolution. Currently, there are no imaging arrays that can be tuned on a pixel-by-pixel basis across the IR band. This technology will enable "staring" FPAs that are capable of adaptively seeing through obscurants, imaging targets in diverse clutter, and performing precise chemical agent identification. Thus, the AFPAs will serve as an intelligent front-end to an optoelectronic microsystem. Owing to its adaptivity, this technology will provide an essential sensing element to the variety of platforms, including autonomous systems being developed under the Future Combat Systems program, and other DoD platforms such as future unmanned air vehicles or space platforms. The program is beginning in FY 2003 with the development of component technology for tunable photodetectors utilizing tunable microelectromechanical systems etalons and high-gain, multipass cavities. In FY 2004, we will integrate the detector array through array processing technology development and tunable array integration and fabrication.

The goal of the **Chip-Scale Wavelength Division Multiplexing** (CS-WDM) program is to develop new materials, components, and subsystems for use in optical communications based on wavelength division multiplexing, delivering high-capacity, mission-adaptable networks for use in data intensive military weapons systems. In FY 2002, the WDM program conducted modeling, simulation, and analysis of artificial dielectrics and new materials for ultra-compact WDM components, conducted experimental efforts in the growth and fabrication of these new materials, determined suitable processing procedures, and planned construction of WDM components. In FY 2003, the program will fabricate and test novel WDM components, including tunable lasers and wavelength cross connect switches 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 testbeds. In FY 2004, the program will construct a CS-WDM demonstration testbed to quantify component operating characteristics and benefits to operationally significant user applications, such as reconfigurable networks for airborne platforms or surface ships.

The **Optical Code Division Multiple Access** (O-CDMA) program represents a paradigm shift from the current wavelength division multiplex/time domain multiplex optical networks. Instead of assigning a wavelength and a time slot to a user, O-CDMA assigns a code to a user. The goal of this program is to demonstrate technology for an advanced O-CDMA communications system. Such a system potentially offers the benefit of multilevel security, low probability of interception, detection and jamming, decentralized network, and higher spectral efficiency. In FY 2003, the program plans to: (i) demonstrate 10 simultaneous users at 10 gigabits per second per user with a low bit error rate; (ii) demonstrate scalability to 100 simultaneous users and cardinality of 1000; and (iii) demonstrate spectral efficiency scalable to one bit-per-second-hertz. In FY 2004, the program will: (i) complete testbed construction; (ii) test/evaluate phase I hardware; and (iii) quantify transmission impairments. Also, the program will identify network management issues with fiber and free-space based O-CDMA networks.

The goal of the **Semiconductor Ultraviolet Optical Sources** program is to develop wide band gap materials for optical emission in the ultraviolet region for bio-sensing and covert communications. This program will develop high conductivity p-type (positive charge carrier) material and highly efficient active region suitable for ultraviolet emission. We will exploit these results to enable the development of heterojunction bipolar transistors. In FY 2002, the program demonstrated p-type 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, heterojunction bipolar transistors). In FY 2004, the program will develop light-emitting diode devices suitable for point detection of weaponized bioagents, biological clouds, and non-line-of-site tactical communications.

MICROELECTROMECHANICAL SYSTEMS (MEMS)

The **Chip-Scale Gas Analyzer** program aims to use the latest MEMS technologies to implement separation-based analyzers (e.g., gas chromatographs, mass spectrometers, and poly-chromator-like devices) at the microscale to greatly enhance the selectivity of sensors to specific species, and, thus, enable extremely reliable, remote detection of chemical/biological agents. The use of MEMS technology should also make possible operation of complex analyzer systems at extremely low power levels – perhaps low enough for operation as autonomous, wireless sensors. The many challenges in this program include the exploration and realization of microscale preconcentrator approaches, stacked gas columns, multiple sensor arrays, ionizers, micromechanical vacuum pumps, and vacuum packaging. The success of this program will yield sensors substantially more selective than conventional sensors, making them particularly suitable for detection and identification of airborne toxins. The program begins in FY 2004 and will first establish design tradeoffs in (column) length vs. species separation efficiency for microscale gas chromatographs, mass spectrometers, and resonator-based separation mechanisms. Then we will demonstrate fabrication technologies that enable needed gas analyzer components, such as high gain preconcentrators, stacked microcolumns, and micromechanical vacuum pumps.

The **Harsh Environment Robust Micromechanical Technology** (HERMiT) program aims to demonstrate micromechanical devices that can operate under harsh conditions (e.g., large temperature excursions, large power throughputs, high g-forces, and corrosive environments), while maintaining unprecedented performance, stability, and lifetimes. Although HERMiT realizations of micromechanical radio frequency switches are of particular interest (where sizable power throughputs and direct surface-to-surface mechanical impacts during operation constitute harsh operational environments), implementations for vibrating resonator reference tanks, gyroscopes, accelerometers, and other DoD-relevant MEMS devices, are also of interest. Among the most promising HERMiT implementations are: (i) wafer-level encapsulation or packaging strategies based on MEMS technology that isolate a micromechanical device from its surroundings, while maintaining a desired local environment via passive or active control; or (ii) material and design engineering strategies that enhance the robustness of a micromechanical device and render it impervious to its environment, with or without a package (if possible). A key approach in this program that should allow orders-of-magnitude power savings is to selectively control only the needed microscale environment or volume via MEMS-enabled isolation technologies. The success of this program should enable myriad capabilities, including: (i) lower cost, more complex phased-array antennas for radar applications; (ii) tiny frequency references with long- and short-term stabilities that greatly extend the portability of ultra-secure communications; and (iii) microscale inertial measurement units with bias stabilities approaching navigation-grade. The program will begin in the last quarter of FY 2003, during which the feasibility of engineering approaches to environmentally impervious materials will be established, and methods for low-cost, wafer-level encapsulation of micromechanical devices will be pursued. In FY 2004, the program will demonstrate wafer-level encapsulation/isolation technologies and engineered materials and/or surface treatments that can enhance the robustness of a micromechanical device and render it impervious to its surroundings or operating environment.

The objective of the **MEMS Micro Power Generation** program is to replace today's primary and rechargeable battery technologies, which severely limit mission endurance and capabilities, by developing microelectronic machine technology to realize power generators based on microscale mechanical actuation, fuel cell, and thermal-electric means, and that are capable of using fuels with substantially higher energy density than batteries to greatly extend power supply lifetime. With dimensions in the range of one to three centimeters, these micropower generators will be capable of generating sustained power in the 0.1 to 10 milliwatt range, with burst powers up to 30 milliwatts for wireless data transmission, for use with remote, field-deployed microsensors and microactuators that must operate autonomously for months at a time. In FY 2002, the program demonstrated capabilities in fuel processing, energy conversion to electricity, and thermal and exhaust management. It also demonstrated functional MEMS microheat engine and microfuel cell components. In FY 2003, the program will demonstrate the integration of various microscale power-generation components to achieve stand-alone, small power generators using high energy density fuels, e.g., hydrocarbon fuels. In FY 2004, the program will demonstrate: (i) the integration of various power generation components with microsensors and microactuators; and (ii) stand-alone, remotely distributed microsensors and actuators with built-in power supply and wireless communication.

The **Micro Adaptive Flow Control** (MAFC) program seeks to control the behavior of large-scale air flows by exploiting the natural amplification of disturbances triggered by small-scale actuators. By combining innovative actuator technologies with adaptive control strategies, the program will develop, assess, and demonstrate flow control approaches that can adaptively respond to changes in operating conditions, thereby providing radical new military system performance capabilities, e.g., in airframes, propulsion systems, control surfaces, or weapons systems. In FY 2002 phase II, DARPA conducted testing and evaluation of closed-loop MAFC technologies with a focus on transonic and supersonic speeds. In FY 2003, DARPA successfully conducted the first full-scale phase III demonstration flight test of the XV-15 tiltrotor aircraft to show the capability of MAFC for download reduction. In FY 2004, a supersonic weapons release demonstration is planned.

COMBINED SYSTEMS-ON-A-CHIP

The **Chip Scale Atomic Clock** program aims 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 is at least 200 times smaller than the smallest atomic reference unit. This degree of size reduction allows the insertion of atomic time references directly into hand-held devices, which greatly expands the application range for atomic clocks. Among the applications to benefit from this program are: (i) military Global Positioning System receivers with improved jamming margins, faster reacquisition capabilities, and better position identification accuracy; (ii) jam-resistant communications, for which accurate clocks are of utmost importance; (iii) radars with improved resolution; and (iv) devices for higher-confidence identification of friend-or-foe. The program began in the last quarter of FY 2002, and commenced demonstrating the feasibility and theoretical limits associated with miniaturization of cesium and rubidium cells. In FY 2003, the program will demonstrate subcomponent fabrication technologies that address miniaturization of atomic chambers, and excitation and detection functions. 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 less than one cubic centimeter, excluding batteries. In FY 2004, the program will create and demonstrate ultra-miniaturized atomic-confinement cells, gigahertz resonators, phase-locking or directly-coupling mechanisms, and interface electronics. Research issues include coupling and transduction mechanisms, magnetic thin-film coatings on resonators, hermetic packaging of resonators and cesium or rubidium confinement cells, temperature isolation and compensation, and magnetic shielding. The central theme of this phase is the demonstration of functionality of crucial components with high-frequency stability.

The **Digital Control of Analog Circuits RF Front Ends** program will demonstrate analog/radio frequency electronic components with the ability to self-assess and adapt in real-time (sub-microseconds) by self-tuning their impedance-matched networks, 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 150-fold improvements in power-bandwidth and linearity-efficiency products. In FY 2002, the program demonstrated real-time, active self-assessment and monitoring of radio frequency/analog functions using nanoCMOS digital and mixed-signal technologies to achieve stability, signal agility, and multifunctionality. In FY 2003, the program will develop hardware techniques and algorithms to manage the monitoring and assessment of active radio frequency devices, develop MEMS and related tunable devices, and optimize their performance for real-time microsystem adaptation. Additionally, we will demonstrate on-chip radio frequency monitoring capability with less than 10 percent radio frequency performance degradation over design bandwidth, and we will demonstrate the capability to actively tune, in less than 10 microseconds, an impedance-matched network for real-time adaptability. In FY 2004, the program will lead the demonstration at the level of one active device (transistor) with multiple active networks (input/output impedances) and fabricate self-assessment control integrated circuits and tunable MEMS control integrated circuits. The program will demonstrate chip-scale, real-time self-assessment of analog functions, and we will demonstrate integrated tunable impedance-matched networks for real-time adaptation.

The objective of the **Technology for Efficient, Agile Mixed Signal Microsystems** (TEAM) program is the fabrication of 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. In FY 2002, the TEAM program: (i) demonstrated deep submicron (less than 0.25 micron critical dimension) silicon-based structures and associated fabrication processes to achieve high-speed analog/radio frequency functions; (ii) optimized device and process parameters for high-speed mixed-signal circuits; (iii) produced test devices for analog/radio frequency parameter extraction; and (iv) demonstrated Complementary Metal Oxide Semiconductor (CMOS)-compatible fabrication processes that can yield integrated transistor counts greater than 10,000 analog/radio frequency devices. In FY 2003, the TEAM program will demonstrate: (i) operation of high-performance, mixed-signal circuits based on deep submicron devices; and (ii) low-noise interface and high isolation (up to 100 decibel) between high performance analog circuits and associated digital signal processing functions. In FY 2004, the program will complete: (i) the demonstration of devices with operating frequencies above 200 gigahertz and circuits with more than 1000 of these high performance devices; (ii) and a study of the impact of these devices/circuits for future “system on a chip” applications, such as radar or electronic surveillance receivers.

The **Technology for Frequency Agile Digitally Synthesized Transmitters** program will develop super-scaled Indium Phosphide (InP) Heterojunction Bipolar Transistor (HBT) technology compatible with a 10-fold increase in transistor integration for complex mixed-signal circuits. Phase I will establish the core transistor and circuit technology to enable the demonstration of critical small-scale circuit building blocks suitable for complex mixed-signal circuits operating at speeds three times faster than that currently achievable, with 10 times lower power consumption. Phase II will extend the technology to the demonstration of complex (more than 20,000 transistors) mixed-signal circuits with an emphasis on direct digital synthesizers for frequency-agile transmitters. In FY 2003, the program will: (i) develop material and process technology for super-scaled InP double heterostructure bipolar transistors (DHBTs); (ii) leverage the process technology used in the silicon and silicon-germanium industry to produce a planar, highly scalable InP HBT; (iii) extend the core DHBT and interconnect technology with the implementation of complex mixed-signal circuits; (iv) develop super-scaled InP HBT processing technology for 0.25 micron (and below) critical dimension; (v) develop high-current, planar, InP HBTs compatible with high levels of integration; (vi) develop greater than 100 gigahertz mixed-signal circuit building blocks; and

(vii) demonstrate record performance InP HBTs in a planar process for complex mixed-signal circuits. In FY 2004, the program will extend the core DHBT and interconnect technology to enable the implementation of complex mixed-signal circuits. Technology integration approaches will be demonstrated that are compatible with circuit complexity of greater than (or equal to) 20,000 transistors Mixed-signal circuit designs will be developed for high, spur-free dynamic range direct digital synthesizers and other related circuits with a three-fold increase in circuit clock speed and up to a 10-fold reduction in circuit power. The circuit demonstrations will target various DoD system applications, including space platforms, communication links, electronic warfare systems, and radar systems.

The objective of **University Opto-Centers** program is to develop technologies that enable chip-scale microsystems based on hybrid integration of photonic, electronic, and microelectromechanical devices. These technologies will be demonstrated in applications to bio-sensing and bio-sample manipulation, and in high-speed computing and switching systems. The program has developed designs for, and preliminary demonstration of, chip-scale "laboratories," or microsystems, for manipulating and analyzing extremely small quantities (nanoliters) of biological samples, miniaturized and rugged optical spectrometers for chemical species detection and identification, and laser systems for efficient extraction of DNA and RNA molecules from cells. The program also demonstrated all-optical switching of ultra-fast (100 gigahertz) optical signals for potential use in very high bit-rate communication systems and novel optical methods for producing extremely fine (less than 100 nanometer) lithographic features over large substrates.

INFORMATION TECHNOLOGY

DARPA's strategic thrust in Cognitive Computing is significantly reshaping the Agency's enduring foundation in Information Technology (see the discussion in the **Cognitive Computing** strategic thrust, above). DARPA's efforts build on traditional and revolutionary computing environments and strive to provide such things as improved device/system control, human-robot and robot-robot collaboration, and enhanced human cognition. Among these programs are:

The **Taskable Agent Software Kit** (TASK) program is developing tools for the construction and analysis of multiagent systems that realize a global objective through local decisions based on embedded models of the mission, the environment, and interaction with other agents. While agent technology holds much promise for certain classes of military problems, current development methods are *ad hoc*, and little is understood about how to engineer desirable global results from local, autonomous actions, while mitigating potentially undesirable emergent behaviors. Tools developed under the TASK program will provide a mathematically sound, common engineering foundation for the development and deployment of high-confidence, agent-based computing solutions to a spectrum of military problems requiring robust, scalable, decentralized approaches in dynamically changing environments. In FY 2002, initial TASK program results were demonstrated in the context of two exploratory domains, command and control and logistics, leading to initial definition of design techniques and metrics. In a Civil Reserve Air Fleet scenario, it was shown that a combination of competitive (auction-like) resource allocation and limited collaboration among carriers led to a solution that was not only efficient in satisfying global objectives, but also significantly reduced costs to the individual carriers. In FY 2003, integrated design and analysis methods will be applied to challenge problems in a consolidated scenario focused on surveillance and targeting missions for cooperative autonomous vehicles. In FY 2004, advanced algorithms capable of handling increased uncertainty in the environment and agent failures will be demonstrated, and the design and analysis toolkit will be publicly released.

The **Data Intensive Systems** program, completed in early FY 2002, 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 100-fold for a wide range of DoD target applications, such as a radar beam steering controller, graphics rendering, and ray-tracing for a T-80 tank. Processor-in-memory devices and unique memory-aware techniques were developed and implemented. These basic innovative technology developments are now being incorporated in commercial computing systems used by the DoD and Department of Energy laboratories, and are providing crucial data-intensive technology underpinnings for future computer systems.

The **Common Software for Autonomous Robotics** program is developing software technologies for large groups of extremely small and highly resource-constrained microrobots. 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. One part of Common Software for Autonomous Robotics is the **Software for Distributed Robotics** (SDR) project, which has already transitioned task allocation, reusable components, and energy-conserving protocols to the Army Research Laboratory's Robotic Collaborative Technology Alliance, the Future Combat Systems - Communications program, and Urbot, being developed by the Unmanned Ground Vehicle/Systems Joint Program Office and the U.S. Space and Naval Warfare Systems Command. In FY 2002, SDR demonstrated robust formations of over 40 robots using cooperative behaviors based upon implicit communications and controlled by a single operator. In FY 2003, using over 100 robots, SDR will demonstrate distributed simultaneous localization and mapping to search the interior area of a building and establish a sentry perimeter to monitor intruder detection over a sustained period of time. The program will also develop minimal-resource behavioral algorithms and simulation tools to implement highly scaleable, distributed approaches to simultaneous localization and mapping, communications, and threat detection. The technology will transition to support "Swarming Entities" concepts of operation currently being developed by the Department of Defense.

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** (DASADA) is developing the equivalent of software "probes," "gauges," and tools so that systems can: (i) monitor their own 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. Recent program successes include automated code generation that is 33 percent more reliable than Capability Maturity Model Level 4 human team, and 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 DASADA program, which concludes in FY 2003, will transition technologies that include: (i) DASADA's Acme language, which will be adopted by the Object Management Group standards organization as the basis for the Unified Modeling Language (the most commonly used Architecture Description Language (ADL)); (ii) the "dynamic server" technology will be used to adapt the Global Command and Control System based on the deployed environment; and (iii) the DASADA xADL will be used by NASA Jet Propulsion Laboratory's Mission Data System project for future Mars missions.

The **Control of Agent Based Systems** (CoABS) program has forged the technology for run-time interoperability of heterogeneous systems by creating the CoABS Grid and toolkits for rapid creation of interoperable agents to automatically perform integration and myriad additional functions. 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 accomplished 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 preexisting Government standard. The CoABS Agent technology and Grid have been demonstrated to all the Military Services and are key technology enablers for the Navy's Expeditionary Sensor Grid, a lead exemplar of net-centric warfare. CoABS agent technologies and tools have been used in military scenarios to demonstrate the run-time integration and interoperability of heterogeneous systems. For the first time, in two multinational coalition experiments, Fleet Battle Experiment Juliette (FBE-J) and the

Coalition Agents eXperiment (CoAX) demonstration at the U.S. Naval Warfare Development Command, real-time interoperability connections were made and a common situation display was available to all coalition participants using their own particular applications as a direct result of CoABS technologies. During FBE-J (Millenium Challenge 2002), coalition forces (United Kingdom, Canada, Australia, and the United States) exchanged tactical data and shared a real-time common tactical picture across geographically distributed platforms, and each coalition partner used his own indigenous command and control system to display his common picture through the CoABS Grid. During CoAX 2002, agents seamlessly provided for, and maintained interoperability of, this heterogeneous network of 14 clients at five sites on three operating systems for four countries over four types of communications networks throughout the experiment – without human intervention. CoABS agent technology enabled the dynamic reconfiguration of the system architecture and recovery from communications outages in about 10 seconds without human intervention. In FY 2003, CoABS will continue to support the Navy's work in the Expeditionary Sensor Grid during several Limited Objective Experiments (LOEs) under a joint Memorandum of Agreement with the Office of Naval Research. In addition, the program intends to participate in a Joint Forces Multinational LOE.

The **Ultra High-Performance Networking** program, which is ending in FY 2003, has advanced transparent, all-optical networking and gigabit wireless techniques to dramatically enhance the bandwidth reliably available to end-applications. To focus the research, the program is leveraging work initiated under DARPA's Gigabyte Applications program (see FY 2003 Descriptive Summaries) by further developing key DoD applications that take advantage of the robust capability to stream gigabyte real-time sensor data. Notably, the program has demonstrated the first radar to send wide band signals in real-time over a high-speed network with standard Internet protocols. Moreover, it has conducted the first demonstration of real-time, sparseband sensor processing technology, where multiple gigabit-per-second streams from radars operating in different bands are coherently processed to dramatically enhance the sensitivity and resolution that could be attained from independent sensors. This technology is being transferred to the U.S. Space Command and the satellite imaging radars at Kwajalein Missile Range. The program has also demonstrated a hybrid optical/wireless self-healing link operating at 600 Mbps. This hybrid technology provides high availability communications under adverse weather conditions, since radio frequency and optical links are not equally sensitive to conditions such as fog, mist, and rain.

Energy and power management have now become a critical factor for computing applications. The **Power Aware Computing and Communications** program is developing integrated software/hardware power management comprising 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 1000-fold in military applications ranging from hand-held computing devices to unmanned air vehicles. The program has developed and evaluated individual power-aware technologies at the device, operating system, compiler, algorithm, and mission levels. Results in FY 2002 and early FY 2003 produced savings up to five orders-of-magnitude at the mission and scenario levels, up to 900 times at the subsystem and algorithm level, up to 10 times at the software and compilation levels, up to 10 times at the operating systems level, and up to 22 times at the architectural and device levels. In FY 2003, we have initiated focused system technology risk reduction demonstrations, incorporating a composite of these high-payoff technologies. The demonstration application areas are Land Warrior, Joint Tactical Radio System, space applications, sensor fields, and generic distributed sensors and communications power aware testbeds. In FY 2004, the demonstration areas will develop and implement power-aware techniques. We plan final demonstrations of the integrated power-aware techniques and technologies in early FY 2005. A common power-aware development tool environment will be released in FY 2004 to five technology transition demonstration teams.

The **High Productivity Computing Systems** (HPCS) 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 the emerging biotechnology area. The HPCS program is being implemented in three phases: concept study (phase I), research and development (phase II), and full-scale development (phase III). The HPCS phase I industry concept studies, awarded in FY 2002 to Cray, Hewlett-Packard, IBM, SGI, and Sun, are providing critical technology assessments, developing innovative HPCS concept solutions and providing new productivity metrics. Phase I, completing in FY 2003, will establish the concepts, methods, and architectures to be pursued as HPCS phase II research and development. 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-end computer mission requirement assessments to establish the basis for system design, select supporting technology, and develop early prototypes for the HPCS phase II. Phase II HPCS research and early concept prototyping activities will be initiated in FY 2003. System design and technology assessments supporting research and development of HPCS phase II will continue in FY 2004 and FY 2005, establishing the basis for HPCS phase III.

Index of Programs

DARPA Programs Cross-Referenced by Program Element and Project Number

(President's FY 2004 Budget*)

DARPA Program	PE	Project
A160 Hummingbird Warrior	0603285E	ASP-01
Acceleration of Anthrax Therapeutics	0602383E	BW-01
Acoustic Micro-Sensors	0602712E	MPT-02
Active Templates	0603760E	CCC-01
Activity Detection Technologies ("Sensors")	0602383E	BW-01
Adaptive Focal Plane Array	0602712E	MPT-02
Adaptive Networking	0602301E	ST-30
Advanced Lithography	0603739E	MT-10
Advanced Medical Diagnostics ("Advanced Diagnostics")	0602383E	BW-01
Advanced Speech Encoding	0603760E	CCC-02
Advanced Tactical Targeting Technology	0603762E	SGT-01
Advisable Systems	0602301E	ST-33
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
Antipersonnel Landmine Alternatives	0602702E	TT-04
Architectures for Cognitive Information Processing	0602301E	ST-32
Augmented Cognition	0602301E	ST-31
Autonomous Negotiation Teams	0602301E	ST-19
Autonomous Software for Intelligent Control	0602301E	ST-33
Babylon	0602301E	ST-29
Bio/Info/Micro Sciences	0601101E	BLS-01
BioComputational Systems	0601101E	BLS-01
Biodynotics ("Bioinspired and Bioderived Materials")	0602712E	MPT-09
Bio-Event Advanced Leading Indicator Recognition Technology	0602301E	ST-28
Biological Input/Output Systems ("Biological Adaptation, Assembly, and Manufacture")	0601101E	BLS-01
Biological Time-of-Flight Sensor ("Sensors")	0602383E	BW-01
Biological Warfare Defense	0602383E	BW-01
Bio-Magnetic Interfacing Concepts	0602712E	MPT-09

* Some programs described in this Fact File do not appear explicitly by name in the Descriptive Summaries, but are activities within items formally referenced in the Descriptive Summaries. In this table, the names of those programs are followed, in parenthesis, by the reference in the Descriptive Summaries, e.g., Piranha ("Undersea Littoral Warfare").

DARPA Program	PE	Project
Biomolecular Motors (“Bioinspired and Bioderived Materials”)	0602712E	MPT-09
Brain Machine Interface	0601101E	BLS-01
BWD Detection (“Sensors”)	0602383E	BW-01
Canard Rotor/Wing	0603285E	ASP-01
Chip Scale Atomic Clock	0602712E	MPT-02
Chip-Scale Gas Analyzer	0603739E	MT-12
Chip-Scale Wavelength Division Multiplexing	0603739E	MT-15
Clockless Logic, Analysis, Synthesis, and Systems	0602712E	MPT-02
Coalition Networking Experimentation (“Partners in Experimentation”)	0602301E	ST-24
Coherent Communications, Imaging and Targeting	0602702E	TT-06
Collaborative Cognition	0602301E	ST-31
Command Post of The Future	0603760E	CCC-02
Common Software for Autonomous Robotics	0602302E	AE-02
Compact Hybrid Actuators (“Smart Materials and Actuators)”	0602712E	MPT-01
Composable High Assurance Trusted Systems	0602301E	ST-24
Computer Exploitation and Human Collaboration	0601101E	CCS-02
Continuous Assisted Performance	0602383E	MPT-09
Control of Agent Based Systems	0603760E	CCC-01
Controlled Biological and Biomimetic Systems (“Sensors”)	0602383E	BW-01
Counter Camouflage, Concealment and Deception	0603762E	SGT-04
Counter-Underground Facilities	0603762E	SGT-02
Cyber Panel	0602301E	ST-24
DARPA Agent Markup Language	0602301E	ST-11
DARPA Titanium (“Structural Materials and Devices”)	0602712E	MPT-01
Data Intensive Systems	0602301E	ST-19
Deception Detection	0602301E	ST-28
Deep View	0603285E	ASP-02
Digital Control of Analog Circuits RF Front Ends	0603739E	MT-15
Digital Radio Frequency Tags	0603762E	SGT-02
Distributed Robotics	0603739E	MT-04
Dynamic Assembly for Systems Adaptability, Dependability and Assurance	0602302E	AE-03
Dynamic Coalitions	0602301E	ST-24
Dynamic Quarantine of Worms in Military Enterprise Networks (“Malicious Code Analysis”)	0602301E	ST-24
Dynamic Tactical Targeting	0603762E	SGT-04
Effective, Affordable, Reusable Speech-To-Text	0602301E	ST-29
Engineered Bio-Molecular Nano-Devices/Systems	0601101E	MS-01
Engineered Tissue Constructs (“Sensors”)	0602383E	BW-01
Evidence Extraction and Link Discovery	0602301E	ST-28

DARPA Program	PE	Project
Exoskeletons for Human Performance Augmentation (“Smart Materials and Actuators)”	0602712E	MPT-01
Exploitation Of 3-D Data	0603762E	SGT-04
Eyeball	0603762E	SGT-04
Fault Tolerant Networks	0602301E	ST-24
Foliage Penetration Reconnaissance, Surveillance, Tracking and Engagement Radar	0603762E	SGT-04
Force Application and Launch from CONUS (formerly “HyperSoar”)	0603285E	ASP-02
Friction Drag Reduction	0602702E	TT-03
Friction Stir Processing (“Structural Materials and Devices”)	0602712E	MPT-01
Functional Materials (“Functional Materials and Devices”)	0602712E	MPT-01
Future Combat Systems	0603764E	LNW-03
Future Combat Systems Command and Control (“FCS Supporting Technologies”)	0603764E	LNW-03
Genisys	0602301E	ST-28
Genisys Privacy Protection	0602301E	ST-28
Genoa II	0603760E	CCC-03
Global Autonomous Language Exploitation	0602301E	ST-29
Global Positioning Experiments	0603762E	SGT-01
Harsh Environment Robust Micromechanical Technology (“Harsh Environment Micromechanical Devices”)	0603739E	MT-12
High Efficiency Distributed Lighting	0602702E	TT-03
High Energy Liquid Laser Area Defense System	0602702E	TT-06
High Frequency Active Auroral Research Project	0603285E	ASP-02
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
Highly Integrated Millimeter Wave Electronically Scanned Array	0602712E	MPT-02
Human Threat Identification at a Distance	0602301E	ST-28
Hypersonics Flight Demonstration	0602702E	TT-03
Immune Building	0602383E	BW-01
Information Assurance and Survivability	0602301E	ST-24
Innovative Space-Based Radar Antenna Technology	0603285E	ASP-02
Integrated Sensing and Processing	0602702E	TT-06
Jigsaw	0603764E	LNW-03
Knowledge Based Systems	0602301E	ST-33
Language and Speech Exploitation of Resources Advanced Concept Technology Demonstration	0602702E	TT-06

DARPA Program	PE	Project
Littoral Naval Architecture Study ("Undersea Littoral Warfare")	0603763E	MRN-02
Loki	0603763E (FY 2003) 0603766E (FY 2004-05)	MRN-02 (FY 2003) NET-02 (FY 2004-05)
Long-Range Mine Detection ("Undersea Littoral Warfare")	0603763E	MRN-02
Low-Cost Cruise Missile Defense	0603762E	SGT-03
Malicious Code Analysis	0602301E	ST-24
MEMS Micro Power Generation	0603739E	MT-12
Mesoscopic Integrated Conformal Electronics ("Functional Materials and Devices")	0602712E	MPT-01
Metabolic Dominance ("Biochemical Materials")	0602712E	MPT-09
Metabolic Engineering for Cellular Stasis ("Biological Adaptation, Assembly, and Manufacture")	0601101E	BLS-01 & MPT-09
Metamaterials ("Functional Materials and Devices")	0602712E	MPT-01
Micro Adaptive Flow Control	0602702E	TT-07
Micro-Air Vehicle Advanced Concept Technology Demonstration	0603764E	LNW-01 (FY 2003) NET-01 (FY 2004)
Microelectronic Bioprocesses ("BioComputational Systems")	0601101E	BLS-01
Mis-Information Detection	0602301E	ST-28
Mission Specific Processing	0602702E	TT-06
Mixed Initiative Control of Automa-Teams	0602301E (FY 2003) 0602702E (FY 2004)	ST-19 (FY 2003) TT-13 (FY 2004)
Model-Based Integration of Embedded Software	0602302E	AE-01
Molecular Observation, Spectroscopy, and Imaging using Cantilevers ("Nanostructure in Biology")	0601101E	BLS-01
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
Multifunctional Materials ("Structural Materials and Devices")	0602712E	MPT-01
National/Tactical Exploitation	0603762E	SGT-04
Naval Unmanned Combat Air Vehicle	0603285E	ASP-01
NetFires	0603764E	LNW-03
Network Modeling and Simulation	0602301E	ST-31
Network-Centric Infrastructure For Command, Control and Intelligence	0602301E	ST-32
Networked Embedded Systems Technology	0602301E	ST-19

DARPA Program	PE	Project
Networking in Extreme Environments	0602702E	TT-04
Next Generation Communications ("Next Generation")	0603760E	CCC-02
Next Generation Face Recognition	0602301E	ST-28
Operational Partners in Experimentation ("Partners in Experimentation")	0602301E	ST-24
Optical Code Division Multiple Access	0603739E	MT-15
Orbital Express	0603285E	ASP-02
Organic Air Vehicle	0603764E	LNW-03
Organic Air Vehicle in the Trees	0602702E	TT-07
Organically Assured and Survivable Information Systems	0603760E	CCC-01
Organically Assured and Survivable Information Systems Demonstration/Validation	0603760E	CCC-01
Palm Power ("Materials for Logistics (Air, Water, Power)")	0602712E	MPT-01
Perception for Off-Road Robotics	0603764E	LNW-03
Perceptive Assistant that Learns	0602301E	ST-30
Persistence in Combat ("Biochemical Materials")	0602712E	MPT-09
Piezoelectric Single Crystals ("Smart Materials and Actuators)"	0602712E	MPT-01
Piranha ("Undersea Littoral Warfare")	0603763E (FY 2003) 0603766E (FY 2004)	MRN-02 (FY 2003) NET-02 (FY 2004)
Polymorphous Computing Architectures	0602712E	MPT-08
Power Aware Computing and Communications	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
Rapid Analytic Wargaming	0602301E	ST-28
Rapid Knowledge Formation	0602301E	ST-11
Rapid On-Orbit Anomaly Surveillance and Tracking	0603285E	ASP-02
Real-Time Battle Damage Assessment	0603762E	SGT-04
Real-World Learning Technology	0602301E	ST-30
Reconfigurable Aperture	0602712E	MPT-02
Reconnaissance, Surveillance and Targeting Vehicle	0603764E	LNW-01
Responsive Access, Small Cargo, Affordable Launch	0603285E	ASP-02
Robolife ("Bioinspired and Bioderived Materials")	0602712E	MPT-09
Robust Passive Sonar	0603763E	MRN-02
Satellite Protection and Warning/Space Awareness	0603285E	ASP-02
Scalable Social Network Analysis Algorithms	0602301E	ST-28
Self-Aware Peer-to-Peer Networks	0602301E	ST-31

DARPA Program	PE	Project
Self-Healing Minefield (“Antipersonnel Landmine Alternatives”)	0602702E	TT-04
Self-Regenerative Systems	0602301E	ST-32
Semiconductor Ultraviolet Optical Sources	0603739E	MT-04
Sensor Information Technology	0602302E	AE-03
Simulation of Bio-Molecular Microsystems	0601101E	BLS-01
Situational Awareness System	0603764E	LNW-02
Smart Actuators and Marine Projects Demonstration (“Undersea Littoral Warfare”)	0603763E	MRN-02
Smart Structures and Materials (“Smart Materials and Actuators)”	0602712E	MPT-01
Software Enabled Control	0602302E	AE-02
Software for Distributed Robotics (“Common Software for Autonomous Robotics”)	0602302E	AE-02
Space Surveillance Telescope	0603285E	ASP-02
Spins in Semiconductors (“Spin Dependent Materials and Devices”)	0601101E	MS-01
Standoff Precision Identification in Three Dimensions	0603762E	SGT-04
Steered Agile Laser Beams	0603739E	MT-15
Structural Amorphous Metals (“Structural Materials and Devices”)	0602712E	MPT-01
Sub-0.1 Micron Lithographies (“Advanced Lithography”)	0603739E	MT-10
Submarine Design Study (“Undersea Littoral Warfare”)	0603763E	MRN-02
Supersonic Miniature Air-Launched Interceptor	0603285E	ASP-01 (FY 2002)
Symbiotic Communications	0603760E	CCC-02
Symphony	0602301E	ST-29
Synthetic Aperture Ladar for Tactical Imaging	0603762E	SGT-04
Synthetic Approaches to Bio-Optics (“Bioinspired and Bioderived Materials”)	0602712E	MPT-09
Tactical Sensors	0603764E	LNW-02
Tactical Targeting Network Technologies	0603762E	SGT-04
Taskable Agent Software Kit	0602301E	ST-11
Technology for Efficient, Agile Mixed Signal Microsystems	0602712E	MPT-02
Technology for Frequency Agile Digitally Synthesized Transmitters	0602712E	MPT-02
Tera Hertz Operational Reachback	0603760E	CCC-02
Terrorism Information Awareness	0603760E	CCC-03
Threat Activity Recognition and Monitoring	0602301E	ST-28
Tissue Based Biosensors (“Sensors”)	0602383E	BW-01
Training Superiority	0602702E	TT-06
Translingual Information Detection, Extraction and Summarization	0602301E	ST-29

DARPA Program	PE	Project
Triangulation for Genetic Evaluation of Risks	0602383E	BW-01
Ultra High-Performance Networking	0602301E	ST-19
Ultra Wide Band Array Antenna	0603739E	MT-15
Ultralog	0602702E	TT-10
Unconventional Pathogen Countermeasures (“Unconventional Therapeutics”)	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
Visibly-Controllable Computing	0602301E	ST-32
Vortex Combustor	0603763E (FY 2003) 0603766E (FY 2004-05)	MRN-02 (FY 2003) NET-02 (FY 2004-05)
Wargaming the Asymmetric Environment	0602301E	ST-28
Water Harvesting (“Materials for Logistics (Air, Water, Power)”)	0602712E	MPT-01
Wolfpack	0603764E	LNW-02