Basic Research Plan

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This first edition of the DoD Basic Research Plan joins the suite of planning tools that we have created to integrate our corporate science and technology program. It is the product of Service and Defense Agency science program managers working together in the context of both Defense Reliance and the Defense Committee on Research.

The Basic Research Plan sets forth our basic research strategy. It describes twelve scientific disciplines which span the great majority of the scientific activity in the DoD basic research program. It formulates broad visions of what might be achieved in each of the twelve areas. These visions are broad by necessity. While scientific research is richly productive, results are unpredictable. So our visions will evolve, even abruptly change, over time.

This Plan also presents six Strategic Research Objectives. These scientific Objectives are the focus of less than 10% of all defense basic research work, but the Objectives define rapidly expanding research fronts with the potential for high military benefit, rich with scientific opportunities that crosscut multiple fields of science. Our intent is to explore these research areas in a concerted way, and to focus our investments to hasten genuinely new inventions and creations. The U.S. has military advantage over all potential adversaries today. U.S. science critically enabled that advantage.

The Basic Research Plan is a working document. As a product of corporate planning, it provides guidance to the Services and Defense Agencies so that their combined research efforts may enable our primary customer -- the warfighter -- to gain military advantage in the future.

Anita K. Jones
Director of Defense Research and Engineering

COMMENTS FROM THE DEFENSE COMMITTEE ON RESEARCH

In 1993, the Director of Defense Research and Engineering, initiated a corporate Science and Technology (S&T) planning process designed to more effectively link the products of the Defense S&T program with the needs of the warfighter. The foundation of this process is the *Defense S&T Strategy* supported by: the *Joint Warfighting S&T Plan*, the *Technology Area Plan*, and this first edition of the *Basic Research Plan*. These documents present the DoD S&T vision, strategy, plan, and objectives for the planners, programmers, and performers of Defense S&T. Revised annually, these documents are a collaborative product of the Office of the Secretary of Defense, Joint Staff, Military Services, and Defense Agencies.

The *Strategy* and *Plans* are fully responsive to the Chairman of the Joint Chiefs of Staff's *Vision* and *Joint Vision 2010* and the White House National Security S&T Council *National Security S&T Strategy*. The *Strategy* and *Plans*, and supporting individual S&T Master Plans of the Military Services and Defense Agencies, guide the annual preparation of the Defense Program and Budget.

The Basic Research Plan presents the DoD objectives and investment strategy for DoD sponsored research performed by universities, industry and government laboratories. In addition to presenting the planned investment in 12 broad research areas, this year's plan highlights 6 strategic research objectives holding great promise for the development of enabling breakthrough technologies.

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EXECUTIVE SUMMARY

The DoD Basic Research Program has long played a crucial role in the development of technology and in the education and training of scientific personnel required to support continuing technical advances critical to maintaining superior military capabilities. As the initial and fundamental step in the process of scientific discovery, Basic Research can have considerable impact on the development cycle time and the operational capability of a broad range of military systems. This Basic Research Plan (BRP) addresses these important issues by providing a strategy that is flexible with respect to current budget priorities but also properly structured to effectively respond to requirements of the warfighter. The BRP complements two other DoD Science and Technology (S&T) planning documents: the Joint Warfighting S&T Plan and the Defense Technology Area Plans (DTAPs). Together the three documents reflect a comprehensive strategic planning process designed to significantly enhance the quality of the overall S&T program.

The basic research strategy presented in this plan is derived from warfighting requirements identified by the Chairman of the Joint Chiefs of Staff as part of Joint Vision 2010. This conceptual framework is intended to provide common direction for the Services in pursuing information superiority and technological innovations capable of producing powerful new warfighting strategies. Basic Research provides a firm foundation for such advances and technological innovation, and steady progress will be maintained by following a strategy for supporting world-class research that consists of four main components:

- Execute a superior quality, competitive, multifaceted research program
- Maintain a flexible and balanced investment portfolio
- Sustain an essential research infrastructure
- Conduct visionary planning, resource constrained prioritization, and oversight

An important part of the strategy will be to provide a sharper focus for certain research activities by establishing a number of Strategic Research Objectives (SROs) in selected multidisciplinary areas considered to offer significant and comprehensive benefits to our military capabilities. Research accomplishments in some of these fertile areas have already had a significant impact on technology areas such as advanced structures and new classes of sensitive detectors. The SRO areas are part of the long-term broad and diverse DoD research and education agenda. Together, these two components will enable the Basic Research program to be flexible and focused yet also able to capitalize on technologies and synergies that take longer to mature. The SROs identified and described in this BRP include:

- **Biomimetics:** enable the development of novel synthetic materials, processes, and sensors through advanced understanding and exploitation of design principles found in nature.

- **Nanoscience:** achieve dramatic, innovative enhancements in the properties and performance of structures, materials, and devices having ultra-small but controllable features on the nanoscale (i.e., tens of angstroms) level.
- **Smart Structures:** achieve advanced capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multi-element, deformable structures used in land, sea, and aerospace vehicles and systems.
- **Broad Band Communications:** provide fundamental advances enabling the rapid and secure transmission of large quantities of multimedia information (speech, data, graphics, and video) from point to point, broadcast and multicast over distributed, heterogeneous networks linking C3I systems.
- **Intelligent Systems:** enable the development of advanced systems able to sense, analyze, learn, adapt, and function effectively in changing and/or hostile environments until completing assigned missions or functions.
- **Compact Power Sources:** achieve significant improvements in the performance (power and energy density, operating temperature, reliability and safety) of compact power sources through fundamental advances relevant to current technologies (e.g., batteries and fuel cells) and the identification and exploitation of new concepts.

The BRP includes a comprehensive and detailed presentation of ongoing research activities and plans, funding levels, and specific research objectives for each of the 12 technical disciplinary areas comprising the Basic Research Program. Special aspects of the program such as the University Research Initiative are also reviewed. The BRP concludes with a description of selected basic research successes funded by the Air Force Office of Scientific Research (AFOSR), the Office of Naval Research (ONR), the Army Research Office (ARO), the Ballistic Missile Defense Organization (BMDO) and the Defense Advanced Research Projects Agency (DARPA). These examples underscore the continuing importance of Basic Research Program contributions to meeting both current and future US defense needs.

1.0 INTRODUCTION

Over the last few years, the Director of Defense Research and Engineering (DDR&E) has guided the continuing evolution of a corporate Science and Technology (S&T) strategic planning process designed to enhance the quality of the S&T program and more effectively link the products of the program with the needs of the warfighter. This process addresses the Joint Chiefs of Staff (JCS) Vision 2010 with a sound Department of Defense (DoD) S&T strategy linked to specific technology objectives via “technology roadmaps.” When Defense Basic Research is integrated into this overall planning process, the relevance of research becomes more explicit than ever before.

This Basic Research Plan (BRP) is the third element of the DoD S&T program planning triad, the other two elements being the Joint Warfighting S&T Plan and the Defense Technology Area Plans (DTAPs). This natural linkage highlights the fact that Basic Research is the cornerstone of the DoD S&T investment. Together, the three documents describe a comprehensive strategy and plan for the overall S&T program.

Basic Research has its own unique characteristics, however, and no strategy can accurately capture the synergistic and unpredictable nature of innovation and discovery. By their nature, the end products of Basic Research are sometimes difficult to predict and often result in applications not originally envisioned. We can only provide broad and constant support to allow this complex and serendipitous process to occur, wherein seemingly unimportant elements often provide significant benefits over the long term. For example, packet switching research funded by the Defense Advanced Research Projects Agency (DARPA) more than twenty years ago led to the evolution of the Internet. Likewise, molecular spectroscopy research conducted as part of the Joint Services Electronic Program led to the development of the laser; various types of lasers are currently used in range-finders, airborne mine sweepers, communications systems, and other military equipment. Yet research in lasers continues today because there are still important breakthroughs to be made. The products of basic research can also feed directly into existing military systems. Research on low-cost, high-strength steels funded by the Office of Naval Research (ONR), for example, enabled the production of lower-cost hulls for surface ships.

Consequently, the Defense Basic Research Program must initiate and sustain both *evolutionary* research responsive to recognized needs of current military systems, as well as *revolutionary* research not specifically focused on current military applications but capable of providing exciting new opportunities for meeting our future defense requirements. The Basic Research strategy must strive to maintain and strengthen in-house laboratory research capabilities as a foundation for subsequent applied research and systems development activities. It must encourage collaborative efforts and partnerships among DoD laboratories, universities, and industry. It must further leverage and enhance our national research assets by exploiting knowledge from the international scientific community The strategy must also contribute to ensuring the continuing availability of competent young scientists and engineers, as well as quality research facilities, to the Defense research community through significant and unwavering support of university-centered research. Over the last few decades, such support has enabled many of this nation's scientific and engineering leaders to earn graduate degrees.

An effective research strategy must remain responsive not only to historical threats but also to new threats and challenges brought on by shrinking defense budgets and global influences. Now, more than ever, our Basic Research investments must be aimed at securing warfighting capabilities most needed by our military in the future, as identified in the JCS Vision 2010. Meeting recognized needs and achieving critical new capabilities requires leveraging technological advances and information superiority with the traditional operational concepts of maneuver, strike, protection, and logistics. Consequently, powerful and new operational concepts emerge:

- **Dominant Maneuver**: The multi-dimensional application of information and maneuver capabilities to provide coherent operations involving land, sea, air, and space forces throughout the breadth, depth, and height of the battlespace, thereby enabling our forces to seize the initiative, control the tempo of the operation, and achieve a decisive conclusion.

- **Precision Engagement:** The capability to accurately locate the enemy, effectively command and control our forces, precisely attack key enemy forces or capabilities, and accurately assess the level of success.

- **Full-Dimensional Protection:** The ability to protect our forces at all levels and obtain freedom of action while they deploy, maneuver, and engage an adversary.

- **Focused Logistics:** The capability to respond rapidly to crises, shift warfighting assets between geographic routes, monitor critical resources enroute, and directly deliver tailored logistics at the level required by operations.

Our potential adversaries are continuing to reap the benefits of a worldwide proliferation of high-technology weapons and systems. Unless DoD can sustain a stable investment in research, the superior technological prowess our warfighting units currently possess will eventually erode. The current Defense Planning Guidance calls for this investment to remain steady, growing only with inflation, for the foreseeable future. This Basic Research Plan presents a wide-ranging strategy for making wise investment choices in implementing and maintaining all aspects of the Basic Research Program. Its effective execution will help to ensure that the current technological superiority of our warfighters can be maintained well into the future.

2.0 DEFENSE RESEARCH STRATEGY

The primary objective of the Defense Basic Research Strategy is to provide the means for conducting world-class research that enables new technologies and capabilities to be developed and used by the warfighter in order to maintain a technologically superior military force. Defense-sponsored research creates future technology opportunities. To achieve this objective, a strategy has been devised consisting of the following four components:

- Execute a superior quality, competitive, multifaceted research program
- Maintain a flexible and balanced investment portfolio
- Sustain essential research infrastructure
- Conduct visionary planning, resource-constrained prioritization, and oversight

2.1 Major Strategy Components

2.1.1 Execute a Superior Quality, Competitive, Multifaceted Research Program

DoD recognizes that universities, in-house DoD laboratories, and industry are all vitally important to the Basic Research Program. University centers, Federated laboratories, consortia, the academic single investigator, and industrial research are all modes of conducting research that are addressed by this strategy. DoD will invest broadly across a wide range of technical disciplines and achieve scientific and technological advances by supporting those research performers who do it best. Where appropriate, specific programs will bring various types of performers together to achieve specific technical or functional goals. DoD laboratories operated by the military departments will be both performers and purchasers of research and technology. Investments will be made in these facilities for the performance of research that would not get performed elsewhere. Figure 2.1 illustrates how DoD has invested its basic research dollars across various types of performers.

This component of the basic research strategy will employ competition as an important tool in achieving quality research. When seeking new ideas, DoD will use the Broad Agency Announcement process, electronic media, and other mechanisms to reach the largest possible segment of the scientific research community. Awards will be made using competitive procedures. As appropriate, DoD in-house research activities will be subjected to peer review and selected on a competitive basis.

Over 58 percent of all DoD basic research funding is spent at universities. Universities are key performers of research for DoD. Over the past 15 years, science and engineering research at universities has expanded to fill many gaps left by the reduction in basic research performed by industry. Universities have become partners with industry in providing the innovation for military technology in such areas as lasers, electronics, computing, and materials. Science magazine reports that over 35 percent of all patents issued to industry are the result of collaboration with universities, and the percentage is growing.

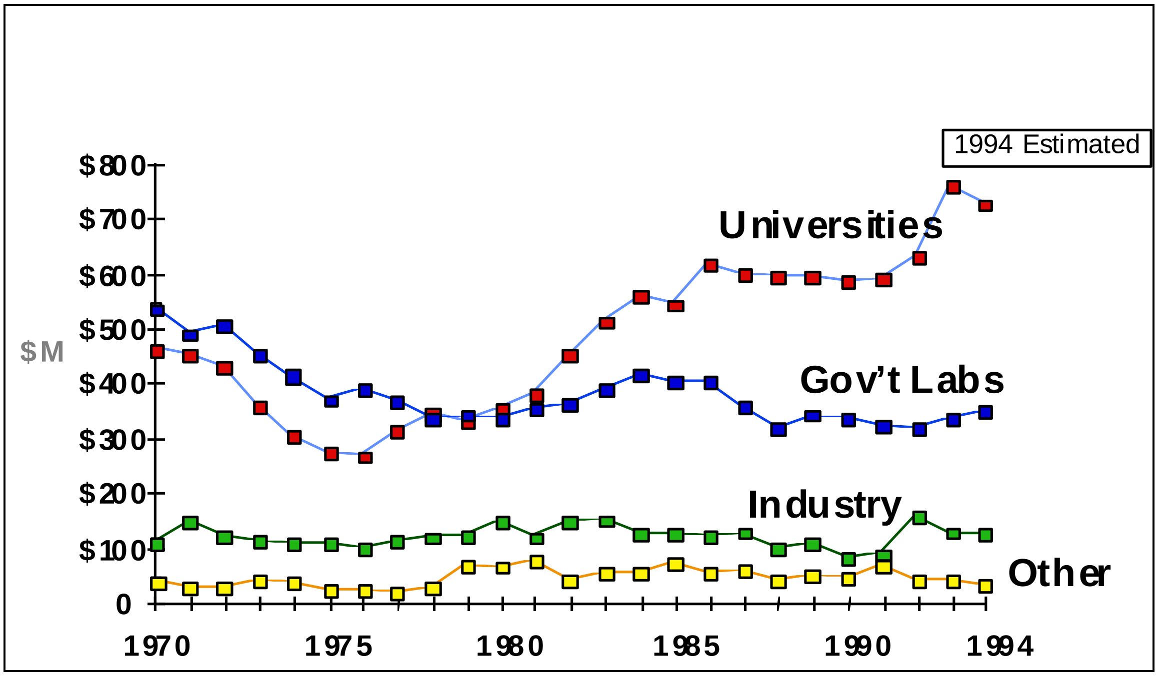


Figure 2.1. Basic Research Funding (FY 1994 Constant $)

DoD in-house laboratories provide the technical expertise to enable the military Services to be smart buyers and users. The DoD laboratories perform a number of critical functions: (1) identifying the connections between warfighters' needs and technological opportunity; (2) responding with high-quality research solutions to warfighters' needs in areas where no external performer can reliably assist; and (3) providing continuity and direct support to acquisition commands – Program Executive Officers and program managers – through technical expertise, contract management, work force training, and staff support. For example, the Army emphasizes information technologies (mathematics, computer science, electronics) for digitizing the battlefield, materials science for armor and soldier protection, optical sciences for target recognition, and chemistry and biological sciences for chemical and biological agent defense. The Navy has a full-spectrum program that places special emphasis on a wide range of ocean sciences activities, including the prediction of weather and currents, mapping the ocean floor, acoustics for detection of objects in the ocean, and biotechnology; this latter area includes work focused on both understanding and mimicking mammal communications. Air Force expertise is concentrated in the aerospace sciences, materials, physics, electronics, chemistry, life sciences, mathematics, and geosciences for application to air vehicles and space systems. Besides directly supporting their military departments, DoD laboratories act as agents for DARPA, the Ballistic Missile Defense Organization (BMDO), and other Defense Agencies with research and technology development functions.

Finally, the DoD basic research strategy will leverage industrial and international research efforts through cooperative and joint programs. DoD will continue to offer guidance and review industry Independent Research & Development (IR&D) programs that offer potential military application.

2.1.2 Maintain a Flexible and Balanced Investment Portfolio

DoD will continue its long-term research investment in core scientific disciplines. Concurrently, investments will be made in technical areas pertinent to identified Strategic Research Objectives (discussed in Section 3) or high profile scientific areas of strong military relevance that are focused and that exploit research advances in multiple core disciplines. Figure 2.2 shows the distribution of overall Federal funding for 6.1 Basic Research. Although the figure indicates that DoD provides only about 10% of all Federal basic research funding, it is important to realize that DoD dominates federal funding of R&D at universities in a number of critical fields, including computer sciences, electronics, optics, materials, aerospace engineering, and oceanography. Historically, DoD spends its research dollars supporting the scientific and engineering disciplines that can most significantly impact future warfighting capabilities. In particular, DoD funds about 33% of the total federal investment in engineering basic research. When 6.1 Basic Research and 6.2 Exploratory Development funding levels for FY94 are combined, the specific levels of DoD investments in critical fields as a percentage of total Federal research are typically much higher, as indicated in Table 2.1.

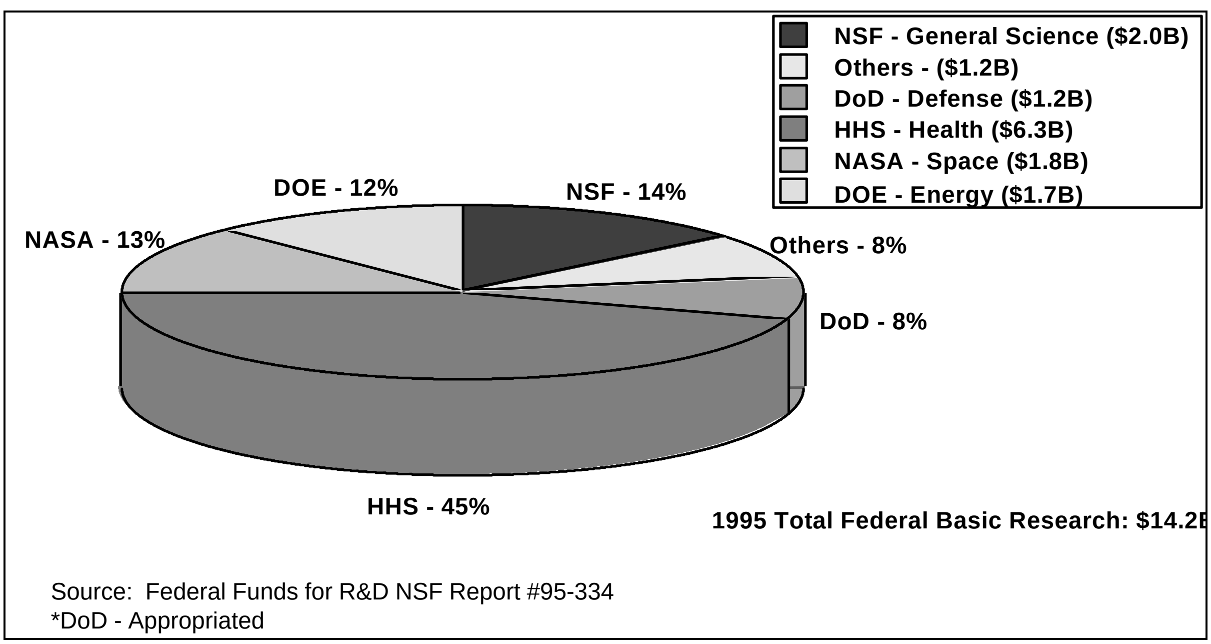


Figure 2.2. 1995 Federal Basic Research Funding (6.1 Category)

Table 2.1. DoD Support for Basic and Applied Research (FY94)

Critical Fields	Percentages
Electrical engineering	75
Metallurgy & materials	62
Mechanical engineering	59
Computer science	56
Civil engineering	45
All engineering	37
Psychology	37
Mathematics	28
DoD Investment as a Percentage of all Federal Funding	**16**

Source NSF Division of Science Resources Studies

DoD basic research will focus on a variety of military problems: some requiring near-term or immediate and/or partial solutions, and others requiring sustained investment over longer periods of time to attain success. Long-term research in a dozen scientific disciplines will address enduring military requirements such as improved information systems, sensors, advanced electronics, and materials.

The DoD Basic Research Program will achieve depth in critical areas with obvious military potential, yet maintain breadth by leveraging research in other Federal agencies and research entities and the international scientific and engineering community. DoD will encourage innovation by maintaining flexibility to invest in promising areas of research that do not easily fit into established programs. Care will be taken to assess non-military applications and, where appropriate, ensure that accomplishments are transitioned into the civilian sector.

2.1.3 Sustain Essential Research Infrastructure

Students, modern equipment, and facilities are necessary ingredients for future DoD research. The Basic Research Program will provide for the education and involvement of graduate students and young investigators through a variety of policies and programs designed to create new generations of scientists and engineers. In addition, DoD will maintain continuing education programs for its own technically trained employees, who comprise almost half the number of scientists and engineers employed by the Federal government. Figure 2.3 illustrates the strength of the DoD commitment to support graduate students in science and engineering.

Special equipment programs will link purchases of modern research tools to programs. In some cases, unique and essential facilities may be upgraded or created. Like other elements of the DoD infrastructure, the laboratories are participating in the processes of reinvention and acquisition reform. The laboratory work force is being reduced, the facilities infrastructure is being reorganized, and opportunities for consolidation and cross-Service integration are being examined. Accompanying this reduction in size are new personnel demonstration systems designed to reinvigorate in-house quality and new organizational structures and acquisition procedures that stress interaction and partnership with extramural performers.

DoD recognizes the importance of Historically Black College and University / Minority Institution (HBCU/MI) programs for the future of basic research and will strive to provide opportunities to minority groups through programs that build infrastructure and through ties to core research efforts. In the past, these programs have provided approximately $60M/year to fund individual researchers, research consortia, instrumentation purchases, and the creation of aerospace science and technology centers at eligible institutions.

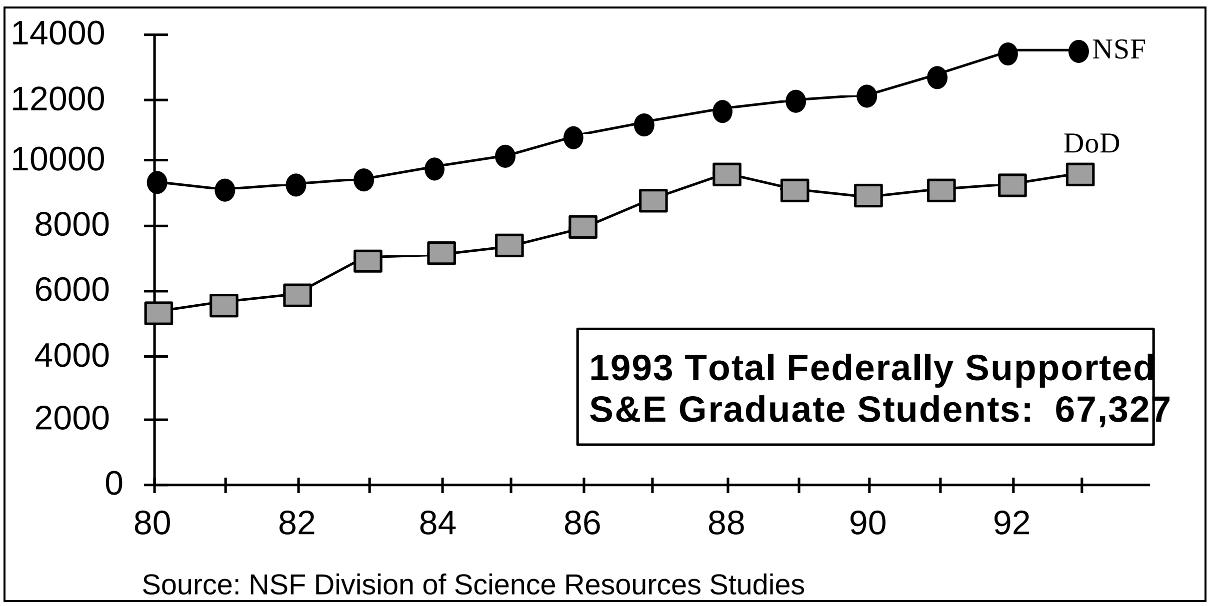


Figure 2.3. Supported Science and Engineering Graduate Students (1980 - 1993)

2.1.4 Conduct Visionary Planning, Resource-Constrained Prioritization, and Oversight

DoD will plan its research through a blend of top-down guidance and bottom-up innovation. The BRP will be linked to the National Security S&T Strategy, the JCS Vision 2010, the Joint Warfighting S&T Plan, the DoD S&T Strategy, and the Defense Technology Area Plans. This relationship is shown in Figure 2.4. Together, these documents will provide a basis for consistent planning across all facets of the S&T Program. The Basic Research program will be reviewed each year by ODDR&E through the Technology Area

Review and Assessment (TARA) process to provide guidance for POM submission and priorities for major program elements. This review focuses on research quality and relevance to military requirements using the BRP as the 6.1 analog to the Defense Technology Area Plans (DTAPs) and an important source document for the TARA process. Quality and relevance will be assured through periodic reviews of all research efforts by expert panels of representatives from other Services and government agencies, industry, and academia. The BRP is guided by input from the Defense Science and Technology Strategy and the DDR&E S&T Annual Guidance Letter, as well as by feedback from the TARA review. Figure 2.5 depicts the annual review and analysis cycle for the S&T program.

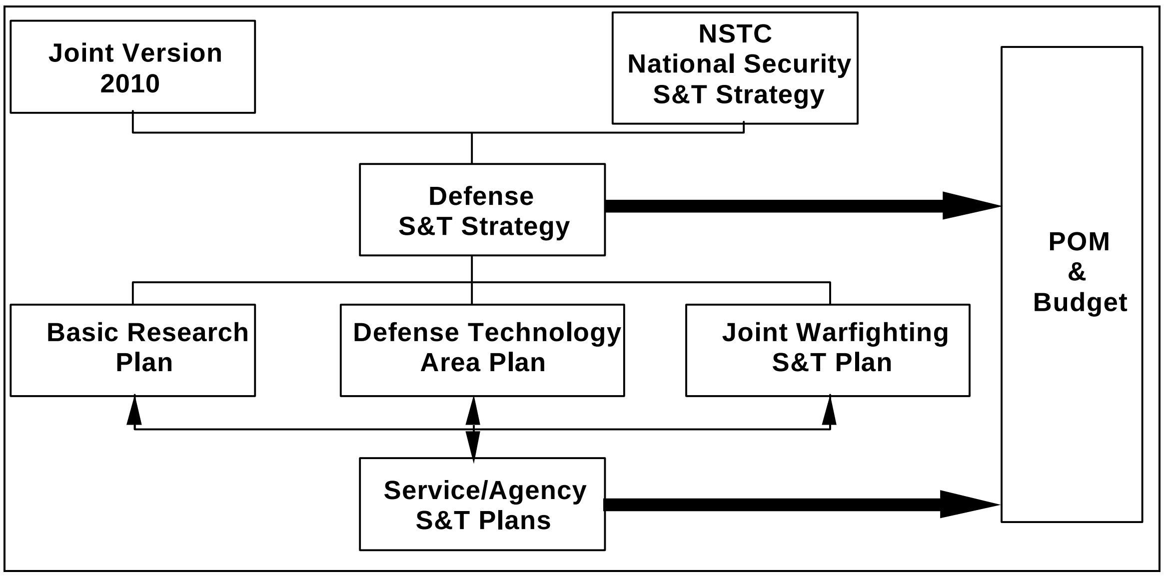


Figure 2.4. DoD Science and Technology Strategy Planning Process

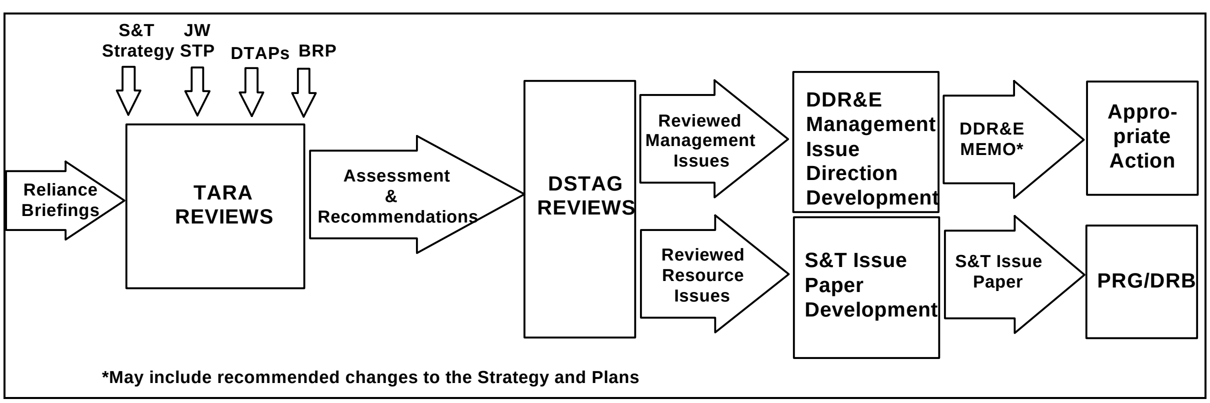


Figure 2.5. TARA Process in Context

The BRP is developed, coordinated, and implemented by the Military Services and Defense Agencies through a group called the Defense Committee on Research (DCOR). The Services are responsible for training and equipping the military forces; they rely on the S&T

program to provide warfighting and system options for their components. The Defense Agencies are responsible for certain multi-Service aspects of S&T, as well as for designated programs that support national security objectives. Members of the DCOR are:

- Director for Research, ODDR&E, leader
- Director, Army Research and Laboratory Management
- Director, Army Research Office (ARO)
- Director, Air Force Office of Scientific Research (AFOSR)
- Deputy Director for Research; Office of Naval Research (ONR)
- Director, Science and Technology, BMDO
- Director, Defense Sciences Office, DARPA

The annual basic research review cycle starts with project-level reviews at the individual research agencies (ARO, ONR, AFOSR). These sessions are followed by a program-level review of the combined research agencies and the generation of the Basic Research Annual Report. Budget projections for the next year are then prepared and submitted. The performance of the Basic Research Program with respect to inter-Defense Agency coordination and guidance from the S&T Plan is evaluated by the DDR&E, with feedback to the agencies after the annual program review. The Services and Defense Agencies also conduct their own periodic program reviews to assess quality, relevance, and scientific progress.

A significant aspect of the DoD basic research strategy involves the role of Reliance. In 1995, the DDR&E adopted the goals and structure of the S&T Reliance initiative, and the Deputy Director, Defense Research & Engineering (DDDR&E) assumed the chair of the Defense S&T Reliance Executive Committee (EXCOM). The new DDR&E-led S&T strategy and planning process focuses on assuring the transition of technology to address warfighting needs, strengthening the commercial-military industrial base, promoting basic research, and assuring quality throughout the entire DoD S&T Community.

Defense S&T Reliance is a set of agreements among and implemented by the military departments for joint planning, collocated in-house work, or lead-Service assignment that cover the majority of non-Service-unique portions of the Service 6.1 (Basic Research), 6.2 (Exploratory Development), and 6.3 (Advanced Development) S&T programs. Basic Research, functioning as a separate area, is organizationally comprised of 12 research disciplines. Each of these disciplines is discussed in Section 4 of this plan, and each area has been examined closely by its participants to establish areas of common interest. Through such joint planning and coordination of programs, undesired duplications of individual Service efforts are prevented.

2.2 Management of Basic Research and Funding Levels

Defense basic research is managed and coordinated through 10 Scientific Planning Groups (SPGs) that include representatives from the three Services, DARPA, and BMDO. The SPGs cover all 12 of the technical disciplines comprising the Basic Research Program and are specifically defined for physics, chemistry, mathematics and computer science, electronics, materials science, mechanics, ocean and terrestrial sciences, atmospheric and space sciences, biological sciences, and cognitive and neural science. The SPGs assure the coordination of basic research among the Services and Defense Agencies. The SPGs also coordinate with managers of the Technology Area Plans in order to ensure the transition of basic research into applied research. For FY95, funding for the 12 research disciplines managed and coordinated through the SPGs, excluding University Research Initiative efforts, was:

	($ Millions)
Physics	74.4
Chemistry	63.9
Mathematics	49.9
Computer Sciences	51.8
Electronics	127.1
Materials Science	92.7
Mechanics	90.4
Terrestrial Sciences	25.4
Ocean Sciences	92.0
Atmospheric & Space Sciences	40.1
Biological Sciences	88.8
Cognitive and Neural Science	32.9
Total	**829.4**

2.3 Relationship to 6.2 and 6.3 Programs

The Basic Research Program is funded under the 6.1 Budget Activity of DoD. The program serves as a strong foundation for the acquisition process by providing significant innovation and technological opportunities for subsequent use in 6.2 (Exploratory Development) and 6.3 (Advanced Development) programs. The scientific objectives of the Basic Disciplines and the Strategic Research Objectives support multiple Defense Technology Objectives in the Defense Technology Area Plans and the Joint Warfighting S&T Plan. Researchers and research program managers encourage the military and technical development community to facilitate transition of the more mature research results, including preliminary assessment and evaluation, and the development of requirements. The output of Basic Research usually impacts multiple technology objectives and potential military applications. This broad applicability is focused on the most promising avenues by collaboration between the research managers and the planners of 6.2 and 6.3 programs. In rare instances, results of basic research can even impact 6.4 (Engineering Development) programs and fielded systems.

2.4 Basic Research Programs

The Basic Research Program is primarily composed of three main elements: Defense Research Sciences (DRS), In-house Laboratory Independent Research (ILIR), and the University Research Initiative (URI). Funding profiles for the total DoD Basic Research Program broken out by the major program components, as well as by Service and Defense Agency, are shown in Table 2.2.

2.4.1 Defense Research Sciences

Collectively, the DRS programs of the services, DARPA, and the Office of the Secretary of Defense comprise the largest component of the Basic Research program, about 70% of total 6.1 funding. They also represent the largest source of DoD research funding for universities, with the research primarily carried out by traditional single-investigator efforts. DRS programs also support research efforts performed by industry, government laboratories, non-profit organizations, state and local governments, and Federally Funded Research and Development Centers (FFRDCs).

2.4.2 In-House Laboratory Independent Research

The primary goals of the ILIR program are to conduct quality basic research in support of laboratory missions and to provide a research environment conducive to the recruitment and retention of outstanding scientists and engineers. Capitalizing on special facilities and capabilities, the ILIR program typically conducts militarily relevant research that would not or could not be performed elsewhere. ILIR also provides high-level visibility to researchers achieving significant accomplishments.

2.4.3 University Research Initiative

The URI is a collection of special research programs performed by academic institutions. Its main thrust is multidisciplinary research. URI activities help to improve the quality of defense research carried out by universities and support the education of young scientists and engineers in disciplines critical to national defense needs. Specific aspects of the program are described below:

The <u>Multidisciplinary University Research Initiative</u> (MURI) supports teams of researchers investigating selected topics that intersect more than one traditional technical discipline. This multidisciplinary-team approach complements the single-investigator university research funded by the Service and Defense Agency DRS programs. For many complex problems, the multidisciplinary approach provides an effective means for accelerating research progress and transitioning the results to military applications. Total

URI funding for multidisciplinary research is $117M in FY96, including $13M for new starts of interest to two or more Services.

The Defense University Research Instrumentation Program (DURIP) enables university researchers to purchase major research equipment (i.e., equipment costing $50K or more) that cannot be acquired with resources typical amounts of single-investigator awards. By providing support for major instruments that are critical to sustaining universities' long-term capabilities to perform cutting-edge research, DURIP complements investments made by Service and Defense Agency DRS programs in more modest research instruments. DURIP provided $30M for major research instrumentation in FY96.

The Augmentation Awards for Science and Engineering Research Training (AASERT) program increases the number of high-quality science and engineering graduate students that receive support through defense research for their degree-related research training. It also provides support for involving undergraduate students in defense research to stimulate their interest in advanced science or engineering studies. AASERT awards augment Service and Defense Agency DRS awards, building on the research infrastructure established by those programs, by supporting additional graduate students on research projects important to maintaining the vitality of the national science and engineering talent pool in defense-critical fields. In FY96, AASERT is supporting about 1500 graduate and 300 undergraduate students.

National Defense Science and Engineering Graduate Fellowships are awarded for study and research leading to doctoral degrees in mathematical, physical, biological, ocean, and engineering sciences. These fellowships provide special recognition for some of the best and the brightest students in science and engineering, encouraging them to continue their academic studies and complete the research training needed to earn advanced degrees. These fellowships thus complement the incentives provided through research assistantships and traineeships. Approximately 300 fellows are being supported this year.

The University Research Infrastructure Support Program (URISP), in accordance with goals set by Congress to broaden the base of academic institutions participating in defense research, provided approximately $3M in FY95 to institutions, that had not traditionally received much DoD funding. URISP builds infrastructure at those institutions through awards for research, equipment, and student assistance.

2.4.4 Other Programs

Historically Black College and University/Minority Institution (HBCU/MI) programs have previously provided approximately $60M/year to fund individual researchers, research consortia, instrumentation purchases, and the creation of aerospace science and technology centers at eligible institutions.

The Focused Research Initiative (FRI) is a DoD program (funded at $9M in FY96) to support teams from academia, industry, and (when appropriate) Federal laboratories involved in collaborative research leading to more rapid transition from research to applications of defense-critical and dual-use technologies. Current topics are:

- Virtual Environments for Training
- Cryoelectronics
- Wireless, Distributed Multimedia Communications Networks for the Digital Battlefield
- Photonics for Data Fusion Networks
- Low Emissions, High Performance Gas Turbine Engines

Table 2.2. DoD Basic Research Funding

DoD Basic Research
(Then Year $ Millions)

		FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001
Services							
Army							
61101A	In-house Laboratory Independent Research	14	15	16	17	18	19
61102A	Defense Research Sciences	125	142	147	153	162	167
61104A	Univ & Industry Research Centers	47	47	52	54	57	60
	Total Army 6.1	**186**	**204**	**215**	**224**	**236**	**246**
Navy							
61152N	In-house Laboratory Independent Research	15	15	17	17	17	18
61153N	Defense Research Sciences	362	372	386	411	432	452
	Total Navy 6.1	**377**	**387**	**403**	**428**	**449**	**470**
Air Force							
61102F	Defense Research Sciences	**224**	**234**	**240**	**245**	**249**	**254**
TOTAL SERVICES		**787**	**825**	**858**	**897**	**934**	**970**

Defense Agencies							
Chem & Bio Defense Program							
61138B	Chem and Bio Defense Programs	**27**	**29**	**26**	**27**	**28**	**29**
Office of Secretary of Defense							
61101D	In-house Laboratory Independent Research	3	2	1	1	0	0
61103D	University Research Initiatives	222	209	237	247	255	262
61110D	Focused Research Initiatives	9	16	21	22	22	23
	Total OSD 6.1	234	227	259	270	277	285
Advanced Research Projects Agency							
61101E	Defense Research Sciences	78	75	75	76	78	77
TOTAL DEFENSE AGENCIES		**339**	**331**	**360**	**373**	**383**	**391**
TOTAL DoD		**1,126**	**1,156**	**1,218**	**1,270**	**1,317**	**1,361**

3.0 STRATEGIC RESEARCH OBJECTIVES

The DoD Basic Research Program supports a broad range of diverse activities spanning numerous scientific disciplines. The results of these extensive fundamental research efforts help to provide a sound technical foundation for meeting both recognized current U.S. defense requirements and projected – but less-well-defined – future needs. To provide a sharper focus for certain research activities in areas considered to offer significant and comprehensive benefits to our national peacekeeping and warfighting capabilities, a number of strategic research objectives have recently been established. Most of these objectives reflect the high-payoff potential of newer but maturing research fields recognized through the continual basic research review process. Others reflect the continuing importance of more established areas to achieving critical new capabilities for many types of military missions. These strategic research objectives – and the associated research areas – include the following:

Biomimetics: *enable the development of novel synthetic materials, processes, and sensors through advanced understanding and exploitation of design principles found in nature.*

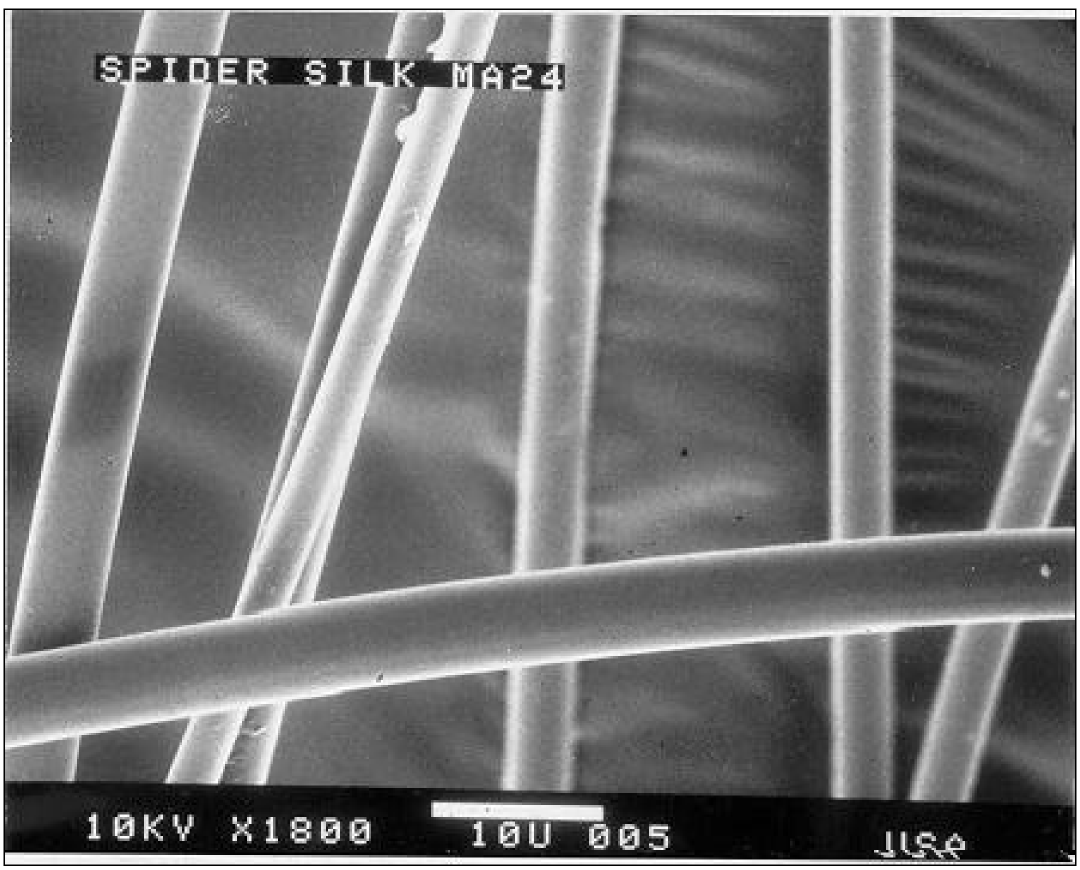


Figure 3.1. Genetically Engineered High-Strength Silk Fibers. Spider silk fibers, which are about 5 microns in diameter, are 100% tougher than Kevlar aramid fibers. Spider silks have

recently been genetically engineered for production using bacteria. Analytical-scale fiber spinning evaluations are ongoing.

Materials and structures of intricate complexity, and which exhibit remarkable properties, are found throughout the biological world. A unique feature of many biological systems is that their functionality derives from fabrication processes comprised of several levels of self-assembly involving molecular clusters organized into structures of different length scales. The result is an optimized architecture tailored for specific applications through molecular, nanoscale, microscale, and macroscale levels that is unobtainable through conventional, equilibrium-based, synthetic fabrication methods. The integration of the principles of biotechnology with materials science and engineering to create a new field called biomimetics establishes a conceptual approach for unraveling many of nature's secrets and exploiting them for a wide range of military applications. Biological system characteristics of interest include infrared signature visualization, exquisite sensing capabilities like sniffing and tasting that allow rapid and selective detection of only a few molecules of certain chemical species, echolocation that can detect and classify objects in noisy and cluttered environments, heightened agility and control capabilities in stressing environments, and protection of animals by shells and horns. Examples of possible products of biomimetics research include adhesives for emergency repairs and special operations, advanced sensors for detecting mines and biological/chemical warfare agents, and composite lightweight armor materials that integrate very hard and softer components to optimize strength and toughness. Advances in the field of biomimetics are also likely to contribute to accelerated production of designer vaccines and pharmaceuticals, novel gene therapies, and new detectors for environmental monitoring.

Nanoscience: *achieve dramatic, innovative enhancements in the properties and performance of structures, materials, and devices that have ultra-small – but controllable – features on the nanoscale (i.e., tens of angstroms).*

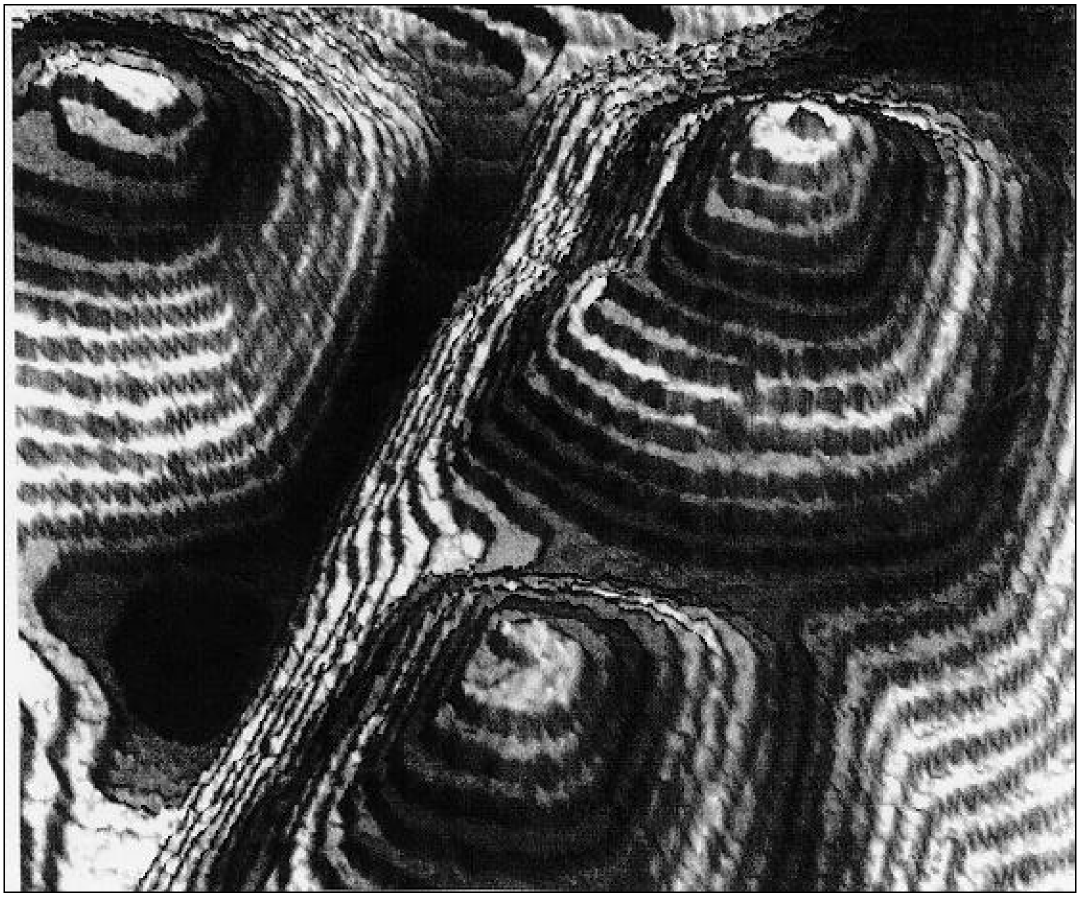


Figure 3.2. Spiral Growth of GaSb Film on GaAs at Nanoscale. A scanning tunneling microscope (STM) image of spiral dislocations spontaneously formed on a 4-micron thick film of GaSb grown on GaAs by molecular beam epitaxy. The image, with a field of view of ~1 micron x 1 micron, was acquired in-situ following growth of the film. Atomic-scale control of surfaces and interfaces requires the combination of advanced materials growth techniques with in-situ characterization. The ability to determine and control structures at the nanometer atomic scale will revolutionize next-generation electronic and optoelectronic devices, bringing new capabilities to DoD sensors and signal processing systems.

The ability to fabricate structures at the nanoscale will enable new approaches and processes for manufacturing novel, more reliable, lower cost, and more flexible electronic and mechanical devices for numerous military and commercial applications. Such devices will exhibit exceptional properties not predicted by macroscopic scientific principles. DoD-supported nanoscience research is focused on creating new theoretical and experimental results involving atomic-scale imaging methods, sub-angstrom measurement techniques, and fabrication methods with atomic control that will provide reproducible materials and features. It also includes investigations of phenomena dominated by size effects (i.e., quantum and interface effects). Scientific opportunities include understanding new phenomena in low-dimensional structures, nucleation and growth, site-specific reactions, elastic/plastic deformation, nanostructural materials, solid-fluid interfaces, and supramolecular materials. Recognized military applications of nanoscience include ultra-small and fast computers with terabit non-volatile memory and teraflop speed, personal environmental monitoring and control, miniature personal communications devices, high-density information storage devices, microfabricated sensors for chemical and biological agent detection, catalysts for enhancing and controlling energetic reactions, synthesis of new compounds (e.g., narrow band-gap materials and non-linear optic materials) for advanced electronic and optical sensors, and ultra-sensitive magnetic field sensors.

Smart Structures: *achieve advanced capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multi-element, deformable structures used in land, sea, and aerospace vehicles and systems.*

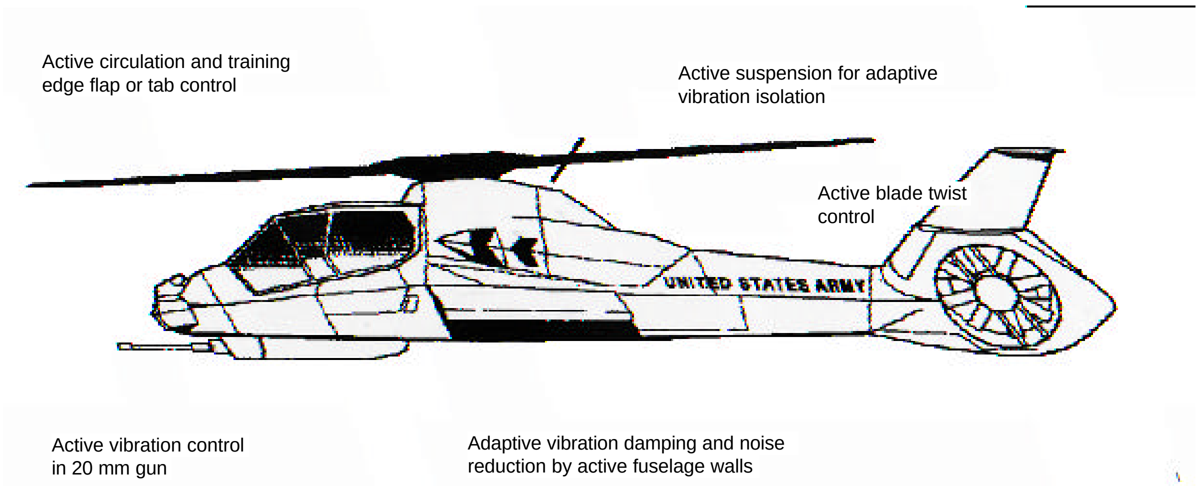


Figure 3.3. Programmable Control of Dynamic Loads on Rotocraft. Smart structures research will provide many important military payoffs, including programmable control of dynamic loads on Army and Navy helicopters. Effective application of research results in fielded systems will help to reduce vibration levels and acoustic signatures, increase the maximum lift/drag ratio, extend rotor blade fatigue life, and lower maintenance costs.

Such “smart structures” offer significant potential for expanding the effective operations envelope and improving certain critical operational characteristics for many DoD systems. Key features of smart structures include integral or bonded sensors and actuators linked to a controller responsive to external stimuli to compensate for undesirable effects or to enhance overall system performance. To help realize the full potential of smart structures in military systems, the DoD basic research program is supporting fundamental investigations that address active/passive structural damping techniques, advanced actuator concepts able to provide greater forces and displacements, embeddable and non-intrusive sensors, and smart actuator materials (e.g., electrostatic and piezoelectric materials, shape memory alloys, and magnetorheological fluids). Important studies focused on new fabrication processes for actuators and sensors on the micron to millimeter scale, computationally accurate and efficient constitutive models for smart materials, advanced mathematical models for non-conservative and non-linear structural and actuator response, robust hierarchical control with distributed sensors and actuators, and concurrent, integrated structural design and control methodologies are also being pursued. Specific potential military applications of smart structures include: shock isolation and machinery vibration and radiated noise control in submarines and surface ships; noise suppression, shape and flow control in submarine propulsors to reduce signature, improve maneuvering control, and eliminate cavitation; vibration control and stability augmentation systems in fixed- and rotary-wing aircraft; vibration control and precision metrology of surviellance spacecraft systems; barrier structures providing improved protection against chemical and biological agents; structural damage detection and mitigation systems; more accurate rapid-fire weapon systems; fire-control and battle damage identification, assessment and control on surface ships; control of conformal antennas, phased arrays, and broad band spiral antenna systems; and smart skins for high-performance combat aircraft.

Broad Band Communications: *provide fundamental advances enabling the rapid and secure transmission of large quantities of multimedia information (speech, data, graphics, and video) from point to point, broadcast and multicast over distributed, heterogeneous networks linking C3I systems.*

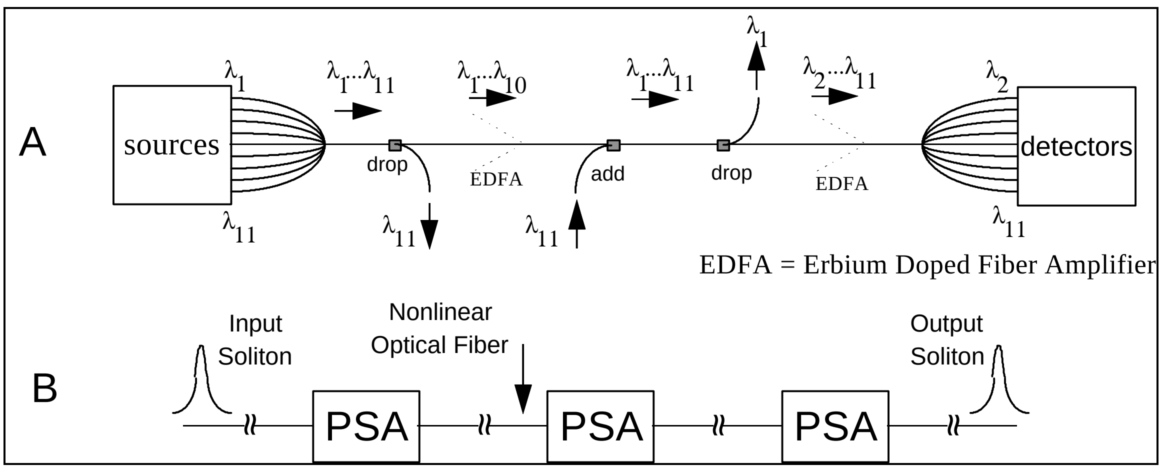


Figure 3.4. Multi-Wavelength Optical Networks. The ability to reliably transmit voice, video, and data at ultra-high rates (terabits/sec) is critical to many military missions, including command and control (C2), surveillance, fire control, and identification friend or foe (IFF). Over short-to-moderate distances (A), optical networks will be effective, but improved performance requires basic research advances in optoelectronics components for routing, modulating, and amplifying signals. At longer distances (B), point-to-point communications will rely on soliton propagation and novel components such as phase-sensitive amplifiers (PSA); research involving linear and non-linear propagation phenomena and PSA design will help to improve the performance of these systems. For both types of optical networks, basic research progress will reduce photon-electron conversion stages and dramatically increase information-handling capability.

Research in this area provides the technology for establishing and maintaining effective network communications on the move under the harsh and highly dynamic conditions expected on modern battlefields. Civil networks have a fixed structural component not possible in mobile military systems, and the military channel is more arrival of messages is highly critical in military networks, which can have no single points of failure and must be self-organizing to be survivable. Research in photonic and wireless communications is needed to dramatically improve the throughput, reliability, and security of complex communications systems critical to the viability and success of many military operations. New laser materials, non-linear materials and devices, and advances in systems engineering are producing more powerful optical modulators with greater bandwidth to fully utilize the transmission capacity (~2 terahertz) of current optical fibers. Tunable optical sources and integrated diffractive optics provide methods for multiple access and parallel bit streams on optical fibers using wavelength division multiplexing. For wireless communications, research on devices, sources, waveguides, and techniques such as quasi-optical combining is increasing operating frequency beyond 20 gigahertz for wider channels. Research on smart antenna beamsteering with optical control and new methods of source, channel, and modulation coding enables increased capacity over limited-bandwidth wireless channels with lower power. Protocol engineering research provides the technology to integrate photonic and wireless communications and to maintain connectivity, routing, and quality of service for multimedia communications in highly dynamic networks. Advances in broad band communications will significantly increase the capacity of the Defense Information Infrastructure.

Intelligent Systems: *enable the development of advanced systems able to sense, analyze, learn, adapt, and function effectively in changing and/or hostile environments until completing assigned missions or functions.*

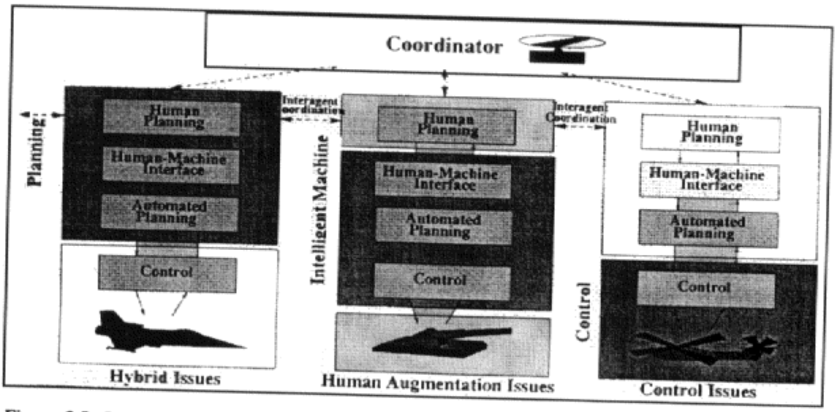


Figure 3.5. Intelligent Digital Battlefield Architecture. Intelligent Systems research includes activities pertinent to the performance of hybrid systems, human intelligence augmentation, and low-level control. Hybrid system research will lead to robust design of advanced architecture for multi-agent/distributed control. Research involving representation and learning in the presence of uncertainties or incomplete information (soft computing: neural networks, fuzzy logic, Bayesian decision theory, etc.) will provide tools for intelligence augmentation of human-centered decision systems.

Such systems offer exciting new possibilities for conducting many types of military operations, ranging from reconnaissance and surveillance activities to a variety of specialized combat operations. Intelligent systems typically consist of a dynamic network of agents interconnected via spatial and communications links that operate in uncertain and dynamically changing environments using decentralized or distributed input, and under localized goals that may change over time. The agents may be people, information sources, automated systems such as robots, software, and computing modules. Intelligent systems must be capable of gathering relevant, available information about their environment, analyzing its significance in terms of assigned missions/functions, and defining the most appropriate course of action consistent with programmed decision logic. Achieving these objectives requires significant scientific and technological advances in many diverse fields: electronics, physics, mathematics, materials, biology, computer science, cognitive and neural sciences, control theory and mechanisms, and electrical and systems engineering. The numerous potential military applications of intelligent systems include unmanned vehicles (air, ground, and underwater types), smart weapons, real-time command and control systems for future battlefields, and chemical/biological defense systems.

Compact Power Sources: *achieve significant improvements in the performance (power and energy density, operating temperature, reliability, and safety) of compact power sources through fundamental advances relevant to current technologies (e.g., batteries and fuel cells) and the identification and exploitation of new concepts.*

Efficient, long-life, durable, and quiet compact power sources are a critical requirement for numerous defense applications, including electronics, heating and cooling, weapons, and propulsion systems. To improve battery performance, anode, cathode, and supercapacitor material breakthroughs are being sought, in conjunction with investigations of novel manufacturing methods. For fuel cells, which meet long-mission requirements not possible with battery technology, increased emphasis is being given to fuel issues and the development of new membrane materials. For both batteries and fuel cells, new diagnostic tools and advanced modeling capabilities are also needed to understand the structural and dynamic properties of working cells. New compact power concepts being considered include thermo-photovoltaics and micro gas turbine generators based on MEMS (micro-electromechanical systems) technology that could provide very high power-to-weight ratios (e.g., 100 watts per gram). Specific applications of advanced compact power sources include lightweight night-vision equipment, portable communications systems, satellites, equipment and soldier status-monitoring devices, command and control hardware, smart weapons, surveillance devices, and environmental monitoring systems.

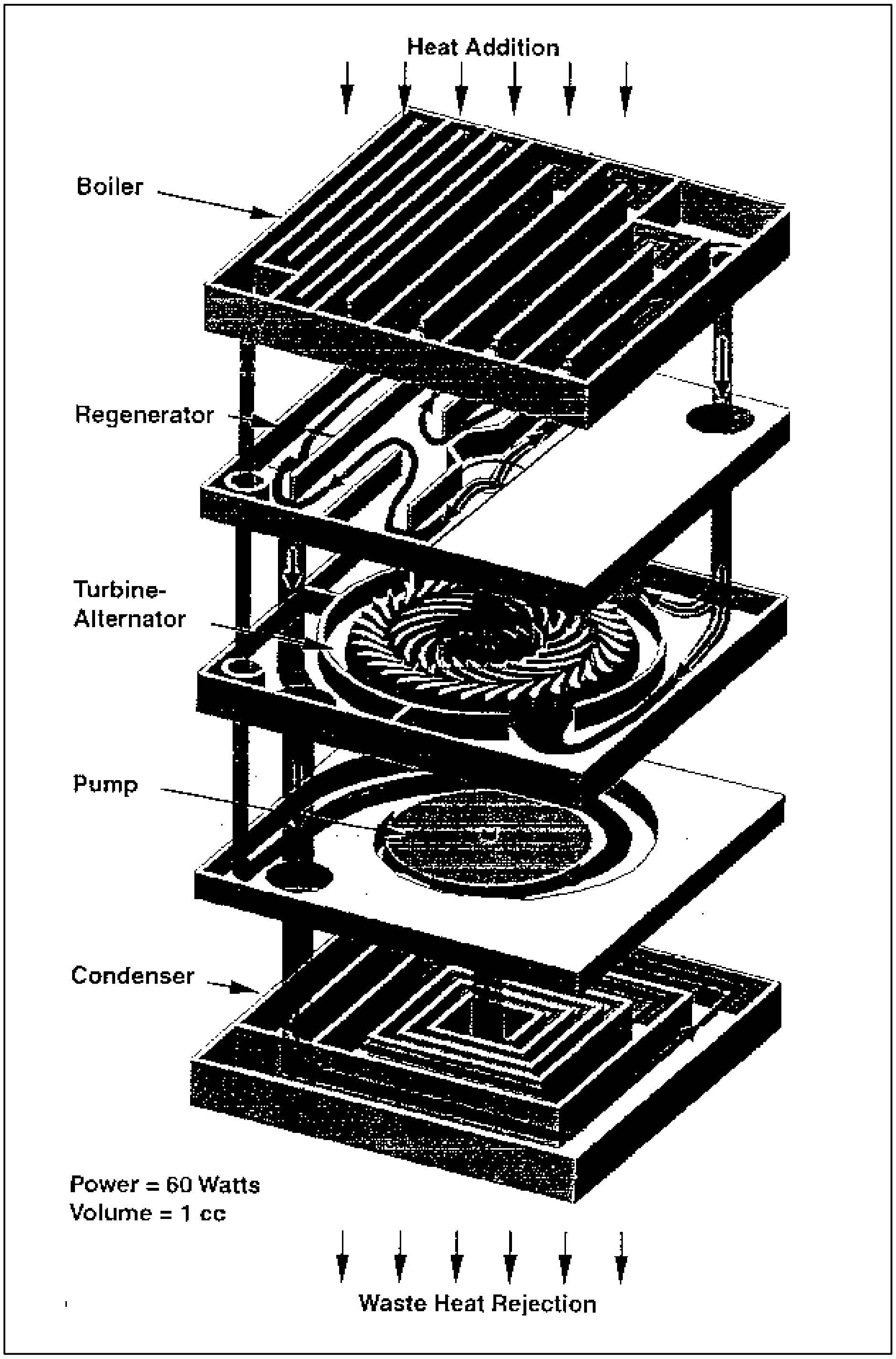


Figure 3.6. Microfabricated Rankine Cycle "Power Module." Research focused on a variety of fundamental materials, thermal management, design, and fabrication issues pertinent to the development of a microfabricated Rankine cycle power module concept is being carried out at Penn State University. This work exploits, in part, a miniature gas turbine generator being developed at MIT under DoD sponsorship. Advanced power systems based on this concept, which accommodates a wide range of working fluids, may yield compact thermal-to-electric energy-

conversion devices for numerous military applications, including individual soldier power.

Consideration of many projected research results for these areas relative to numerous specific technology objectives cited in the individual Technology Area Plans (TAPs) comprising the DoD Defense Technology Plan (September 1994) has served to underscore the pervasive importance of the Strategic Research Objectives to improving U.S. defense capabilities applicable to a wide range of military systems and operations. In managing the basic research program, special attention is being given to these areas and objectives to help ensure that their great potential can be realized through subsequent technology and systems development efforts. Identification of additional such areas and objectives will be sought in continuing reviews of basic research activities. Funding data for basic reseach work supporting the Strategic Research Objectives is provided in Table 3.1. Representative specific research goals associated with the Strategic Research Objectives described above are provided in Table 3.2.

Table 3.1. Funding Profiles for Basic Research Supporting the Strategic Research Objectives

	($ Millions)		
	FY95	**FY96**	**FY97**
Biomimetics	7.0	8.0	10.0
Nanoscience	24.7	26.4	23.9
Smart Structures	9.3	9.8	8.7
Broad Band Communications	15.4	13.0	17.2
Intelligent Systems	16.5	18.5	18.5
Compact Power Sources	8.0	9.0	9.5

Table 3.2. Representative Specific Basic Research Goals Associated with Strategic Research Objectives

	2000	2005	2010
Biomimetics	Demonstrate advanced design principles for high-performance composites Fabricate/evaluate new advanced armor and semi/super-conductor materials based on biomimetic principles Demonstrate biologically derived advanced materials for optical modulators	Demonstrate advanced adhesives for use in adverse environments Utilize principles of metabolic design for synthesis of advanced materials Fabricate porous lightweight and resilient structural materials with novel properties and uses Demonstrate new materials for improved uncooled IR detectors	Demonstrate utility of biochemical transducers for MEMS devices Achieve decontamination of chemical agents using biomimetic catalysts Demonstrate principles of stealth propulsion w/o motors or gears Demonstrate new sensors based on the olfactory system
Nanoscience	Adapt scanning probe technology to sensing Fabricate multi-layer semiconductor interfaces with atomic control Achieve useful magnetic interactions between small single domains Demonstrate applicability of “dusty plasma” physics to improved surface treatment	Utilize nanostructure elements for 10 nm computer memory elements Demonstrate enhanced propellants and explosives with nanoparticle surface chemistry Demonstrate sensing of biomolecules for medical diagnosis with scanning probes Achieve improved, ultra-dense holographic memories	Demonstrate advanced electronic devices based on single atoms or molecules Utilize novel electronic transport in nanostructures for faster clock speeds Lower life-cycle costs by 10% through in-situ detection of material failures on the nanometer scale Demonstrate quantum computing
Smart Structures	Demonstrate new, reliable, cost-effective composite smart materials for low- and high-frequency structural control applications Achieve up to 40 dB reduction in vibration using embedded shaped sensors in rotorcraft box beams	Demonstrate up to 60 dB vibration reduction using shaped sensors and adaptive control algorithms Achieve MEMS wireless communications in a rotorcraft flight structure Demonstrate new impact-energy-dissipating smart materials	Demonstrate low-cost, self-tuning vibration damping patch with integrated power and sensing microprocessors Demonstrate addressable fiber optic sensor arrays for damage detection in composite structures

Table 3.2. Representative Specific Basic Research Goals Associated with Strategic Research Objectives (cont.)

	2000	2005	2010
Broad Band Communications	Demonstrate wireless low-frame-rate/SNR video capabilities Achieve two-fold increase in throughput of wireless systems Demonstrate scaleable data-compression methods adaptable to variable bandwidths using multi-resolution methods Demonstrate use of HTS technology in Ghz-frequency active filters	Demonstrate improved video capabilities in wireless multimedia systems Demonstrate new methods for analyzing security properties of wireless networks to enhance inter-system compatibility Achieve Internet (ATM) compatibility between different protocols	Achieve full video capability in wireless multimedia systems Demonstrate adaptive antennas for battlefield communications Enable development of advanced minimum energy systems Demonstrate fully distributed networks (mobile to mobile communication)
Intelligent Systems	Establish fundamental roles played by hierarchical organization, compositionality, and learning in IS design Define/characterize simulated battlefield environments for testing IS methodologies Demonstrate intelligence augmentation of human-centered systems, with emphasis on cognitive issues	Establish a framework for integrating high- and low-level aspects of intelligent systems Exploit framework in devising next-generation control algorithms and designing prototype systems (e.g., that have integrated vision/control systems) Define/characterize integration of intelligent systems into larger network of systems (e.g., C3I)	Achieve new understanding of learning styles in the human brain relevant to the design of intelligent systems Demonstrate useful performance characteristics of fully autonomous intelligent systems Demonstrate advanced sensor/ control capabilities for fully autonomous intelligent systems
Compact Power Sources	Achieve single-ion conduction in polymer electrolytes for enhanced battery performance Demonstrate higher performance ultracapacitor, battery, and fuel cell catalyst materials Demonstrate hydrogen-fueled MEMS-based microturbines	Achieve 2X increases in the power and energy density of rechargeable lithium batteries Demonstrate advanced micro-turbine generators with efficient power electronics (>10W/cm^3) Demonstrate quiet liquid-fueled thermovoltaic power sources (250 W/kg)	Demonstrate a MEMS-based closed-loop thermal energy system Demonstrate compact 150W fuel cell that operates on logistics fuels at moderate temperature Demonstrate liquid-fueled micro-turbine generators with efficient power electronics (>100W/cm^3)

4.0 RESEARCH AREAS

This chapter provides descriptions of the twelve science research disciplines comprising the great majority of the scientific activity in the DoD Basic Research Program. Selected details regarding budgets, commonality and divergence of Service interests, and representative research goals are included.

4.1 Physics

Physics research is directed toward the understanding of fundamental principles that determine the operational bounds of military equipment. The Physics SPG plans and executes a well-integrated, forward-looking Basic Research Program that supports Service-specific technologies in the areas of weapons, weapon platforms, sensors, communications, navigation, surveillance, countermeasures, and information processing. As such, the Physics SPG supports all four elements of the Joint Warfighting S&T Plan (see section 1.0) by supporting, for example, the following S&T contributions to military needs: ground, sea, air and space sensor research, sensor improvement research, advanced radiation sources, littoral mine detection, precision strike (targeting), surveillance, guidance and control, lethality technologies, high power microwaves (HPM; which can be used to neutralize, disable, disorient, or confuse without lasting effects), atomic clock improvements (which in turn affect GPS performance improvements), deployable unattended sensors, and techniques for detecting and evaluating the existence of manufacturing capabilities for weapons of mass destruction (WMD).

A number of research activities are under way in other governmental agencies that address Service-specific needs. These programs are well known to DoD Basic Research Program managers and are used to leverage DoD investments.. The definition of Service-specific research in physics clearly follows lines of respective mission applications. The Army focuses on soldier platforms, the Navy on surface ship and underwater applications, and the Air Force on atmospheric and space flight applications. The need for lightweight, small devices for airborne platforms by the Air Force has resulted in a program to develop visible laser technology for possible use in optical countermeasures. The Army has an active program in displays and smart focal planes to support the combat soldier, along with uncooled detectors to lighten the soldier's load. Research for mobile power sources for the soldier and for land vehicles is also being conducted by the Army. The Navy continues to pursue research to develop blue/green lasers for undersea communications and mine detection. In addition, Navy research in acoustics is focused on physical acoustics and underwater acoustics involving propagation and transducers. Application of nonlinear control to signal discrimination in ocean acoustics is also of interest to the Navy. The Air Force has an active program in optical compensation for the imaging of space objects through the atmosphere. Budget information for physics research is provided in Table 4.1.1. Table 4.1.2 provides a more detailed outline of Service specifics and commonality in the physics research subareas.

Within the DoD, basic research in physics falls into four general areas (the approaches to these four areas are included in their description below). Physics supports the

Defense strategic investment specific technology priority in sensors, and the two generic priorities of dual-use and affordability.

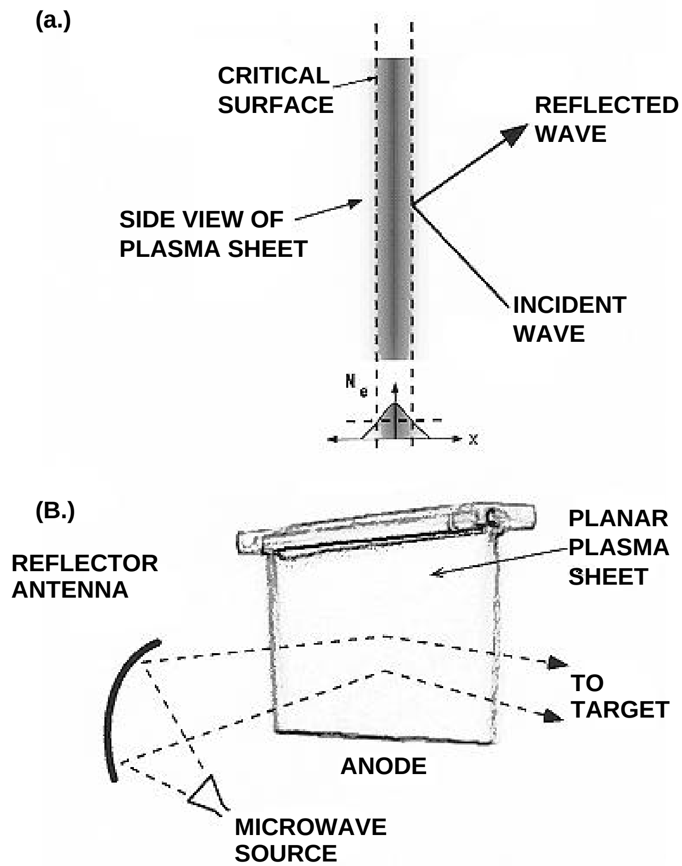


Figure 4.1. Plasma Mirror for Shipboard Radar A new type of shipboard radar that could combine wide bandwidth capability with electronic beam steering is under research and development at the Naval Research Laboratory. This radar utilizes a planar sheet of high-density plasma formed by driving a discharge in a low-pressure gas chamber. Microwaves incident on the plasma bounce off the plasma distribution as long as the density is above the critical density for a given microwave frequency (a 10 Ghz beam requires plasma density of $>1.2\text{x}10^{12}\text{cm}^{-3}$), as shown in (a.). If the plasma distribution is flat, then the reflected microwaves maintain the illuminating antenna's radiation pattern after reflection. By changing the orientation of the plasma sheet, the microwave beam can be directed toward a target, as shown in (b.). Multiple frequency or broad band transmitters can be used with a single plasma sheet. Successive plasma mirrors can be formed in arbitrary orientations, allowing both azimuth and elevation steering. Experiments have shown that the plasma sheet can be turned on and off in 10 microseconds and maintained for many milliseconds. This will enable a single plasma mirror based radar to rapidly track and target multiple high velocity missiles. The broad band capability will allow optimization of transmission frequency, electronic warfare target illumination, and detection of low radar cross section targets.

Radiation: *Research in this area runs the gamut from the x-ray to microwave regimes. Advanced radiation sources are needed to satisfy DoD requirements for C^3I, radar, sensors, electronic warfare (EW), directed energy weapons (DEW), and other* *systems.* In addition to radiation sources, this area involves the propagation of radiation and detection of objects using radiation in different military environments. Some research thrusts in this area include novel (e.g., ultraviolet) and blue/green lasers, high power microwaves, uncooled detectors, nonlinear optics, and optical compensation.

Matter and Materials: *Matter and materials research ranges from microscale (atomic scale systems) to macroscale (high Tc superconductor materials) characteristics that impact DoD systems, such as GPS performance improvement (atom traps and their impact on atomic clocks) and low observables (e.g., band-gap engineered materials).* Accordingly, the area involves elements in the plasma (the fourth state of matter), optical, and atomic arenas. For example, advances in the scientific understanding of plasma processing will in turn affect the microelectronics fabrication area, which will enable smaller feature sizes (submicron) in semiconductor wafers. Technology requirements for future DoD electronics systems are introducing increasingly stressing requirements, which can only be met by an increased scientific understanding in the processing area.

Energetic Processes: *All DoD systems are impacted by research in energetic processes because they require means for power generation and high voltage.* This area involves elements in high-voltage, plasmas, power generation, and energy storage. Representative research thrusts in this area include mobile power sources, thermo-photovoltaics, compact accelerators, pulsed power, ultra-high field physics, and plasmas (neutral and non-neutral, collisionless and collisional). In addition, neutral plasma effects can provide stealthy conditions for DoD aircraft and satellites.

Target Acquisition: *The survivability of DoD platforms (ships, tanks, aircraft) and systems (C^3I satellites, etc.) depend on advances made in the target acquisition area.* As such, the area involves an element within the oceanographic and atmospheric arena. Research thrusts in this area are focused on detection means (devices) and displays. For example, in order for the Army to "see" tanks through the fog of battle, advances are needed in imaging science. The Navy performs research in nonlinear dynamics, acoustic and non-acoustic wave (e.g., use of extremely low frequency/ very low frequency – ELF/VLF) propagation in order to counter the threat of submarines and mines in littoral regions. Moreover, the Air Force needs to be able to image space objects through the atmosphere.

A roadmap of representative research objectives for physics in the near and far term is shown in Table 4.1.3.

Table 4.1.1. Basic Research Funding for Physics ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61101A	Army	10.3	7.45	8.2
PE 61104A	Army	5.0	0.75	1.5
PE 61152N	Navy	2.9	2.8	2.9
PE 61153N	Navy	38.7	36.8	37.1
PE 61102F	Air Force	15.3	14.3	14.7
	Total	72.2	62.1	64.4

Table 4.1.2. Service Specific Interests and Commonality in Physics

Subarea	Army	Navy	Air Force
RADIATION Sources Detection Propagation	Uncooled detectors Sub-mmw research	X-ray sources Blue-green lasers Quantum noise	Optical compensation Microwave sources
		Areas of Common Interest	
	Optical image processing (A,AF) Ultra-fast EO (A,N,AF)	Novel lasers (A,N,AF) Optical diagnostics & testing (A,N,AF)	High power microwaves (N,AF) Nonlinear optics (A,N,AF)
MATTER AND MATERIALS Plasma Optical Atomic	Atomic scale systems Low observables Soldier displays	Physical acoustics Energetic & nonlinear IR materials	Visible lasers Semiconductor lasers
		Areas of Common Interest	
	Character of plasma processing (A,N) Ferroelectrics (A,N)	Nanostructures (A,N,AF) Surfaces & interfaces (A,AF) Atomic interferometry (A,N,AF)	High T_C super-conductors (N,AF) Atom traps (N,AF) Computational physics (A,N,AF)
ENERGETIC PROCESSES High voltage Plasmas Power Generation	Mobile power sources Thermophotovoltaics	Compact accelerators Pulsed power research Ultra-high-field physics	Neutral plasma effects
		Areas of Common Interest	
	Non neutral plasmas (N,AF)		Collective phenomena (N,AF)
TARGET ACQUISITION Oceanographic & Atmospheric	Smart focal plane arrays Foundations of image science	Nonlinear acoustic phenomena Sound/fluid/structure interactions Active & passive sonar Long range acoustic propagation	Atmospheric discharges
		Areas of Common Interest	
	Ionosphere modification & propagation (N,AF)		Nonlinear dynamics (A,N,AF)

Table 4.1.3. Representative Basic Research Goals: Physics

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Radiation	Imaging of GEO satellites	Sensors and Electronics	Atmospheric compensation	Hyperspectral image processing	Centimeter- scale resolution
	Man-portable (head-mounted) thermal imagers	Sensors and Electronics	Background-limited detection	Affordable detector arrays	Man-integrated intelligent display
	Optical mine detection	Sensors and Electronics	High-efficiency coherent sources	Single-pulse imaging capability	3-D imaging capability
Matter and Materials	Low observables	Weapons Sensors and Electronics	Ferroelectric layered structures	Photonic band-gap engineered materials	Actively controlled absorbing materials
	Optical countermeasures	Weapons Sensors and Electronics	Active eye protection	Efficient visible lasers	Optically based RF jammers
	Precision targeting and GPS performance improvement	Sensors and Electronics	Compact optical clock	Atom trap lattices	Table-top field isolated atom traps
Energetic Processes	Mobile power systems	Human Systems Weapons	Disposable fuel cell	Man-portable thermo-photovoltaics	Logistically compatible fuel cell
	EW and DEW systems	Weapons	Plasma stealth	Compact laser-plasma accelerators Agile plasma mirror	Compact reflex triodes Air Plasmas
Target Acquisition	Automatic target recognition (ATR)	Sensors and Electronics	Algorithm performance	Quantification of scene clutter	Theory of image complexity
	Littoral ASW	Sensors and Electronics	Nonlinear signal processing for detection/classification	Acoustic imaging in shallow water Ray chaos models	Acoustic holography

4.2 Chemistry

Chemistry research directly impacts a wide range of critical DoD missions. Chemistry research is central to developing advanced materials for specific DoD applications and to developing suitable processes for producing such materials in cost-effective ways. Examples are developing materials for protection against chemical weapons, producing novel propellants and power sources, developing processes to protect materials against corrosion, and developing methods to demilitarize munitions. The ability to tailor material properties to meet DoD needs arises from an understanding at the molecular level of the relationships between structure and properties. This understanding of molecular processes and properties established through chemical research enables the design of components that exploit these properties for optimal performance.

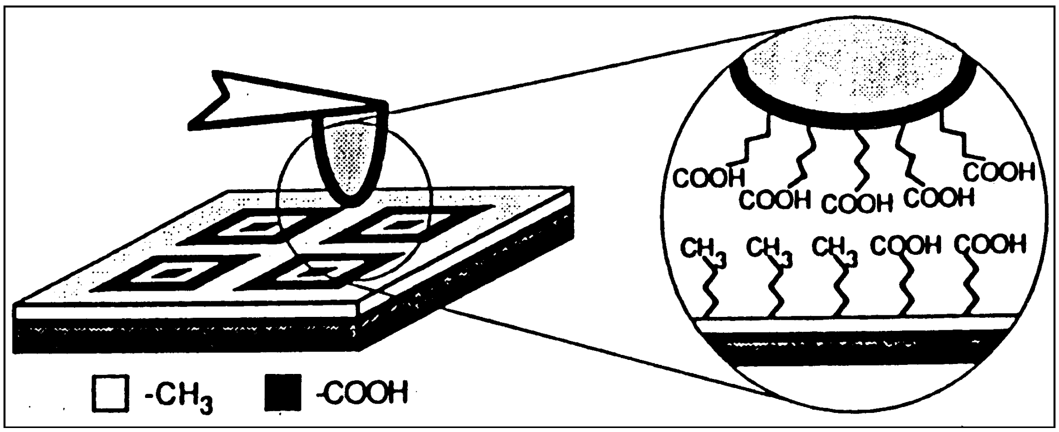


Figure 4.2. Chemical Force Microscopy. The technique of Chemical Force Microscopy was developed in AFOSR-supported work by Prof. Charles Lieber at Harvard University. Chemical Force Microscopy enables the identification of the *chemical* properties of molecules on surfaces with nanometer resolution.

Budget information for chemistry research is provided in Table 4.2.1. Responsibilities for topics within the chemistry subarea have been distributed in accordance with Service mission considerations, as reflected in Table 4.2.2. These coordinated programs retain the responsiveness to pursue new scientific developments and Service needs. The Army continues to emphasize systems related to chemical and biological defense (permeability, reactive and catalytic polymers) and to elastomers because of the heavy use of rubbery components in land vehicles. Important Navy areas of concentration include special considerations due to the marine environment, adhesion and surface properties relating to ship antifouling coatings, electronic and optical materials and properties, and transducer and display applications. The Air Force emphasizes materials that maintain their integrity in extreme environments, corrosion chemistry related to aging aircraft, advanced ceramic precursors for high temperature engine applications, chemical lasers, and processes that affect operations in the atmosphere and in space. DoD requirements for power sources are currently covered by the extensive Army and Navy efforts and their respective DARPA programs. Topics of common interest continue to be: energetic materials, led by the Army (there is no civilian effort on which to depend); optical polymers for rapidly disseminating and displaying information to the warfighters; and very exciting forefront topics where specific applications remain the subject of speculation (e.g., nanostructures, biomimetics).

Chemistry research within the DoD Basic Research Program is divided into two major subareas:

***Materials Chemistry**: Advanced materials play a key role in numerous DoD systems having widespread applications. Chemistry research focuses on the molecular design and synthesis of materials with properties that can be tailored to specific DoD requirements.* Structure/property relationships are determined to enable design of optimal material systems. In addition to the applications cited above, other widespread applications include developing materials for marine and aerospace environments, strong and lightweight composite materials, electronic materials, semiconductors, superconductors, and barriers for chemical and biological weapons.

***Processes:** Controlling the interaction between materials and their environments can be exploited for many DoD applications. Controlling friction and adhesion, corrosion, signatures, and the fate and transport of chemicals are some of the areas where this work impacts DoD operations.* Molecular processes are also being exploited to develop compact fuel cells as portable, clean power sources; to develop chemical lasers for directed energy weapons; to control ignition and detonation of munitions; and to store energy in propellants.

Army research on polymers and elastomers continues to develop materials with properties tailored for chemical and biological defense needs. Research is ongoing on the destruction of munitions, and on the catalytic oxidation and hydrolysis of chemical agents and toxins, as well as techniques for the detection of trace amounts of chemical hazards. The Army has consolidated its efforts in the area of highly branched dendritic molecules and will lead the Services in that area. Research on hydrogen, methanol, and liquid hydrocarbon fuel cells continues as a growing area led by the Army. The Navy continues its leadership in electrode interfaces and materials and the eventual development of medium- to large-scale energy conversion systems. The Navy leads work on semiconductors involving the development of site-selective dopants and deposition processes for improved optoelectronics and transistors. Research in tribology is developing an understanding of the role of surface chemistry in friction and wear. The Air Force continues to develop new materials synthesis methods, such as those for ceramics, composites, and sol gels for operation in extreme environments. Novel work on inorganic polymers holds promise of a new class of versatile materials. Current work is also aimed at providing windows of opportunity for IR-detection countermeasures. Air Force work to understand, detect, and prevent corrosion of aircraft is increasing. Common efforts within the SPG in chemical synthesis address energetic materials, supra molecular chemistry for biomimetics and detection, and optical materials. Research developing optical polymers for information processing applications is continuing to make great progress addressing important DoD needs for information processing. Representative basic research goals in chemistry are cited in Table 4.2.3.

Table 4.2.1. Basic Research Funding for Chemistry ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61101A	Army	1.4	1.8	1.9
PE 61102A	Army	7.9	5.6	5.9
PE 61104A	Army	0	2.0	2.0
PE 61152N	Navy	1.2	1.1	1.1
PE 61153N	Navy	29.6	27.5	27.7
PE 61102F	Air Force	23.6	24.1	24.8
	Total	**63.7**	**62.1**	**63.4**

Table 4.2.2. Service Specific Interests and Commonality in Chemistry

Subarea	Army	Navy	Air Force
MATERIALS CHEMISTRY Theory, Molecular design, Synthesis and properties of compounds	Catalysts (CBW) Elastomers Reactive polymers (CBW) Barrier materials Dendritic Molecules	Acoustic materials Electronics materials Inorganic semi-/super-conductors Minimally adhesive surfaces IR materials Organic composites	Ceramics Organic superconductors Biotechnology/ biosynthesis Ceramic materials, coatings, composites
		Areas of Common Interest	
	Biomimetics (N, AF) Nanostructures (N, AF)	Energetic materials (A,N,AF) Power sources (A,N)	Polymers with delocalized electronic states (N,AF)
PROCESSES Basic theory, mechanisms and chemistry related to energy-transfer, reaction, understanding and exploitation	Reactions in SCF Combustion (DEMIL) CBW detection Organized assemblies DECON Diffusion/transport in polymers Energetic ignition/detonation	Biomimetic catalysis (CBW) Combustion/conflagration in fuels Tribology Adhesion Thin-film growth processes	Chemical lasers Atmospheric and space signatures and backgrounds Corrosion chemistry Processing (ceramics, polymers, sol gels) Biodegradation Environmental processes
		Areas of Common Interest	
	Power sources (A,N)	Dynamics (A,N,AF)	Biocorrosion (N,AF)

Table 4.2.3. Representative Basic Research Goals: Chemistry

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Materials Chemistry	Chemical/biological defense	Chemical/ Biological Defense and Nuclear Biomedical Science and Technology	Point biodetectors Equipment for decontamination High temp catalysts General percolation model	Remote sensors for known biothreats Wide area decontamination Room temp catalysts Fabric percolation model	Sensors for unknown bio-threats Satellite-based sensors Active uniform barrier Smart coatings to destroy chem/bio agents
	Information processing and Displays	Sensors and Electronics Information Systems and Technology	Efficient blue opto-electronics Higher speed micro-wave/mm wave devices Molecular transistors	Full color, low power opto-electronics Chemically deposited phosphors for FED Atomic control of deposition/ doping	SAM technology for semiconductor processing
	Communications and information transfer	Information Systems and Technology Sensors and Electronics	Thermally stable NLO polymers	Polymer modulators Intrinsically polar polymers	All polymer display Ultrafast information processing
	Ordnance and propulsion	Weapons Space Platforms	Energetic additives for liquid-fueled rockets Environmentally benign and lower toxicity propellants	Process-efficient motor formulations Chlorine-free liquid oxidizers	Cryogenic solid hybrid propellants Chlorine-free solid oxidizers
Processes	Power sources for soldiers, Military vehicles and devices	Ground Vehicles and Watercraft Human Systems Sensors and Electronics	New processing technologies for porous electrodes Hydrogen sources for man-portable fuel cells Prototype direct methanol and high-temperature liquid hydrocarbon fuel cells	Control neutral transport in PEM fuel-cell membranes Cooling for hydrogen fuel cells Fielded methanol fuel cells Low temp liquid hydrocarbon fuel cells	Double current density capability of non-aqueous battery systems Fielded low-temp liquid hydrocarbon fuel cells

Table 4.2.3. Representative Basic Research Goals: Chemistry (cont.)

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Processes	Demilitarization of munitions	Materials and Processes Chemical, Biological Defense and Nuclear	Robust reactors for demilitarization to safe products	Mobile seekers for non-stockpile chemical munitions and unexploded ordnance Portable DEMIL reactors	Energetic materials recycling units
	Tribology	Materials and Processes Ground Vehicles and Watercraft Air Platforms	Microscopic model of friction/wear	Sensors to detect friction, wear, corrosion Lubricant design	Combine sensors/data fusion/lubricant design for prolonged life of rotating machinery
	Directed energy weapons	Weapons	Pulsed, frequency-shifted COIL target illuminator	COIL-based airborne laser High-pressure COIL mixing nozzle/pressure recovery	Lightweight gas-phase generator to power iodine lasers

4.3 Mathematics

Mathematics research contributes the analytical tools required to satisfy DoD needs in advanced materials, manufacturing processes, fluid flow, combustion and detonation, power and directed energy, microelectronics and photonics, sensors, distributed control, optimization, and logistics. Advances in these areas of DoD interest are dependent on advances in a number of mathematical subdisciplines. For example, certain promising approaches to computer vision for automatic target recognition (ATR) require research in a wide range of mathematics areas, including constructive geometry, numerical methods for stochastic differential equations, Bayesian statistics, tree-structured methods in statistics, probabilistic algorithms, and distributed parallel computation. Another example is determination of the dispersion of liquid contents (including chemical and biological agents) of theater-range missiles after interception. Basic research in analytical, computational and experimental fluid dynamics is needed to obtain accurate estimates of the area of liquid dispersion. The Mathematics SPG plans and conducts a balanced program involving both need-driven and opportunity-driven topics. Budget information for mathematics research is provided in Table 4.3.1.

Figure 4.3. Mathematical Computational Approaches to Adaptive Military Systems. A new computational methodology for designing robust controllers based on limited data is critical in ensuring adaptive and survivable military systems. The controllers have potential to be used in gun control systems, in vehicle suspension and for active noise and vibration suppression in rotorcraft.

The Services support basic research on nonlinear dynamics and on multiscale phenomena. The results of this research are applicable both to the specific issues of each Service as well as to common issues. Because of the Army's need for understanding of armor and of anti-armor systems, the Army leads in mathematics for materials. The Navy leads in ocean modeling and acoustics. The Air Force leads in control and guidance because of its special needs for weaponry with advanced capabilities in these areas. A major interest in computational mathematics is in adaptive methods. In stochastic analysis and operations research, the prime topic of DoD interest is mathematical programming because of the needs of all three Services for improved algorithms for large, complex planning problems and logistics. The Air Force has the lead in compressible and hypersonic flow (for aerodynamic design). The Navy has the lead in random fields (for ocean modeling) and in incompressible flows (for hydrodynamic design). The Army has the lead in probabilistic methods for automatic/aided target recognition.

In all three subareas of research in mathematics, there are issues of common interest among the three Services as well as issues of particular interest to one or two of the Services. Table 4.3.2 provides an outline of Service-specific interests and commonality in the mathematics research subareas.

Within the DoD Basic Research Program, research in mathematics falls into three general areas:

Modeling and Mathematical Analysis: *The fundamental knowledge provided by this area increases DoD's ability to develop ground vehicles, aircraft and naval vessels, energetic materials, delivery systems, radar, sonar, sensors and actuators, and other military equipment.* Research in this area provides the mathematical underpinning and analytical tools that enhance understanding of complex nonlinear physical phenomena, such as those occurring in advanced materials, fluid flow, acoustic and EM propagation, opto-electronics and neuro-physiological systems. Emphasis is on the development of mathematical models, especially nonlinear ordinary and partial differential , difference, and integral equations, and on enhancing the understanding of these models by functional analytical means, often in the context of providing the basis for improving or replacing computational procedures.

Computational Mathematics: *This area impacts DoD capabilities in ballistics, penetration, vulnerability, ground vehicles, aircraft, naval vessels, combustion, detonation and stealth technology.* Advanced computational methods are enabling tools for simulation of the diverse physical and engineering problems occurring in developing these capabilities. Emphasis is on the development of numerical methods, on the development of efficient computational procedures for implementing these numerical methods, and on the use of these methods to study dynamic phenomena in complex geometries and media. Accuracy, rigorous error control, and timelines (parallelization) receive particular attention. These results support the effective use of the DoD High Performance Computing Modernization Program to impact warfighting capabilities.

Stochastic Analysis and Operations Research: *This area impacts DoD capabilities in design, testing and evaluation of systems, decision-making under uncertainty, logistics, and resource management.* Stochastic analysis and optimization enable improved system design, development and testing, and also provide the tools for accurate decision-making. Emphasis is on the analysis of data by reliable and robust procedures, probabilistic and statistical understanding of physical and operational phenomena with uncertainty, efficient computational procedures for testing and evaluation, especially for cases with very small and very large amounts of data, and efficient optimization techniques.

A roadmap of representative basic research objectives for mathematics in the near and far term is shown in Table 4.3.3.

Table 4.3.1. Basic Research Funding for Mathematics ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61102A	Army	5.7	4.9	4.6
PE 61152N	Navy	2.9	2.8	2.9
PE 61153N	Navy	18.5	18.9	19.0
PE 61102F	Air Force	20.6	20.1	20.7
	Total	**47.7**	**46.7**	**47.2**

Table 4.3.2. Service Specific Interests and Commonality in Mathematics

Subarea	Army	Navy	Air Force
MODELING AND MATHEMATICAL ANALYSIS	Mathematics of materials science Reactive flows	Ocean modeling and mixing Acoustic propagation and scattering	Control and guidance Non-linear optics
Physical modeling and analysis	Inverse problems (N,AF)	**Areas of Common Interest** Multi-scale phenomena (A,N,AF)	Non-linear dynamics (A,N,AF)
COMPUTATIONAL MATHEMATICS Numerical analysis	Computational mechanics Symbolic methods	Computational acoustics Computational statistics Computational logic	Computational control Compressible and hypersonic flow
Discrete mathematics	Computational geometry (A,N)	**Areas of Common Interest** Adaptive methods (A,N,AF)	Computational electro-magnetics (N,AF)
STOCHASTIC ANALYSIS AND OPERATIONS RESEARCH	Statistical modeling Simulation methodology	Random fields Spatial line and point processes	Intelligent search Chemistry Optimi-zation techniques
	Stochastic image analysis (A,N) Stochastics PDEs (A,N)	**Areas of Common Interest** Mathematical programming (A,N,AF)	Network and graph theory (N,AF)

Table 4.3.3. Representative Basic Research Goals: Mathematics

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Modeling and Mathematical Analysis	Armor/anti-armor sonar Control of missiles· Design of projectiles, ground vehicles, aircraft, ships, submarines· Precision strike targeting	Information Systems and Technology Materials and Manufacturing Weapons	Analysis for penetration of metals Shallow-water sonar High angle-of-attack missile flight Nonlinear controller for complex systems Multisensor images for targeting	Analysis for penetration of advanced composites Reconfigurable self-designing flight control Vision directed tracking and control Real time multisensor images for targeting	Full analysis for penetration of most materials· Active control of hypersonic vehicle drag via magnetics Integrated system for real time multisensor images for targeting
Computational Mathematics	Armor anti-armor Sonar Control of missiles Design of projectiles, ground vehicles, aircraft, ships, submarines· Precision strike targeting	Information Systems and Technology Air Platforms Weapons Ground Vehicles and Watercraft	Response of portions of vehicles to high loading· Medium-size fluid-structure interaction Subcomponent design of complex systems Fast solvers for multisensor images	Response of vehicles to high loading Large-size fluid-structure interaction Subcomponent optimal design of complex systems Real-time solvers for multisensor images	Optimal vehicle design for high loading· Detailed fluid-structure interaction under high loading Optimal design of vehicles and weapons· Algorithms for multisensor systems
Stochastic Analysis and Operations Research	Battlefield management Mission planning Real-time logistics Planning for large programs	Information Systems and Technology Sensors and Electronics	Real-time optimization of medium-sized logistics operations Probabilistics methods for deterministically intractable problems Automated cruise missile allocation and routing	Real-time optimization of large logistics operations Improved sub-pixel target identification using hyperspectral imaging techniques Real-time cruise missile allocation and routing	Optimal design of stochastic network for battlefield management Parallel optimization for materials design (energetic materials, laser hardening) Intelligent on-board decision-making for cruise missiles

4.4 Computer Science

Computer science is central to a variety of DoD issues, including automated acquisition, representation, transformation, fusion, storage, and retrieval of information. The design of intelligent agents, the foundations of heterogeneous and distributed databases, the design and evolution of software systems, and real-time algorithmic and architectural issues for battlefield decision aids are all important DoD areas of interest that involve computer science in a critical way. Advanced distributed simulation is an enabling technology for determining and analyzing alternatives for enhancing warfighting capabilities across all Services. The realism, interoperability, synchronization, and scaling behavior of modeling and simulation for this purpose need enhancement. Defense research in computer science addresses many of these shortfalls by emphasizing work in the areas of software, intelligent systems, and distributed computing and communication. Complete realization of intelligent and flexible manufacturing depends in a critical way on progress made in the subareas of intelligent systems, computer-aided rapid prototyping, and efficient handling of geometric databases. Immersive graphics and visualization techniques will be needed for creating virtual environments for design and prototyping

Figure 4.4. C-17 Paratroop Egress Solution

Figure 4.4. C-17 Paratroop Egress Solution. The value of research in computational fluid dynamics was recently demonstrated when a potential problem with C-17 paratroop egress was discovered. Analyses revealed that attempts to deploy paratroopers simultaneously from both sides of the aircraft could prove hazardous because of severe disruption in air flow due to the air deflected by the wing flap and vortices generated by the landing gear. Small adjustments to aircraft angle-of-attack and flight speed during paratroop deployment significantly displaced the disruptive flows. The high accuracy of the computational solution, coupled with quick turn-around, allowed C-17 flight parameters to be optimized to solve the egress problem without a lengthy, costly flight test program. C-17 flights and successful drops have been made using the new parameters

The diverse needs of the Services, driven primarily by requirements associated with different platforms, are the foundation for the topical computer science areas pursued within each agency. For instance, while the Navy pursues novel computing concepts with potential to help the fleet accomplish its missions affordably, the Army is driven by the requirements pertinent to development of the digital battlefield. Because of demanding computing-speed requirements for aerospace defense, the Air Force has the lead in parallel programming archetypes. In the area of intelligent systems, each of the Service research offices has considerable interest and activity. On the other hand, the virtual environments subarea is being pursued primarily by the Army and Navy to support a variety of combat simulation needs and battlespace management applications. Machine vision is pursued by all Services to support reconnaissance and surveillance missions. However, the focus of this research differs significantly for each Service due to the widely different regimes in which they operate (land, open ocean and littoral zones, space defense). Budget information for computer science research is provided in Table 4.4.1. An outline of Service-specific interests and commonality in the computer science area is given in Table 4.4.2.

Within the DoD Basic Research Program, computer science research falls into three general areas:

Intelligent Systems: *The fundamental knowledge provided by this area directly impacts DoD capabilities in automated C^3 systems, guidance and control of semi-automated and automated platforms, automatic target recognition, and real-time warfare management decision aids.* The principal research thrust in this area is on the design, analysis and development of systems that can operate autonomously or in a semi-automated fashion in dynamic and uncertain environments. Major focal areas include natural language interfaces, the synthesis and design of dynamic networks of agents, high-performance hierarchical and hybrid systems, machine perception and learning, data fusion, and novel computing paradigms for real-time applications.

Software: *This area impacts DoD capabilities in automation, decision support, warfare management systems, distributed interactive simulation, digitization of the battlefield, training, and man-machine interaction.* Advanced software is an enabling tool for all of these capabilities. Emphasis is on developing procedures for software prototyping, development and evolution; on formal methods for software engineering; on knowledgebase/database science; and on efficient and reliable methods for natural language processing in complex situations. The development of sound and efficient computational methodologies for manipulation of large datasets, and development and analysis of mathematical procedures for information processing and dissemination, networks, communication and information retrieval are important additional areas of activity.

Architecture and Systems*: This area impacts DoD capabilities in warfare management, real-time acquisition, training, C^3I, geographic information systems, automatic target recognition, system automation, distributed interactive simulation, and vulnerability and lethality analysis.* Emphasis is on distributed computing systems for C^3I, dependable multi-computing systems, secure computing and systems suitable for interaction with humans. Emphasis is also on geometric algorithms and modeling, robust geometric computation, dynamic and interactive visualization and navigation through complex 3D models, and distributed and parallel computing platforms.

A roadmap of representative basic research objectives for computer science in the near and far term is given in Table 4.4.3.

Table 4.4.1. Basic Research Funding for Computer Science ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61102A*	Army	3.9	4.0	17.3
PE 61104A	Army	0	8.9	9.8
PE 61152N	Navy	1.1	1.0	1.1
PE 61153N	Navy	19.7	20.0	20.2
PE 61102F	Air Force	5.1	5.1	5.2
PE 61101E	DARPA	23.2	22.1	25.1
	Total	**53.0**	**61.1**	**78.7**

*Supports Army Federated Laboratory initiative for digitized battlefield.

Table 4.4.2. Service Specific Interests and Commonality in Computer Science

<table>
<tr><th>SUBAREA</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td rowspan="3">INTELLIGENT SYSTEMS
Control
Learning
NLP
Motion planning
Virtual environments
Data fusion</td><td>Intelligent control
Natural language processing
Machine intelligence</td><td>Case-based reasoning
Machine learning
Motion planning</td><td>Intelligent real-time problem solving
Intelligent tutoring</td></tr>
<tr><td colspan="3">Areas of Common Interest</td></tr>
<tr><td>Data Fusion (A,AF)</td><td>Machine vision (A,N,AF)
Virtual environments (A,N)</td><td>Novel computing paradigms (A,N,AF)</td></tr>
<tr><td rowspan="3">SOFTWARE
Software engineering
Software environments
Languages</td><td>Heterogeneous database
Formal languages
Automation of software development</td><td>Hard real-time computing
Structural complexity
Programming logic</td><td>Parallel programming archetypes</td></tr>
<tr><td colspan="3">Areas of Common Interest</td></tr>
<tr><td>Software environments (A,N,AF)</td><td>Programming languages (A,N,AF)</td><td>Formal design and verification (N,AF)</td></tr>
<tr><td rowspan="3">ARCHITECTURE AND SYSTEMS
Compilers
Operating systems</td><td>Scaleable parallel combat models
Hybrid systems architectures</td><td>Ultra-dependable multi-computing systems
Secure computing</td><td>Distributed computing for C^3</td></tr>
<tr><td colspan="3">Areas of Common Interest</td></tr>
<tr><td>Compiler optimization (A,N)</td><td>Operating systems (A,N,AF)</td><td>Man-machine interface (A,N)</td></tr>
</table>

Table 4.4.3. Representative Basic Research Goals: Computer Science

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Intelligent Systems	Intelligent networks Autonomous robots Advanced decision support Common tactical picture	Information Systems and Technology Sensors and Electronics	Medium-size network of cooperative agents Intelligent agents for structured data Cooperative dynamic systems Medium-size multi-media networks Learning algorithms for sensor fusion	Large-size network with mediators Intelligent agents for searching and filtering structured data Intelligent reactive planning algorithms Intelligent interfaces integrated in medium-sized networks	Adaptive network with multi-faceted mediators Intelligent agents for common tactical picture Concurrent multi-agent planning Large-scale natural-language-driven information synthesis
Software	Increased reliability of software Reduced life-cycle costs for large-scale software Affordable, high-performance weapon systems	Information Systems and Technology Battlespace Platforms	Formalized semi-automated software engineering Parallel programming archetypes for reusable parallel software Embedded system information structures	Automated engineering of domain-specific software Design techniques for hardware-independent software Automated weapons component design	Automated engineering of general software systems Self-improving software Automated complex weapons system design
Architecture and Systems	Real-time interactive distributed computing Network security Human-computer interaction Network communications	Information Systems and Technology Human Systems	Medium-scale interactive system Formal specification/ design for distributed agents for C^3I Multimodal user interface High data-rate SATCOM for mobile meshes	Adaptable, secure, heterogeneous computer and communication architectures High data-rate multi-media SATCOM for mobile meshes	Large-scale interactive system Quantum computing Multimodal group interface Multimodal real-time networked interface 2-way high data-rate mobile SATCOM

4.5 Electronics

Electronics is considered the dominant force-multiplier in DoD systems. Basic research in electronics is supporting all elements of the Joint Warfighting S&T Plan and is both need- and opportunity-driven. The Electronics SPG plans and conducts a forward-looking, well-integrated, basic research program that addresses many of the currently defined mission deficiencies and operational requirements such as: aiming and position accuracy of weapons; unmanned robotic vehicles and aircraft; reliable, and minimum down time global communications and real-time global surveillance as needed for information dominance. These requirements are driven by two factors: (1) affordability, and (2) a continuing need for operational superiority, which requires systems possessing higher accuracy and vastly greater information throughput capacity to impact real-time situation assessment or systems performing autonomously over land, in sea, air or space.

The basic research program in electronics has established a national leadership position and has advanced, exploited and leveraged research results in many fields that impact on technologies of military importance. Representative examples are research efforts on infrared detectors for various military operations under realistic battlefield conditions, wide band gap semiconductor research that is critical for high temperature jet engine controls and high power shipboard switching devices; and optical computing devices that will provide major weight/size reduction in air and spacecraft signal processors. DoD basic research in electronics is distributed over the Services in a manner that avoids duplication and maximizes benefits to specific Service mission requirements. Army research areas are closely coupled to Army mission requirements for ground vehicle and soldier support, Navy programs are driven by considerations derived from ocean and submarine operational needs, and the Air Force research efforts are dictated by requirements for high performance aircraft and space platforms. In addition to Service-specific programs, the SPG plans for multi-Service and multidisciplinary efforts to more effectively focus resources on recognized DoD topics. Budget information for electronics research is provided in Table 4.5.1. A more detailed outline of specific Service interests in the electronics field is given in Table 4.5.2. A roadmap of representative basic research objectives for electronics in the near and far term is presented in Table 4.5.3.

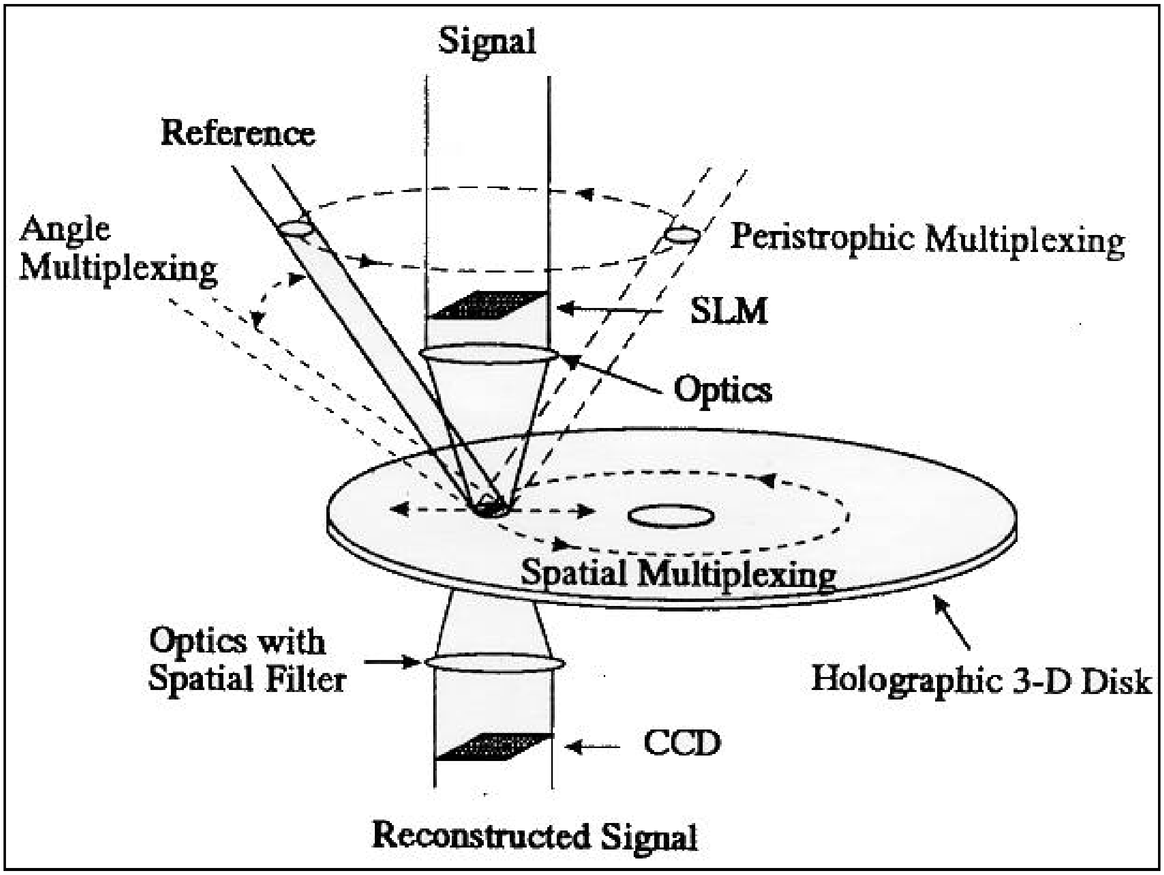


Figure 4.5. Holographic 3-D Disk. A combination of peristrophic, angular, and spatial multiplexing allows a large number of holograms to be stored in thin media. 1,000 holograms of 128 x 128 binary bit patterns were superimposed in a medium 100 mm thick, without errors. Storage density can be increased from current CD storage of 1 bit/square micron to 40 bits/square micron. The increased data storage capability will allow recording and post processing of important satellite-to-ground imaging information for later transmission to ground stations.

The DoD Basic Research Program in electronics is divided into three subareas:

Solid State and Optical Electronics*: Research in this subarea will provide the warfighter with novel or improved electronic and optical hardware for acquisition, tracking, electronic controls, radar and communication, displays, data processors, and advanced computers.* Research in solid-state electronics emphasizes topics of limited commercial interest such as required in low-power, low-voltage applications for soldier or space support; ultrahigh frequency devices to be applied in secure communication or radar; or ultrafast robust building blocks for future generations of efficient, dedicated supercomputers. Optical electronics, including photonics, takes advantage of the very high bandwidth of transmission channels and aims at massive optical storage as critical building blocks of photonic computation. A new program has been established to understand radiation effects in some semiconductor devices that are based on quantum wells and advanced heterojunctions.

Information Electronics: *Basic research in this subarea will push the performance envelope for wireless communications and decision-making by advancing simulation and modeling, coding, and image/target analysis and recognition.* Research in information electronics is dedicated to signal processing for wireless applications and image recognition and analysis. Cooling schemes for secure communication and robust communication networks are being investigated. Optimum control of distributed information processing and transmission are also receiving substantial attention. Also, innovative approaches to modeling and simulation devices and circuits are being pursued.. Modeling and sensor fusion, as well as control and adaptive arrays, are also being emphasized.

Electromagnetics*: Progress in this research subarea will advance DoD capabilities in signal transmission and reception such as found in radar, high power microwaves, or secure communications in built-up areas.* The research program in electromagnetics is focused on fundamentals of antenna designs; on scattering and transmission of EM signals, and on efficient RF components such as vacuum electronics for use predominantly in radar and wireless applications. Computational electromagnetics is receiving strong emphasis, along with novel approaches to time-domain modeling of electromagnetic wave generation, transmission, and propagation. A substantial part of the program is focused on modeling of millimeter wave phenomena by optical means.

Table 4.5.1. Basic Research Funding for Electronics ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61101A	Army	2.1	2.9	3.1
PE 61102A	Army	24.4	13.9	14.9
PE 61104A	Army	0	16.3	17.4
PE 61152N	Navy	0.6	0.6	0.6
PE 61153N	Navy	40.9	41.7	42.0
PE 61102F	Air Force	22.7	21.1	21.7
PE 61101E	ARPA	34.4	38.3	38.0
	Total	**125.1**	**134.8**	**137.7**

Table 4.5.2. Service Specific Interests and Commonality in Electronics

Subarea	Army	Navy	Air Force
SOLID STATE AND OPTICAL ELECTRONICS	Uncooled IR detectors Terahertz electronics Low power and voltage analog electronics	Wide gap semiconductors Magnetic thin films Blue-green semiconductor optics	Optical computing Non-linear optical materials High temperature electronics
Detectors Superconductors Non-linear circuits	Lithography (A,N) Quantum transport (A,N) Nanoscale electronics (A, N, AF)	**Areas of Common Interest** Heterostructures (A,N.AF) Mesoscale devices (A,N,AF) Surfaces &Interfaces (A, N, AF)	Device reliability (N, F) Superconductors (N, AF)
INFORMATION ELECTRONICS Modeling Simulation	Coding for wireless communications Wireless mobile distributed multimedia communication IR target recognition and image analysis	Sensor array processing Distributed networks Soft/fuzzy logic/neural networks Reliable, fault-tolerant VLSI	
	Modeling/simulation of circuits, devices and networks (A, N)	**Areas of Common Interest** Sensor Fusion (A, N, AF) Digital signal processing (A, N,AF) Adaptive arrays (A, N,A F)	Target acquisition (A, AF) Array processing (A, N, AF)
ELECTRO-MAGNETICS	Wireless and radar propagation Quasi-optical devices Printed antennae	Sea ice inverse scattering	Transient electromagnetics Secure propagation
Antennae Transients sensing Tubes	Integrated transmission lines (A, N, AF) EM numerical techniques (A, N, AF)	**Areas of Common Interest** Discontinuities in circuits (A, N, AF) Electromagnetic scattering (N, AF)	Vacuum electronics (N,AF) Optical control of array antennas (A, N, AF) Power efficient RF components (A, N, AF)

Table 3.2. Representative Specific Basic Research Goals Associated with Strategic Research Objectives

	2000	2005	2010
Biomimetics	Demonstrate advanced design principles for high-performance composites Fabricate/evaluate new advanced armor and semi/super-conductor materials based on biomimetic principles Demonstrate biologically derived advanced materials for optical modulators	Demonstrate advanced adhesives for use in adverse environments Utilize principles of metabolic design for synthesis of advanced materials Fabricate porous lightweight and resilient structural materials with novel properties and uses Demonstrate new materials for improved uncooled IR detectors	Demonstrate utility of biochemical transducers for MEMS devices Achieve decontamination of chemical agents using biomimetic catalysts Demonstrate principles of stealth propulsion w/o motors or gears Demonstrate new sensors based on the olfactory system
Nanoscience	Adapt scanning probe technology to sensing Fabricate multi-layer semiconductor interfaces with atomic control Achieve useful magnetic interactions between small single domains Demonstrate applicability of “dusty plasma” physics to improved surface treatment	Utilize nanostructure elements for 10 nm computer memory elements Demonstrate enhanced propellants and explosives with nanoparticle surface chemistry Demonstrate sensing of biomolecules for medical diagnosis with scanning probes Achieve improved, ultra-dense holographic memories	Demonstrate advanced electronic devices based on single atoms or molecules Utilize novel electronic transport in nanostructures for faster clock speeds Lower life-cycle costs by 10% through in-situ detection of material failures on the nanometer scale Demonstrate quantum computing
Smart Structures	Demonstrate new, reliable, cost-effective composite smart materials for low- and high-frequency structural control applications Achieve up to 40 dB reduction in vibration using embedded shaped sensors in rotorcraft box beams	Demonstrate up to 60 dB vibration reduction using shaped sensors and adaptive control algorithms Achieve MEMS wireless communications in a rotorcraft flight structure Demonstrate new impact-energy-dissipating smart materials	Demonstrate low-cost, self-tuning vibration damping patch with integrated power and sensing microprocessors Demonstrate addressable fiber optic sensor arrays for damage detection in composite structures

Table 4.5.3. Representative Basic Research Goals: Electronics

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Solid State and Optical Electronics	Prompt decisive combat Sensors and weapons control	Sensors and Electronics Weapons	Improved wide-bandgap semiconductor materials	Widegap semiconductor devices	Demonstrate multifunctional widegap semiconductor monolithic circuits
	Autonomous systems	Sensors and Electronics	Stable, reliable low voltage devices	Robust, rad-hard, low-power circuits	Ultra-low-power high density memory
	Real-time knowledge of the enemy Situational awareness	Sensors and Electronics Infomation Systems and Technology	Superlattice thermal imagers	Superlattice multispectral imagers	Monolithic multispectral imaging
Information Electronics	Information dominance Robust communication	Infomation Systems and Technology	Multiresolution coding	Multi-resolution video coding	High bandwidth multiresolution video data transmission
	Target detection and classification	Infomation Systems and Technology	Hyperspectral data processing	Optical sensor fusion	Sensor fusion of hyperspsectral data
	Real-time knowledge Situational awareness	Infomation Systems and Technology Sensors and Electronics	Distributed multisosurce, mobile communications	Robust networks	Low-cost, robust, reliable networks for multisource mobile applications
Electromagnetics	Target detection Precision strike	Sensors and Electronics Weapons	Efficient cold cathodes	Compact, low-voltage vacuum electronics	High-power, highly efficient, stable fast-wave amplifiers
	Target detection Precision strike	Sensors and Electronics	Optical and electronic phase control of arrays	Predictive models of patch and printed antennas	Conformal multifunction active arrays

4.6 Materials Science

Advanced materials research being conducted as part of the DoD Basic Research Program includes both need-driven and opportunity-driven elements that will impact virtually all DoD mission areas in the future. The Materials Science SPG plans and conducts an aggressive, integrated research program that is leading to new classes of materials possessing increased strength and toughness, lighter weight, greater resistance to combinations of severe chemical and complex loading environments, and improved optical, magnetic, and electrical properties. These advances are focused on meeting the Joint Chiefs of Staff warfighting needs through access to higher performance and superior weapons systems capabilities, together with improved readiness, decreased need for logistic support, increased reliability, and lower lifetime cost.

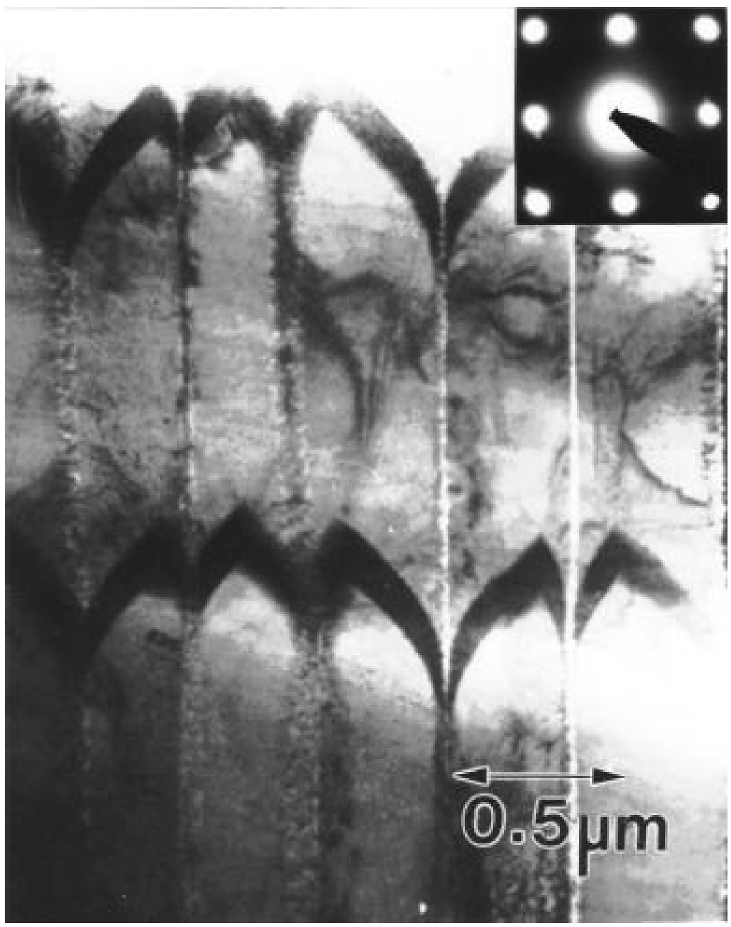


Figure 4.6 High-Temperature Protective Coatings Resistant to Degradation. Superstrong, ultrahard fracture-resistant metal laminate high-temperature coatings are important for a variety of military applications. The symmetry of the X-ray pattern in the upper right corner indicates controlled crystal growth. In this case, the thin white layers are molybdenum toughening phases (~50Å) and the dark layers are Mo/W strengthening phases.

Navy programs are driven by operational considerations such as ocean surface and subsurface vehicle designs, as well as naval air, space, and missile systems parameters. Air Force research efforts are dictated by requirements for high-performance aircraft and space platforms. Army research areas are closely coupled to Army mission requirements for armor/anti-armor systems, advanced rotorcraft, ground vehicles, missiles and projectiles. In certain areas of materials research, more than one Service has a vested interest in supporting programs. These areas of commonality involve large, diverse, and long-term multidisciplinary efforts. Such efforts are jointly planned through the SPG to maximize return on investment. For example, the area of tribology has the potential to impact the operational service life of guns, engines, and aircraft (among many other military systems). The tribology programs were planned with the Army sponsoring work on ion beam engineering/surface modification, the Navy supporting computational and experimental approaches for understanding wear surfaces and interfaces, and the Air Force focusing on failure diagnostics for aging aircraft. Budget information for materials science research is provided in Table 4.6.1. A more detailed outline of Service-specific interests and commonality in materials science research is included in table 4.6.2.

The DoD Basic Research Program in materials science includes two subareas: structural materials and functional materials. Research in both of these subareas includes elements of synthesis processing, structure, and properties. Theory and modeling also play an important role in these programs.

Structural Materials: *Research in this area is needed to satisfy operational requirements of DoD systems such as armor and penetrators, durable, high-temperature components of high-performance engines used in hypersonic air vehicles, and lightweight, tough, and corrosion-resistant hulls of naval ships.* Structural materials of principal interest are metallic materials, ceramics, composites, and polymers. The structural aspects have primarily to do with service under mechanical loads. Research thrusts in this area are focused on microstructural design and processing of new materials to achieve higher performance and improved reliability at lower costs, development of unique nano- and micro-structures, improved understanding of materials under complex loading and environmental conditions, mechanics and chemistry of interfaces, and innovative nondestructive techniques for characterizing interrelationships between processing and performance of advanced materials. Some of the research areas of growing importance germane to these thrusts include computational design, aging systems, biomimetics, and nanomaterials. The area of aging systems is of particular concern for all the Services in that research results may provide new opportunities for affordably maintaining and upgrading aging assets. Each of the Services is investing in multidisciplinary research focused on meeting this long-term need. Research is focused in the areas of corrosion and degradation, failure mechanisms, and life prediction and life management, with each Service concentrating on the special materials and structural aspects of its unique platforms and collaborating in more generic areas.

Functional Materials: *DoD systems that are impacted by research in Functional Materials include a host of electronic devices and components, mobile and fixed electro-optical communication equipment, radars, sonars, and other detection devices, displays,* *readers, and power control devices*. Research in this area is focused on understanding and controlling materials processes to achieve affordable and reliable performance, materials-by-design to provide new materials with unique properties, principles of defect engineering, and nanotechnology. Areas of growing importance include nanostructures, smart systems, and thermoelectrics. For example, in the area of thermoelectrics, novel material approaches that include PbTe-based superlattices, skutterudites, and organic composites are being pursued. These materials offer new opportunities for low temperature cooling of night vision equipment and electronics, and high-temperature applications for shipboard cooling and power generation.

A roadmap of representative research objectives for materials science in the near and far term is shown in Table 4.6.3.

Table 4.6.1. Basic Research Funding for Materials Science ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61101A	Army	1.9	2.6	2.7
PE 61102A	Army	14.3	9.0	10.0
PE 61104A	Army	0	2.8	2.9
PE 61152N	Navy	1.9	1.8	1.9
PE 61153N	Navy	36.1	34.2	34.4
PE 61102F	Air Force	12.1	11.1	11.4
PE 61101E	DARPA	27.8	18.2	21.8
	Total	**94.1**	**79.7**	**85.1**

Table 4.6.2. Service Specific Interests and Commonality in Materials Science

SUBAREA	Army	Navy	Air Force
STRUCTURAL MATERIALS Synthesis Processing Theory Properties Characterization Modeling	Manufacturing science (land/rotocraft systems, armaments) Armor/anti-armor materials Diesel engine materials Gun liner materials	Marine corrosion, oxidation, and fatigue Advanced materials for ships and submarines Acoustically damped structures Layered designed materials	High-temperature fatigue and fracture Aerospace skin materials Aging aircraft Functionally graded materials Hypersonic skin Balanced material properties
	Areas of Common Interest		
	Advanced composites (A, N, AF) Adhesion /Joining (A, N)	Tribology (A, N, AF) Ceramics (A, N, AF)	Intermetallics (N, AF)
FUNCTIONAL MATERIALS Synthesis Processing Theory Properties Characterization Modeling	Defect engineering Gradient index optics IR detectors CBD materials Smart materials	Ferrite films Ferroelectrics Diamond Acoustics/active materials Electronic packaging materials Superconductivity	(Topics addressed under chemistry, electronics, physics, and mechanics SPGs)
	Areas of Common Interest		
	Optoelectronics (A, N)		Magnetic materials (A, N)

Table 4.6.3. Representative Basic Research Goals: Materials Science

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Structural Materials	Aging systems	Materials and Processes	Non-invasive techniques for corrosion detection	Methodology for aging aircraft structural integrity	Real-time condition based maintenance
	Aircraft structures	Air Platforms	Simple smart structures for increased performance	Active control structures for structural integrity and stealth	Robust active controlled multi-functional structures
	Advanced armor	Ground Vehicles and Watercraft	Resin transfer molding of integral armor	Hybrid nanocomposite armor materials	Multi-functional lightweight armor materials
	Ship/sub hulls and machinery	Ground Vehicles and Watercraft	HSLA weldable steels (>100ksi) without preheat	Low carbon weld metals/hull steels at increased strength	Laser weld process for automated fabrication of ship hulls
Functional Materials	Active/passive and imaging sonar	Materials and Processes	Single crystal piezoelectrics of 90% electromechanical coupling	Electromechanical transducer materials with strains of 1-3%	First principle calculations of new piezoelectric materials
	Communications	Materials and Processes	Magnetic biasing films for MIMIC	Integrated ferrite/silicon structures with bulk properties	Frequency agile receivers
	Target acquisition	Materials and Processes	Adaptive opto-mechanical systems	Thermoelectric-based cooling systems	Broad band sensor protection
	Data storage/sensors	Materials and Processes	Thin film nonvolatile, high-density magnetic memory metals	Magnetic film sensors with 10X improved sensitivity	Magnetic film storage materials for greater than 10 Gigabytes/inch

4.7 Mechanics

The DoD Basic Research Program in mechanics represents the major national effort in this field. The overall scientific goal is to understand and control the response of complex phenomena for various military applications, including combat vehicles and weapon systems. Such understanding results in new capabilies for designing weapons, platforms, and subsystems that meet desired performance levels, offer enhanced survivability, and have predictable costs. There is an increasing DoD need for these advanced capabilities because: (1) modern demands for simulation-based design data to support acquisition decisions place a premium on the ability to accurately forecast system capabilities, and (2) longer time periods between major system acquisitions increase demands for major performance improvements with predictable affordability constraints

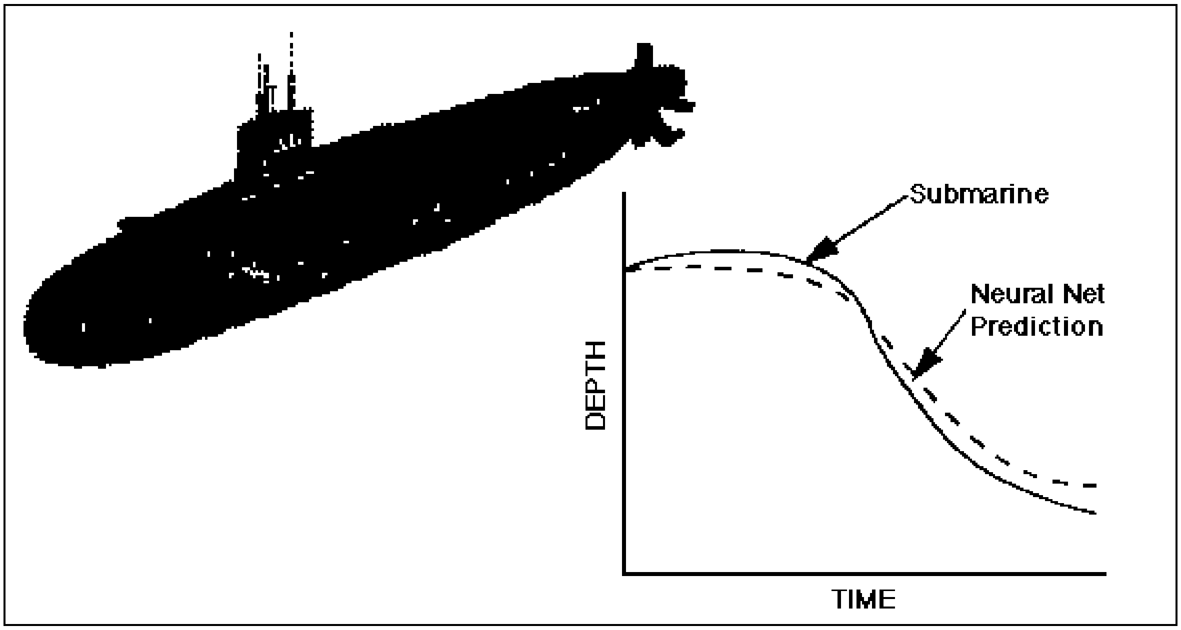


Figure 4.7. Neural Net Predictions of Submarine Behavior. Faithful representation of submarine maneuvers is important: (1) as a predictive design tool, (2) for relating maneuvering data obtained from hydrodynamic facilities to data obtained with real submarines, (3) as a training tool in maneuvering simulators, and (4) as a real-time predictor in an automatic control system that allows expansion of the submerged operating envelope. Neural nets were "trained" from maneuvering data obtained from a radio-controlled submarine (1/20th scale). This accomplishment offers promise for full-scale application of the technology to automatic control systems for submarines.

Mechanics, as an engineering science, is closely tied to the issue of complexity. Complexity manifests itself in several ways, such as the extremely large range of scales present in a phenomenon, or the plethora of simultaneous interactions that govern its dynamics. Characteristics of mechanics research are: (1) a focus on understanding relationships between microscale phenomena and macroscale response; (2) invention of new concepts for predicting and controlling strongly nonlinear/dynamic phenomena; (3) a strong emphasis on interdisciplinary work, with synergistic ideas from analysis, simulation, and diagnostics; and (4) a focus on the appropriate level of complexity relevant to engineering. These characteristics, alone or in combination, are present in all DoD mechanics research. Major research tools include modeling, based on new concepts in analysis and optimization; simulation, often taxing the largest of modern parallel supercomputers; and diagnostics, which measure spatial-temporal variations of multiscale phenomena. Budget information for DoD-supported mechanics research is given in Table 4.7.1.

Mechanics research supported by the Basic Research Program can be conveniently divided into three general areas, as described below. Each Service/Defense Agency performs research responsive to their respective system drivers. In a number of areas the Services/agencies have common interests. In general, each Service/agency performs research in an area of commonality, with specific non-overlapping technology targets. For example, in structural dynamics and smart structures, the Army emphasizes stability/control of rotorcraft structures; the Navy focuses on underwater explosion effects/structural acoustics, and the Air Force targets fixed-wing aeroelasticity and engine dynamics.

Solid and Structural Mechanics: *Research in this area deals with the identification, understanding, prediction, and control of multiscale phenomena that affect the properties and reliability of modern DoD structures*. Such phenomena range from fracture/fatigue initiated at micromechanical levels, to multiple-scale interactions that need to be quantified in order to optimize the dynamics of complex structures. Fracture alone costs DoD billions of dollars every year. Emphasis is in integrating knowledge from micro to macro level, and on macro-optimization. Research on “smart” structures integrates actuators, sensors and control systems into the structure to accomplish damage control, vibration reduction, and reconfigurable shapes (e.g., on “smart” helicopter rotor blades. Opportunities exist for optimizing lift/drag ratio, increasing lift, expanding the flight envelope, and reducing required installed power on DoD air vehicles. Solid mechanics research addresses finite deformation and failure mechanisms, penetration mechanics and computational mechanics. Reliability of ship structures, underwater explosion effects, structural acoustics and dynamics, shock isolation/vibration reduction in machinery, and noise control are addressed. A growing area of interest is the micromechanics of semiconductors, interconnects, and packaging for Power Electronic Building Blocks (PEBBs) used for power distribution. High-cycle-fatigue issues are addressed by new multidisciplinary research in structures, materials, aerodynamics, and control of turbomachinery. The anticipated products are physics-based models for response prediction; an enhanced understanding of unsteady and transient engine behavior; and robust active control.

Fluid Dynamics: *The design, performance and stealth of DoD weapons, platforms and subsystems depends on the tailoring of the distributed fluid mechanical loads that control their dynamics.* Modern supercomputers, whole-field laser diagnostics, sophisticated turbulence models, and microelectromechanical actuators are used, alone or in combination, to produce validated prediction/control methods. Central to fluid dynamics research is the understanding, prediction, and control of high Reynolds number turbulent flows. Such flows can be rotorcraft wakes, unsteady flows around maneuvering fighters, or multiphase flows around marine propulsors. Increased attention is being given to the coupling of helicopter rotor aeroacoustics fields and structural deformation, the understanding of compressibility, and to full-scale Reynolds number effects in aerodynamics and hydrodynamics. Simulations of high-speed flows in complex configurations relevant to hypersonic vehicles are being pursued, with emphasis on integrated approaches to inlets, supersonic combustion, and nozzles. Interdisciplinary research explores intelligent flow control strategies using microelectromechanical systems (MEMS) for thrust vectoring, high lift, drag reduction, and noise/signature reduction. An important new focus involves simulations of free-surface/two-phase flows around surface ships, understanding and predicting the behavior of maneuvering undersea vehicles, and exploring super-cavitation phenomena for high-speed undersea weapons.

Propulsion and Energy Conversion: *Research in this area is crucial to the performance/stealth of DoD weapons or platforms. The research is inherently and strongly multidisciplinary, combining knowledge from chemical kinetics, multiphase turbulent reacting flows, thermodynamics, detonations, plasmas and control*. Increasing emphasis and growth expectation are being given to active sensing, actuation, and control for engines, and integration into an intelligent engine model; high pressure kinetics; and combustion diagnostics. Another research focus involves synthesizing new energetic materials/fuels, characterizing their behavior, and controlling their energy release rates for specific DoD weapons applications. Research on the physical/chemical/material interactions in solid propellants, at realistic pressure environments, addresses their combustion mechanisms. Active combustion control is being pursued for tailoring tactical missile motor behavior and compact shipboard incinerators. High-performance aircraft require engines with high operating temperature and pressure. Research to achieve more efficient and durable combustion dynamics and high thermal capability (supercritical) fuels is being conducted.

Budget information for mechanics research is provided in Table 4.7.1. Service-specific interests and commonality in ongoing mechanics research areas are cited in Table 4.7.2. A roadmap providing selected mechanics research objectives over the next 15 years is given in Table 4.7.3.

Table 4.7.1. Basic Research Funding for Mechanics ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61101A	Army	1.5	2.2	2.3
PE 61102A	Army	21.6	13.6	14.1
PE 61104A	Army	0	16.4	13.3
PE 61152N	Navy	3.8	3.5	3.7
PE 61153N	Navy	36.5	34.1	34.4
PE 61102F	Air Force	29.7	27.8	28.6
	Total	93.1	97.6	96.4

Table 4.7.2. Service Specific Interests and Commonality in Mechanics

Subarea	Army	Navy	Air Force
SOLID AND STRUCTURAL MECHANICS Structural dynamics	Finite deformation, impact , and penetration	Structural acoustics Thick composites Micromechanics of electronic devices and solids	Hypersonic aeroelasticity Mechanics of high temperature materials Particulate mechanics
Composites Aeroelasticity Acoustics	**Areas of Common Interest** Structural dynamics and control (A, N, AF)	Damage and failure mechanics/QNDE (A, N, AF)	"Smart" structures (A,N,AF)
FLUID DYNAMICS Aerodynamics Turbulence Unsteady flow	Rotorcraft aerodynamics Rotorcraft aeropropulsion Projectile aeroballistics	Free-surface phenomena Hydrodynamic wakes Hydroelasticity and hydroacoustics	Turbomachinery aerothermodynamics Fixed wing aerodynamics Hypersonic aerothermodynamics
	Areas of Common Interest Unsteady separated flow (A,N,AF)		Turbulence (N, AF)
PROPULSION AND ENERGY CONVERSION Gas turbines	Reciprocating engines Gun propulsion Small gas turbines	Underwater propulsion Missile propulsion Explosives	Large gas turbines Supersonic combustion Spacecraft and orbit propulsion
Explosives, Soot formation	**Areas of Common Interest** High-energy materials combustion/hazards (A,N)	Soot formation (A, N, AF) Turbulent flows(A,N,AF)	Spray combustion (A, AF)

Table 4.7.3. Representative Basic Research Goals: Mechanics

Subarea	Area of MilitaryImpact	Relevant DTAP(s)	2000	2005	2010
Solid and Structural Mechanics	Ship survivability	Ground Vehicles and Watercraft	Dynamic fracture criteria for welding	Coupled local-global simulation	Validated simulation of underwater explosion effects
	High performance helicopters	Air Platforms	Smart rotor blade concept	Integrated aeromechanics analysis for maneuvering rotorcraft	Embedded smart vibration control concepts
	Gas turbine engine performance	Air Platforms	Engine model for response prediction	Understanding transients	Robust active control transition
Fluid Dynamics	Ship signature effects	Ground Vehicles and Watercraft	Reynolds Average Navier Stokes (RANS) for surface ships	Two-phase flow simulation	Two-phase flow ship simulations
	High-performance helicopters	Air Platforms	Coupled structural deformation/aero-acoustic models	Full Reynolds/Mach number simulation of dynamic stall	Aerodynamic simulation of maneuvering helicopter
	Hypersonic aircraft	Air Platforms	Inlet flow simulations	Understanding of nozzle physics	Simulations of integrated inlet/combustor/nozzle
Propulsion and Energy Conversion	Gun propulsion techniques	Weapons	Liquid propellant hazard kinetics	Accurate models of ram accelerator	Multi-phase interior ballistic models
	New missile propellants	Weapons	Chemistry/material/flow model	Prediction/control of rocket motors	Difluoramino-based propellants
	High-performance liquid engines	Weapons	Physics of supercritical fuels	Low emission supercritical fuels	Supercritical fuels in engines

4.8 Terrestrial Sciences

Research in the terrestrial sciences area is almost entirely supported by the Army. Navy interests are limited to ice mechanics, a collaborative effort with the Army. The vast majority of related Navy work is reported under Ocean Sciences. The Air Force program in solid earth physics, limited to seismology in support of global monitoring of a nuclear test ban, has recently been terminated by Department of Defense Program Budget decision 203C, dated 22 January 1996. The subject of environmental quality, which is included as a subarea of Terrestrial Sciences research by the Army, is assigned to different technical areas by the other Services. Budget information for terrestrial sciences research is provided in Table 4.8.1 Service specific interests and commonality are described in Table 4.8.2. Representative research objectives for terrestrial sciences research are included in Table 4.8.3.

The requirement for research in the terrestrial sciences stems from the impact that the physical environment has on virtually all aspects of Army activity. Programs of theoretical and experimental research in the solid earth and hydrologic sciences are required to support DoD mission in a wide variety of circumstances. To be successful, the modern CONUS-based power-projection Army must be able to perform at full capability throughout the world, in operational theaters that may range from equatorial to polar latitudes, and in terrain that may vary from coastal beach and lowlands to deserts and mountains. The objective of the 21st Century Digital Battlefield requires detailed information regarding distributed terrain conditions and a sophisticated capability for terrain information processing, analysis, and visualization. Despite continuing Army efforts to develop an all-weather/all-terrain capability, terrain and environmental conditions still constrain Army operations, particularly in areas of climatic extreme and in adverse environments. Thus, in the terrestrial sciences context, there is a particular Army need for an improved ability to better understand terrain and utilize terrain information for military purposes. An Army commitment to environmental stewardship is supported through research related to environmental quality.

The DoD Basic Research Program in Terrestrial Sciences includes four subareas:

Solid Earth Sciences: *Research in this area comprises both field studies and laboratory research related to the acquisition, analysis, interpretation, and modeling of information about terrain and terrain behavior under different climatic conditions.* Research on terrain characteristics and behavior is aimed at enhancing the current capability to interpret and utilize remotely sensed information about topography, natural features and man-made objects, and short-term battlefield surface conditions and dynamics at a variety of scales. Other aspects of terrain research focus on multispectral approaches to terraim remote sensing, physical and theoretical terrain characterization, and the automated generation of terrain databases and analysis of terrain information. Areas showing increased attention are radar (IFSAR), elevation matrix generation, high-resolution airborne sensor exploitation, and hyperspectral automated image classification. Integrated terrain analysis, modeling, visualization, and simulation are also important areas being pursed in these research efforts.

Figure 4.8. Rough Terrain Traversal by Heavy Armor. Army M1A1 Abrams main battle tanks outfitted with mine rollers are being used in Bosnia and Herzegovina during Operation JOINT ENDEAVOR. Basic research work in terrestial sciences involving the characterization of traction-related ground properties improves our ability to predict the tactical mobility of both wheeled and tracked vehicles over natural terrain, thereby contributing to the planning and execution of various ground combat operations.

Snow, ice, and frozen ground occur either occasionally or continuously from the mid-latitudes poleward; depending on particular conditions and equipment availability, they can either enhance or hinder survivability and operational mobility. Research in snow, ice, and frozen ground derives from specific needs to better understand the physical and mechanical behavior of these materials. Current efforts are focused on energy propagation processes, biogeochemical processes, and the physical and mechanical properties and behavior of snow, ice, and frozen ground. Areas of emphasis for the near future are ice physics and the mechanical behavior of ice at intermediate to large scales. Ice adhesion is also a subject of increasing interest and activity. The Navy supports work involving sea ice and Arctic marine environments.

Surficial Processes: *Research in this area is directed toward enhancing Army operational mobility through improved characterization of the dynamics of surface and near-surface terrestrial environments, and through better understanding of the dynamic processes that form and modify surficial landscapes.* Of particular interest are the highly interrelated hydrometeorlogical, hydrologic, and hydraulic processes of the hydrologic cycle. Because the Army is responsible for Logistics Over the Shore (LOTS), research to more fully understand the hydrodynamic and sedimentary processes that form and modify beaches is also an important terrestrial sciences requirement.

Current research efforts address the mobility issue from several different perspectives. One major effort is directed toward modeling the dynamic interactions of wheeled and tracked vehicles with terrain in the context of off-road mobility. Another important effort seeks to understand the fundamental structure of drainage basins, the mechanisms of runoff generation, and the effects of temporal/spatial variability of precipitation on runoff hydrography; the aim of this work is to achieve real-time prediction and modeling of the hydrologic response of basins to precipitation events of different magnitudes and durations. Other efforts are focused on subsurface hydrologic modeling, sediment mechanics and erosion processes, and geostatistical analysis. Areas of increasing emphasis include the evaluation of soil response to transient loading, coastal processes and dynamics, atmosphere-terrain dynamic interaction, space-time variability in hydrologic systems, and the dynamics of basin/landscape evolution. Geophysical remote sensing efforts have recently commenced that are directed toward the seismic detection of shallow sedimentary features, voids, and buried objects.

Environmental Quality: *The Army is committed to a policy of environmental stewardship based on the four pillars of Compliance, Restoration, Pollution Prevention, and Conservation.* Therefore, research is being undertaken to provide the Army with required capabilities for (1) conducting activities in compliance with all Federal, state, local, and host-nation regulations; (2) cleaning up contaiminated sites at Army installations; (3) eliminating pollution at its source; and (4) appropriately managing natural and cultural resources on Army installations.

Structures and Facilities: *Research in this area relates to the important Army issues of airfields and pavements and structure survivability.* Current efforts relate to improved pavement performance, modeling the response of pavements to static and dynamic loading, developing materials for multispectral camouflage, development of high-performance cement-based materials, constitutive modeling of geologic and structural materials, and the structural analysis of deformable projectiles during penetration. Topics of increasing importance for the future are pavement overlays and interfaces, the modeling of thixotropy, testing and simulation of advanced penetrators into concrete structures, structures in rock, and high-strength, high-ductility structural materials.

Table 4.8.1. Basic Research Funding for Terrestrial Sciences ($ Mllions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61101A	Army	0.6	0.7	0.7
PE 61102A	Army	15.0	17.1	19.9
PE 61102F	Air Force	4.0	4.0	0
PE 35145F	Air Force	0	0	4.0
	Total	19.6	21.8	24.6

Table 4.8.2. Service Specific Interests and Commonality in Terrestrial Sciences

Subarea	Army	Navy	Air Force
SOLID EARTH SCIENCES Sources Detection	Remote sensing Environmental quality Digital topography Terrain, vegetation scatter Snow, ice, frozen ground Soil Mechanics	Marine ice mechanics (funded in Ocean Sciences)	Seismology
HYDRO-DYNAMICS AND SEDIMENTARY PROCESSES	Tactical mobility LOTS Geomorphology Hydrology	No Service specific programs	No Service specific programs

Table 4.8.3. Representative Basic Research Goals: Terrestrial Sciences

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Solid Earth Sciences	Force Projection	Materials and Processes	Dynamic soil deformation algorithms for mobility models	Algorithms describing repetitive vehicle loading on deformable soils	Constitutive algorithms for predicting temporal response of soils
	Surveillance and target recognition	Sensors and Electronics	Neural network terrain data classification	Direct 3-D imaging of terrain	Fully automated real-time terrain visualization
	Force Projection	Materials and Processes	Multi-phase continuum models for penetration and ground shock	High-resolution internal diagnostics for soil characterization	Plasma hardening of soils
	Force Projection	Materials and Processes Sensors and Electronics	Snow friction effect for wet and dry snow	Model effects of snow chemistry on millimeter wave response	Determine impact of winter environmental conditions on emerging sensing devices
	Force Projection	Materials and Processes Sensors and Electronics	1-10km resolution sea ice model	Coupled ocean-ice model	Coupled air-ocean-ice model
Hydrodynamics and Sedimentary Processes	Force Projection	Materials and Processes Sensors and Electronics	Scaling effects in hydrologic systems	Constituitive model for soil-vehicle interaction	High-resolution simulator of space-time rainfall for mobility assesment
	Force Projection	Materials and Processes	Constituitive relations for sediment transport	Beach-bar evolution model	Predictive model for characterization beach chracter on short time scales

4.9 Ocean Sciences

Because the oceans are the Navy's principal operating environment, robust competency in Ocean Sciences is a core requirement and responsibility of the U.S. Navy. The Army has mission interests in Joint Logistics-Over-The Shore (JLOTS) coastal engineering. These two services share a common interest in near shore/beach processes and in coastal waves.

Important phenomena and parameters in the Ocean Sciences include tides, currents, temperature and salinity of the water column, surface and internal waves, ocean fine structure, surf, optical properties, bubbles, and biological and chemical contents. The dominant area of scientific and technological advance is in nowcasting and forecasting the ocean and its acoustic features from the bottom to the surface. The domain for this advance extends from the open ocean to the beach.

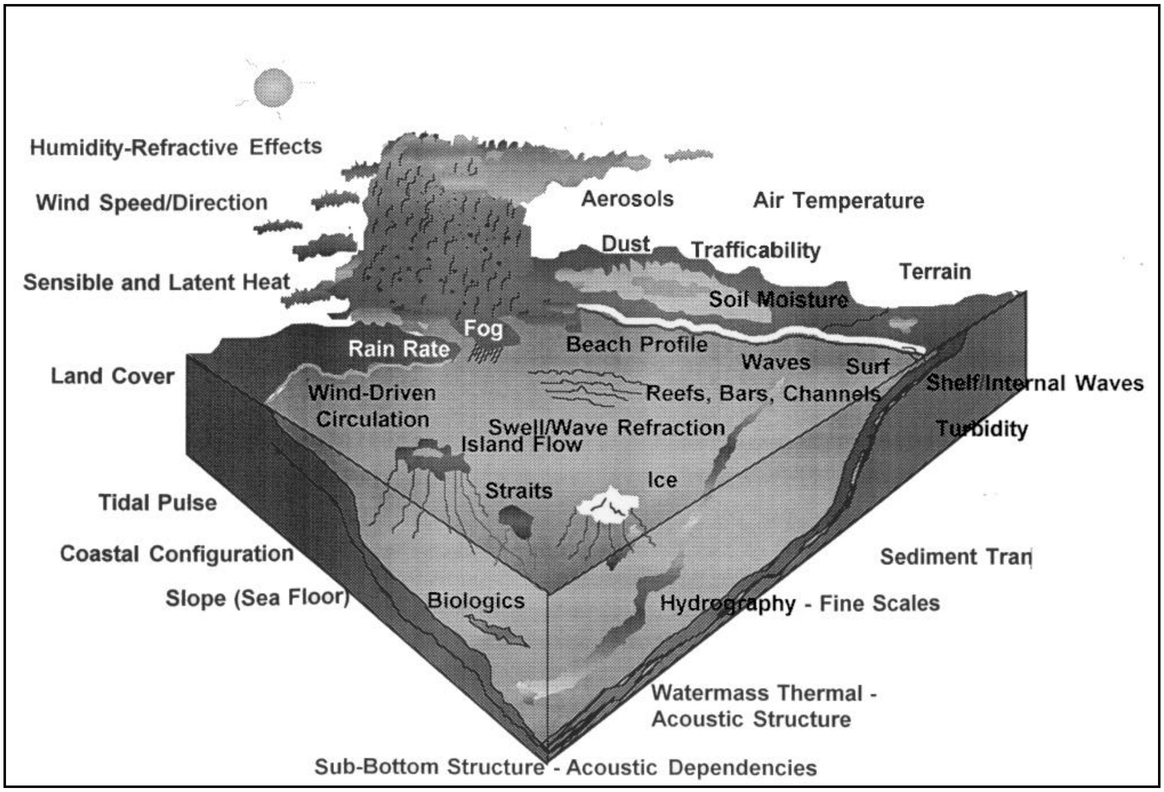


Figure 4.9. The Littoral Environment. The littoral operating environment is one of great complexity and rapid changes. There are complicated boundaries at the coast and bottom of the ocean; coastal topography is often rough and variable; surface waves are often large, dangerous, and quickly-varying; there is fresh-water runoff to the ocean from rivers and estuaries; there is salt-water intrusion (and wave action) on the land; meterological conditions change rapidly in time and space; offshore ocean forcing is major but difficult to measure or forecast; and anthropogenic influences (commerce, noise, pollution) are ubitquitous. Characterization and prediction of the littoral battlespace is difficult on land, in the ocean, and in the atmosphere, yet half the world's population lives within 50 miles of the coast line, so today's warfighter must be able to operate in the littoral realm and to exploit environmental variability. The approach in basic research is to blend observations from remote sensing and on-scene sensors with historical data bases, using physics-

constrained models as smart and adaptive interpolators, extraplolators, and predictors. These are validated and demonstrated in applied research and developmental efforts.

DoD-supported ocean sciences research includes work in three subareas:

Oceanography: *The fundamental knowledge provided by research in this subarea impacts Navy capabilities to operate in the ocean, and to be able to effectively utilize its sensors and weapons. Both Army and Navy capabilities in the coastal and beach regimes are also addressed by this subarea.* While kilometer or-higher-resolution thermal structures, nowcasts and/or forecasts may adequately resolve the ocean scales to support low frequency active acoustic systems in the open ocean, the littoral zones of the world, such as marginal shelves and shallow water coastal regions, require much finer resolution to nowcast/forecast the 4-dimensional ocean environment relevant to operations such as amphibious assault, special operations, and mine countermeasures (MCM) operations. Research thrusts include: regional prediction of ocean surface wave conditions and their time evolution, which affect JLOTS; ship-based models for western boundary currents (e.g., the Gulf Stream) to permit environmentally adaptive prosecution of ASW and safer carrier operations; studies of the rate of conversion of dimethyl-sulfide to sulfur dioxide for projecting aerosol concentrations, which influence the performance of lower-atmosphere electro-optical systems in the marine environment; and investigation of a Laser Line Scan (LLS) fluorescence mapper for benthic spectra to aid optical detection of mines in shallow water. Recent accomplishments include the discovery of ultra-thin layers of oceanic biological activity materially affecting undersea optical surveillance; completion of a major field experiment (Duck-94) to measure the full spectrum of near-shore processes simultaneously; the elimination of wind forcing as an important process for cross shelf transport, thus simplifying the data requirements for near-shore DoD operations; and development of a full Boltzmann shallow water wave model, which impacts the accuracy of coastal wave predictions in support of JLOTS and expeditionary warfare.

Ocean Acoustics*: This area impacts Navy capabilities to detect, classify, and neutralize undersea enemy systems and activities. The ocean is transparent to sound propagation, so fundamental knowledge of ocean acoustics is key to systems design, operating strategies, and tactical decisions.* Recent accomplishments include identification of the importance of range dependence for shallow water acoustics, providing enhanced detection and classification of diesel submarines in coastal environments; development of an efficient poro-elastic numerical code for high frequency acoustics, critical to effective mine-hunting and torpedo guidance in shallow water; identification of internal waves as significant scatterers for long-range acoustic propagation, affecting acoustic systems design to regain acoustic superiority in deep water; and demonstration that multiple upper-ocean parameters will be needed to estimate ambient noise, thus giving a tactical edge in acoustic prosecutions in the littoral region.

Ocean Geophysics*: This area impacts both Navy and Army capabilities to work in the ocean and at its boundaries, and provides part of the essential knowledge base required by the other two subareas.* Recent accomplishments include the development of the sequence stratigraphic methodology for identifying sedimentary regimes, which provides a zero-order statement of bottom sediments in denied areas to support shallow-water ASW and mine-hunting operations; development of tripod design to measure sediment suspension for accurate surveys in the littorals, thus giving an effective and cost-efficient methodology to develop and test models for optical detection of mines; and development of techniques for combining LIDAR bathymetry with hyperspectral images to infer bottom materials and depth, allowing airborne and satellite remote sensing estimation of bottom type and characterization in support of MCM and expeditionary warfare.

Budget information for ocean sciences research is provided in Table 4.9.1. Table 4.9.2 cites representative Service interests in the three Ocean Sciences subareas. A roadmap of representative research objectives for Ocean Sciences in the near, mid, and far term is provided in table 4.9.3.

Table 4.9.1. Basic Research Funding for Ocean Scieces ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61152N	Navy	0.6	0.6	0.6
PE 61153N	Navy	91.4	93	93.6
	Total	92.0	93.6	94.2

Table 4.9.2. Service Specific Interests and Commonality in Ocean Sciences

Subarea	Army	Navy	Air Force
OCEAN-OGRAPHY	No Service specific program	Physical, chemical, biological, optical, modeling and prediction	No Service specific program
OCEAN ACOUSTICS	No Service specific program	Shallow water acoustics High frequency acoustics Long range propagation Acoustic reverberation	No Service specific program
OCEAN GEOPHYSICS	Logistics over the shore (LOTS) Coastal engineering Coastal erosion	Continental terraces Sediment processes	No Service specific program
Common Areas of Interest Nearshore/beach processes (N,A) Coastal waves (N,A) Coastal currents/water levels (A,N) Coastal bathymetry (A,N)			

Table 4.9.3. Representative Basic Research Goals: Ocean Sciences

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Oceanography	Special warfare Mine countermeasures Surveillance Navigation Amphibious landings	Sensors and Elecltronics Space Platforms	Littoral internal wave model Marine atmospheric sulfur model Channel optical scanner	Littoral ocean model Shipboard aerosol model Model to predict biology effects on optics and acoustics	Interactive open ocean-littoral, air-sea model for physical, biological, chemical and /or optical features
Ocean Acoustics	Mine countermeasures Surveillance and reconnaissance Undersea warfare	Sensors and Elecltronics Space Platforms	Model effects of internal waves in shallow water Quantify fluctuations as function of propagation range	Littoral ambient noise model Quantify scattering mechanisms as function of frequency Improved acoustic tomography methods	Ocean bottom scattering model High-frequency propagation model in poro-elastic media
Ocean Geophysics	Mine Countermeasures Navigation Amphibious landings	Sensors and Elecltronics Space Platforms	Stratagraphic extrapolation model 2-D sediment entrainment model High resolution littoral wind wave model Coupled wave-current model Improved sediment concentration sensors	Slope instability model 3-D bottom boundary layer model Littoral sediment transport model Broad-band surf zone hydrodynamics model Coupled wave-current sediment model Nearshore sediment dynamics model	Predictive geologic model for shelf beach/bar morphology Sensor-driven model for coastal prediction Data-driven sediment dynamics model

4.10 Atmospheric and Space Sciences

This program develops knowledge in atmospheric and space sciences for operational use by the Services and across the DoD. Research in meteorology (dynamical, physical, and modeling), remote sensing (active and passive) in and through the atmosphere, and space science is conducted to develop the fundamental knowledge needed to achieve a broad range of DoD objectives. The products of this research are transitioned to the Services for use in deployed weapon platforms, operations, planning, training, and the forecasting of battlespace conditions.

Research programs are dictated by individual Service requirements and identifiable barriers to technological progress. Maintaining a complete program of research across the full spectrum of this area is not feasible. Therefore, the DoD program monitors and leverages related research from other national agencies such as the Office of the Federal Coordinator for Meteorology, NSF, NASA, NOAA, DNA, and DOE. Instances of cost sharing (leveraging) include: (1) tropical storm research (ONR, NOAA); (2) ship cloud effects (ONR, NSF, NASA); (3) space plasma physics (AFOSR, NASA); (4) remote sensing (ARO, NOAA); (5) high resolution modeling (ARO, ONR, AFOSR, NSF, NOAA); (6) atmospheric electricity (AFOSR, NASA); and (7) boundary layer modeling (ARO, NOAA). DOE sponsorship of the Atmospheric Radiation Program provides significant leveraging to Defense-wide thrusts involving cloud dynamics and atmospheric modeling. Defense-wide programs also sponsor special scientific conferences, including Cloud Interactions on DoD Operations and Systems (CIDOS), and the International Symposium on Spectral Sensing Research, providing all national agencies a forum for conveying research results of common interest.

DoD basic research in the area of atmospheric and space sciences includes three subareas, as described below. The Army program emphasizes research in the area of boundary layer dynamics, and propagation of aerosols (including chemical/biological materials). The Navy meteorology program focuses on the marine environment, including tropical cyclones, marine cloud processes, air-sea interaction, and coastal prediction. The Navy space program emphasizes space-based sensing of exo-atmospheric physics, while the analagous Air Force space program is typically ground based. The Navy has a responsibility for global-scale meteorological modeling, while the Air Force emphasizes theater scale modeling over continental areas.

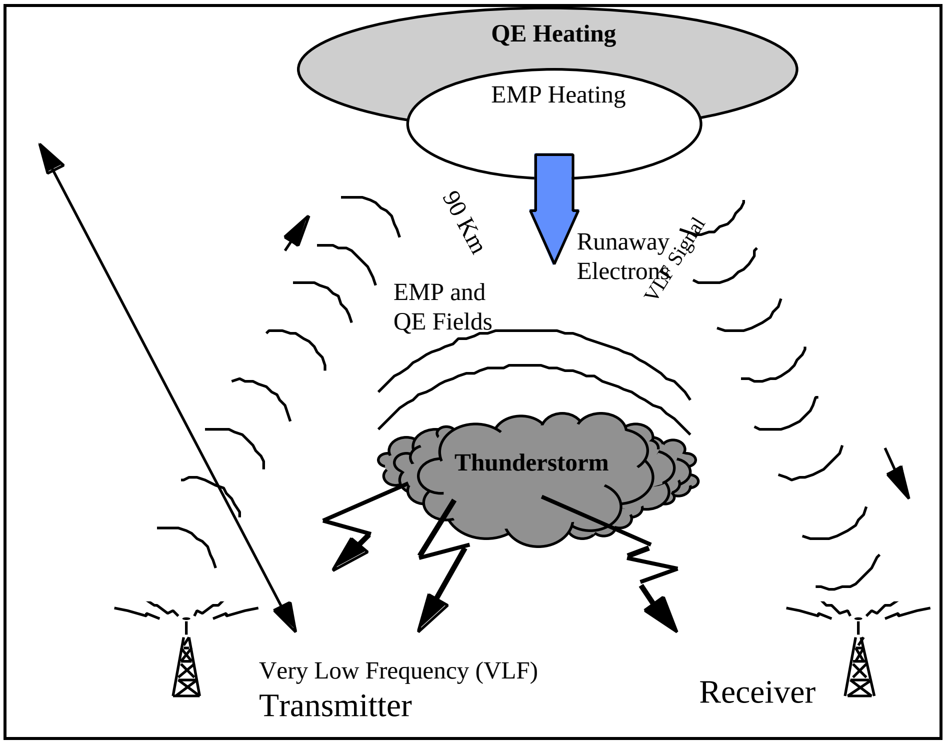


Figure 4.10. Stratospheric Perturbations Resulting from Intense Thunderstorm Electrification (SPRITEs). SPRITES are spontaneous electromagnetic discharges in the upper atmosphere triggered by thunderstorms and upper atmospheric quasi electrostatic (QE) forces and fields that can disrupt various forms of electronic communications and surveillance signals. Researchers are investigating the characteristics and persistence of infrared and ultraviolet signatures created by these discharges to determine their effect on space-based systems.

Meteorology: *The meteorology subarea acts as a force multiplier and impacts safety of operations and personnel, fuel savings and efficiency of operations, and platform, sensor, and weapon performance in support of all military operations. This program emphasizes tactical environmental parameters.* Research in this area is directed toward understanding the basic physical processes in the lower atmosphere (up through the tropopause) over a variety of underlying surfaces. Emphasis is placed on understanding the turbulent nature of the atmosphere over a range of space and time scales over the water (Navy), in coastal regions (Navy and Army), and in the interior of continents (Army). Understanding the nature of atmospheric turbulence affects the ability to predict the transport and diffusion of airborne effluents, aerosols, heat, and moisture. Additional emphasis is on cloudy boundary layers, both those dominated by stratus clouds as well as convective regimes. Special attention is directed toward understanding the behavior and evolution of tropical cyclones in general and in the western Pacific Ocean in particular, where DoD has the lead forecast responsibility for the U.S. This international effort is directed toward improving our knowledge about motion (track), structure (size) and intensity (windspeed) of these important phenomena. The research program achieves an effective balance among theoretical modeling, analytical case studies, and experimental observations. The limits to predictability is an area receiving increasing attention.

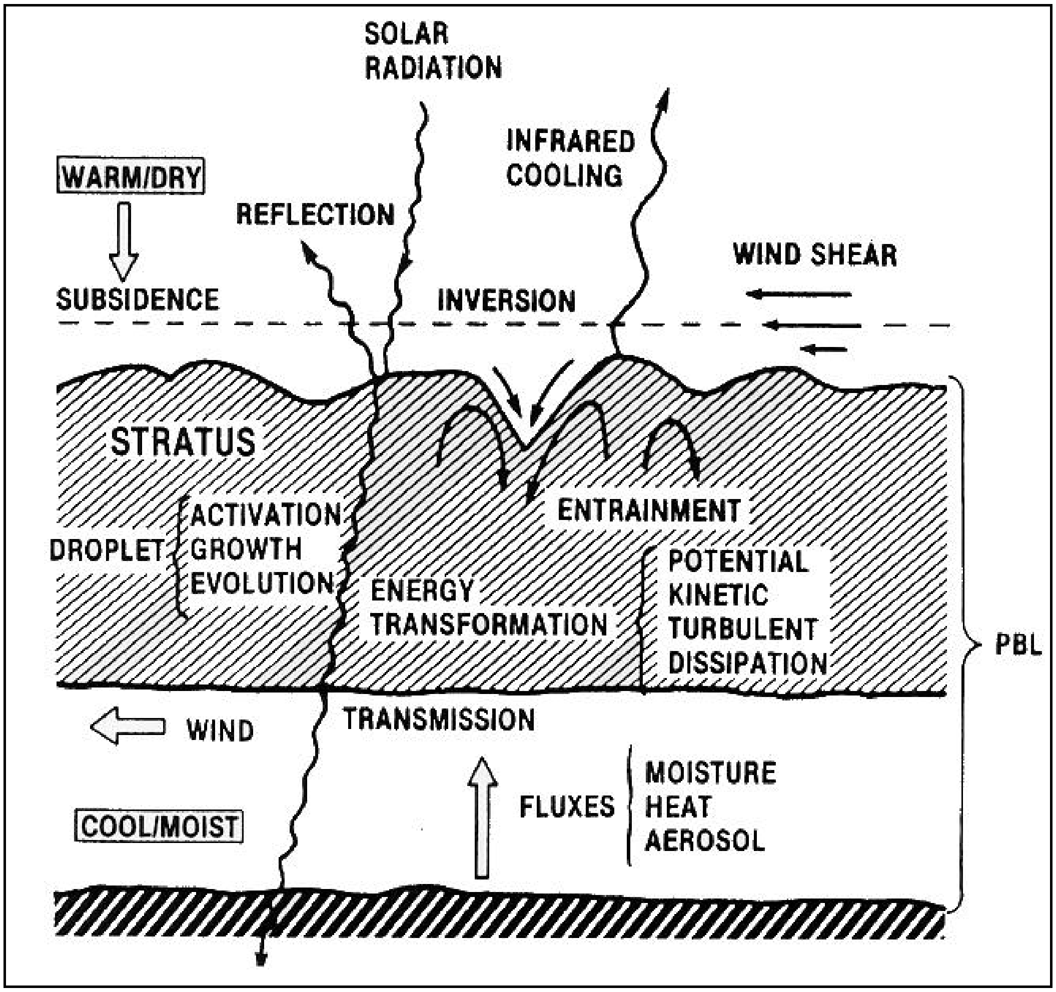


Figure 4.11. Marine Planetary Boundary Layer. The marine planetary boundary layer (BPL) is often capped by stratus clouds. The physical processes governing the breakup of stratus clouds is shown above. Above cloud processes include wind shear, radiative cooling, dry air subsidence; within cloud processes include droplet microphysics, turbulent dissipation and energy transformations through latent heat; below cloud processes are dominated by the heat, moisture, aerosol, and momentum fluxes between the ocean's surface and the atmosphere.

Remote Sensing: *The remote sensing subarea characterizes environmental parameters critical to the performance of electromagnetic and electro-optic weapons and sensors; it also supports chemical and biological warfare.* This subarea focuses on application of wind profiler technology to measure the detailed fine structure of wind, temperature, humidity, and aerosols within the atmospheric boundary layer. Of special importance is the ability to model and predict marine refractivity profiles and surface base ducts.

Space Science: *Improved astrometric reference frames support operational requirements for precision guidance and autonomous satellite navigation. Space physics research is directed towards prediction of solar and geomagnetic disturbances that cause C4I outages and degraded performance. Ionospheric and upper atmospheric neutral density research addresses needs for improved GPS accuracies, precision geolocation of RF* *emitters, and RF communication.* A new Naval optical interferometer may provide positional accuracies of astronomical sources below the milliarcsecond level. Precision time interval and transfer is required for precise targeting and synchronization of communications and other systems. Solar and heliospheric research is directed toward improved understanding of the mechanisms for generation of solar extreme ultraviolet flux, solar flares, coronal mass ejections, and the propagation of these phenomena from the sun through the magnetosphere to the earth. Ionospheric variability affects RF communication at frequencies from VLF through UHF, with diminishing influence with increasing frequency. Upper atmospheric neutral density research is required for improved specification of satellite drag, orbital tracking, and vehicle reentry.

Budget information for basic research work in the atmospheric and space sciendes area is given in Table 4.10.1. Service specific interests and commonality in this research area is indicated in Table 4.10.2. Table 4.10.3 provides a roadmap of relevant basic research objectives for both the near and far term.

Table 4.10.1. Basic Research Funding for Atmospheric and Space Sciences ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61102A	Army	7.3	4.9	5.0
PE 61152N	Navy	0.1	0.1	0.1
PE 61153N	Navy	23.4	23.8	24.0
PE 61102F	Air Force	9.4	10.0	10.3
	Total	40.2	38.8	39.4

Table 4.10.2. Service Specific Interests and Commonality in Atmospheric and Space Sciences

<table>
<tr><th>Subarea</th><th>Army</th><th>Navy</th><th>Air Force</th></tr>
<tr><td rowspan="3">METEOR-
OLOGY</td><td>Continential boundary layer
Small scale meteorology
Transport, diffusion, obscuration
Chemical/biological defense</td><td>Marine boundary layer
Maritime and coastal meteorology
Heterogeneous flows
Major storms, worldwide
Synoptic to mesoscale modeling
Aerosol models</td><td>Upper troposphere
Mesoscale
meterology
Lightning</td></tr>
<tr><td colspan="3">Areas of Common Interest</td></tr>
<tr><td>Aerosol effects (A,N)
Coherent structures (A,N)
Sub-grid scale parameterization (A,N)
Large eddy simulation (A,N)</td><td>Atmospheric transmission (A,N,AF)
Rediative energy transfer (A,N,AF)
Nested models of all scales (A,N,AF)
Surface energy balance (A,N,AF))</td><td>Cloud formation and processes (N,AF)
Contrast transmission (A,N,AF)
4-D data assimilation (A,N,AF)</td></tr>
<tr><td rowspan="3">REMOTE
SENSING</td><td>Fine resolution of wind, temperature and humidity fields within boundary layer
Chemical/biological detection</td><td>Marine refractivity profiles</td><td>Surface based ducts</td></tr>
<tr><td colspan="3">Areas of Common Interest</td></tr>
<tr><td colspan="3">Atmospheric profiles of temperature, humidity, winds, aerosol concentration (A,N,AF)</td></tr>
<tr><td rowspan="3">SPACE</td><td></td><td>Precision time
Space-based solar observation
Wave-particle interactions
Astrometry</td><td>Ground-based solar observations
Energetic solar events
Ionospheric structure and transport
Optical characterization</td></tr>
<tr><td colspan="3">Areas of Common Interest</td></tr>
<tr><td>Neutral density (N,AF)
Ionospheric C3I impacts (N,AF)</td><td></td><td>Celestial Background (N,AF)
Geomagnetic Activity (N,AF)</td></tr>
</table>

Table 4.10.3. Representative Basic Research Goals: Atmospheric and Space Sciences

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Meteorology	Target acquisition Battlefield forecasts	Sensors and Electronics	Lattice techniques for meteorological prediction	Improved algorithms for development and dissipation of transient cumulus clouds	Cloud and atmospheric electrification algorithms
	Surveillance and precise targeting	Space Platforms	Understand coastally trapped disturbances. Assimilation of remotely sensed physical parameters	Assimilation of tactical radar information Targeted weather observing strategies	Full 4-dimensional data assimilation
	Ship Self-Defense	Space Platforms	Improved air-sea transfer parameterizations incorporating wave interactions	Assimilation of remotely sensed marine boundary layer structures Spray aerosol generation models	Complete source/sink / advective marine aerosol models
Remote Sensing	C3I, Target acquisition, battlefield forecasts	Sensors and Electronics	Passive microwave synthetic aperture radiometry techniques	Accurate, high-altitude moisture sensors	Multispectral algorithms for 3-D structure of clouds
Space Science	Precise time; Synchronization	Sensors and Electronics	3-nanosecond time transfer	1-nsec time transfer, 3-nsec synchronization	Sub-nsec time transfer and synchronization
	Astrometry for weapons guidance	Sensors and Electronics	10-milliarcsecond (mas) stellar position accuracies for 1000 objects	3-mas accuracies Preliminary infrared catalogue	Full stellar catalogue at better than 1 mas maintainable accuracy
	RF propagation through the Ionosphere	Sensors and Electronics	New space-based sources of real-time ionospheric sensing	3X Improved accuracies for precision geo-positioning, GPS	Predictive models for ionospheric variability
	Satellite drag and vehicle reentry	Sensors and Electronics	New database of and improved algorithms for neutral densities	3X improvement of satellite trajectories	Validated predictive models of neutral drag
	Space-based solar observations	Sensors and Electronics	New physics models for flares, coronal mass ejections	200% improvement in predictions of C4I outages	Full physics MHD for solar and geomagnetic disturbances

4.11 Biological Sciences

Research in the biological sciences provides the fundamental knowledge required to utilize biological processes and techniques for producing novel materials and processes having important military applications. Major goals are to increase affordability by reducing maintenance and synthetic processing costs, and to inhibit or prevent the deleterious effects of chemical, biological and physical agents from interfering with military warfighting and peace-keeping operations by assuring that safety standards are based on solid scientific evidence.

A single Service now conducts the basic research for all three Services in areas where it is the technology leader for related 6.2 and/or 6.3 programs, or where that Service has the largest investment and program expertise. The Army is the DoD executive manager for chemical and biological defense technology, and ONR and AFOSR rely on the results of Army-executed research in the chemical and biological defense area in meeting their own specific needs.. The Air Force was designated through Reliance agreements to form the Tri-Service Toxicology Center at the Armstrong Laboratory at the Wright-Patterson AFB and has consolidated S&T in non-ionizing radiation and laser radiation bioeffects at Brooks AFB. The Navy is the only Service that supports work in the marine environment. Budget information for biological sciences research is provided in Table 4.11.1. Table 4.11.2 identifies Service specific interests and commonality for this basic research area.

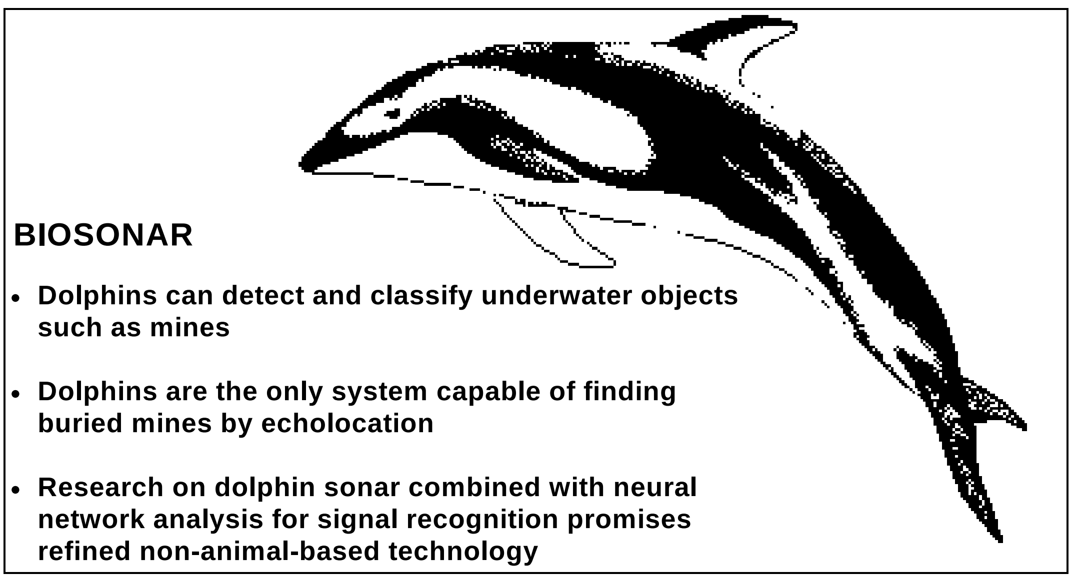


Figure 4.12. Navy Biosonar Research Includes Studies of Marine Mammals.

DoD Basic Research Program activities in the biological sciences area are categorized in two major subareas:

Biotechnology*: Advances in biotechnology provide the warfighter with new options for increasing survivability and mission effectiveness on modern battlefields through novel* *materials, more sensitive and accurate sensors, and new techniques for protecting military personnel and materiel.* Current research programs in biotechnology focus on biomolecular processes and materials, biosensors, and biological transformations in marine environments. The Navy emphasis in this area is on molecular biology of marine organisms, biosensors for marine mine countermeasures and anti-submarine warfare, biodegradation in marine sediments, biofabrication, and bioadhesion. Army research in biotechnology focuses on improvements in military materiel and emphasizes research on cells as manufacturing plants, biocatalysis, cellular information processing, and biomolecular electronics and mechanics. In the common area of biomimetics, the Army program focuses on an understanding of biosynthetic pathways, and the nature of materials produced by such biosynthesis and its exploitation via metabolic engineering.. The Navy focuses on mimicking materials or processes that occur in marine organisms, metabolic engineering, genetic networks, cell-based sensors, and bioadhesives for underwater applications. The Air Force is investigating functional biomimetics such as animal infrared sensing systems and biomineralization processes as potential means for fabricating novel optoelectronic materials.

Cellular/Systems Biology*: The fundamental knowledge provided by this area will dramatically improve DoD's ability to reduce the hazards associated with the modern battlefield and peace-keeping operations and to provide efficient and effective combat casualty care when necessary.* Navy research programs target basic research that will lead to affordable technologies to support global fleet operations. Current Navy research programs in cellular/systems biology address biosonar based on the abilities of marine mammals, effects of low-frequency sound, immunophysiology, military operational medicine, and combat casualty care. Growth areas for the Navy address health issues in shipboard and submarine environments, biolocomotion, and diving physiology. Army research in this area supports performance, sustainment, and adaptability of the soldier to changing, severe environments. The Army Medical R&D Command is responsible for the major DoD research programs in combat casualty care and infectious diseases of military importance. Biological sciences basic research in the Air Force currently has mechanistic toxicology as its major focus. Clarification of the basic mechanisms by which toxic chemicals and non-ionizing radiation cause biological effects will provide the basis for improved safety standards, resulting in less hazardous military operations. Air Force research programs in chronobiology are reported in the Cognitive and Neural Sciences section of this plan.

Table 4.11.3 provides representative basic research goals for work in the biological sciences area.

Table 4.11.1. Basic Research Funding for Biological Sciences ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61101A	Army	4.3	3.9	4.0
PE 61102A	Army	19.6	25.1	25.8
PE 61152N	Navy	1.3	1.2	1.2
PE 61153N	Navy	30.9	29.0	29.1
PE 6102F	Air Force	8.5	6.5	6.7
	Total	64.4	65.7	66.8

Table 4.11.2. Service Specific Interests and Commonality in Biological Sciences

Subarea	Army	Navy	Air Force
BIO-TECHNOLOGY Biomolecular processes and materials Biosensors Biodegradation Biodeterioration Chemical and biological defense	Macromolecular structure and function Biocatalysis Anti-fungal Nanoscale biomechanics Biochemistry for detection, protection and decontamination	Marine biotechnology and biofabrication Combinatorial synthesis Biofabrication Underwater adhesion	No Service specific program
	Areas of Common Interest Biodegradation (A,N,AF)		Biomimetics (A,N,AF)
CELLULAR/ SYSTEMS BIOLOGY Physiology Toxicology Biomedical	Sustainment, performance and adaptations Infectious diseases	Immunophysiology Biosonar Low frequency sound Military operational medicine	Toxic mechanisms Non-ionizing radiation
	Areas of Common Interest Combat casualty care (A,N)		

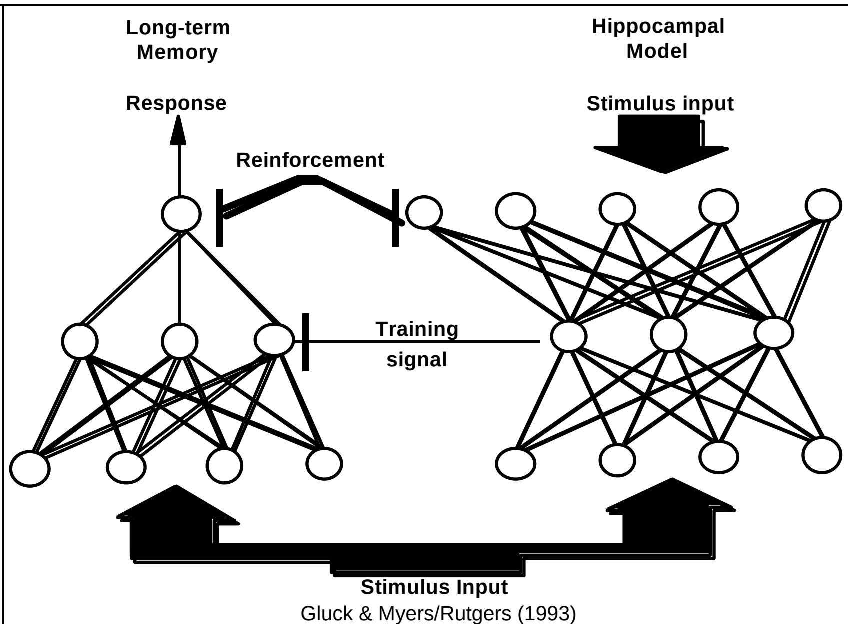
Table 4.11.3. Representative Basic Research Goals: Biological Sciences

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Biotechnology	Personal protection Cost-effective manufacturing	Human Systems Materials and Processes	Biomolecular materials via metabolic engineering	Bioengineered fibers and waterproof adhesives	Novel, multifunction low-observable composites
	Mine detection	Sensors and Electronics	Biological chemosensing mechanisms	Exploit bio-sonar for acoustic detection	Combinatorial synthesis for multi-detector arrays
	Environmental quality	Materials and Processes	Tests for bio-availability of toxicants	Engineered biocatalysts for remediation	"Mix and match" biodegradation for recalcitrant wastes
	Biological threat detection	Chemical, Biological Defense and Nuclear	Biomolecular markers for threat agent interactions	Characterized signal transduction pathways	High selectivity bio-detectors
Cellular/ Systems Biology	Affordable, hazard-free operations	Humans Systems	Validated laser safety standards to protect personnel	*In vitro* alternatives to animal testing (reduce time and cost 50%)	Computational alternative to *in vitro* tests
	Combat casualty care	Biomedical Science and Technology	Combat resuscitation fluids	Freeze-dried blood products	Synthetic blood with high oxygen-carrying capacity

4.12 Cognitive and Neural Science

The Defense-wide program of research in the Cognitive and Neural Sciences develops the science base enabling the optimization of the Services' personnel resources. Areas of application include testing, training and simulation technologies, display support for target recognition and decision-making, techniques to sustain human performance, human factors, and team/organizational design and evaluation methodologies.

• A Model of Cortical-Hippocampal Processing in Classical Conditioning



• Neural Network Based on this Model Tested Against a Data Base of Seeded Faults in - Helicopter Gearboxes. A Novelty Detector.

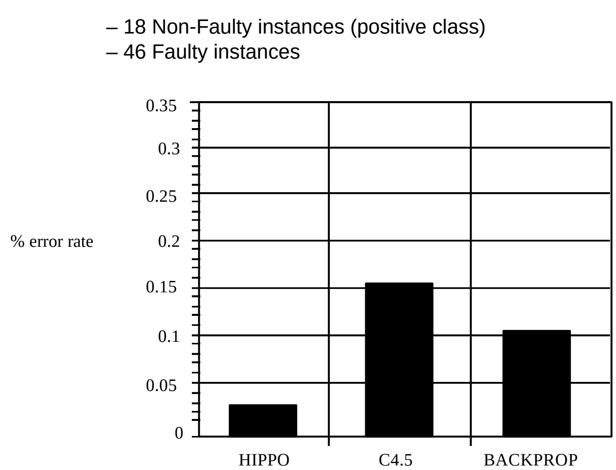


Figure 4.13. A Novel Neural Network Detector for Fault Diagnosis. The hippocampus is that portion of the brain in man and animals that is key to long-term memory storage. A new neural network architecture, based on the hippocampus, has shown excellent results as a new class of fault detector. Recent tests using this novel neural network against other established fault detection

methods showed a clear advantage in the use of the new method for helicopter gearbox fault detection.

Joint agreements in 6.2/6.3 programs apply to manpower, personnel and training issues, and the Defense-wide SPG in Cognitive and Neural Sciences has been responsive in aligning 6.1 programs in those areas. For example, Navy has eliminated its psychometric program, relying on an Air Force investment. This shift enabled the Navy to reinforce its program on Decision-Making in Hierarchical Teams and Distributed Expertise. Budget figures for basic research work in the cognitive and neural science area is given in Table 4.12.1. Table 4.12.2 provides an outline of Service-specific interests and commonality in this research area.

DoD Basic Research Program activities in the cognitive and neural science area involve two subareas:

Human Performance:. *Research in this subarea influences the Services' approach to personnel selection, assignment, and training. It also explores ways to augment personnel performance in military environments, and to develop new ways of organizing better, more effective teams and command and control organizations.* In general areas of common interest, the specific research efforts of the Services are becoming more sharply defined. In teams and organization research, the Army concentrates on group processes, the Navy on coordination in distributed groups and models for evaluating organizational design, and the Air Force on communication strategies important to maintaining situational awareness. In the area of cognition, learning and memory, the Army concentrates on the discovery of training principles that underlie acquisition, retention and transfer of soldier skills. The Navy focus is on artificial intelligence (AI) based models of cognitive architecture. The Air Force focus is on identifying individual differences in cognitive and psychomotor abilities.

In stress and performance research, the Army focuses on performance and psychological consequences of chronic physical and strong emotional stress. The Air Force is investigating brain physiology and biochemistry in response to stress. Electrophysiological measures of cognitive overload will provide new opportunities for human system interface technologies. The Army vision and audition program seeks to optimize the user interface in visual control of vehicles and reduce the effects of intense sound. Navy research focuses on teleoperated undersea requirements, automatic target recognition for precision strike missions, and auditory pattern recognition for sonar signal analysis. More generic principles of human visual display compatibility are being investigated by the Air Force.

***Reverse Engineering*:** *The Reverse Engineering subarea exploits the unique designs of biological neural systems by discovering novel information processing architectures and algorithms potentially implementable in engineered systems.* These efforts seek to imbue machine systems with capabilities for sensing, pattern recognition, learning, locomotion, manual dexterity, and adaptive control that approximate human functionality. The current Navy program in Reverse Engineering combines neurosciences and computational modeling in five topical areas:

(1) Vision: Studies of primate visual processing pathways from retinal compression coding through extraction of color, motion, from properties of recognized objects.

(2) Touch/Manipulation: Studies of human and other primate tactile processing that uderlies object recoginiton by touch and enables dexterous mainpulation of small objects.

(3) Locomotion: Studies of legged locomotion by insects, and undulatory locomotion and maneuver by fish.

(4) Biosonar Studies of bat and dolphin active sonar processing for target detection tracking and classification.

(5) Learning: Studies of various organisms circuitry involved in conditioned response and associative learning.

The Air Force is planning to enhance its program to examine biological sensor system specificity and sensitivity. The Air Force is also beginning new research to provide ambient temperature, lightweight infrared (IR) sensors by examining the mechanisms used by animals to detect IR signals.

A roadmap of representative research objectives for Cognitive and Neural Science in the near and far term is shown in Table 4.12.3.

Table 4.12.1. Basic Research Funding for Cognitive and Neural Science ($ Millions)

Program Element	Service/Agency	FY95	FY96	FY97
PE 61101A	Army	0.1	0.1	0.1
PE 61102A	Army	5.9	5.9	5.6
PE 61152N	Navy	0.7	0.6	0.7
PE 61153N	Navy	16.4	16.7	16.8
PE 61102F	Air Force	10.0	10.8	11.3
	Total	33.1	34.1	34.5

Table 4.12.2. Service Specific Interests and Commonality in Cognitive and Neural Science

Subarea	Army	Navy	Air Force
HUMAN PERFORM-ANCE Sources Detection Propagation	Leadership Motivation Societal Linkages	Tactile information processing Sensory-guided motor control	Chronobiology Neurophamacology
		Areas of Common Interest	
	Teams and Organizations (A,N,AF))	Cognition, Learning and memory (A,N,AF) Stress and performance (A,AF)	Auditory and visual perception (A,N,AF)
REVERSE ENGINEERING Sources Detection Propagation	No Service specific program	Autonomous undersea vehicle/manipulators Neural computation plasticity Automatic sonar classification	3D Audio displays Infrared Biosensors
		Areas of Common Interest	
		Machine vision (N,AF)	

Table 4.12.3. Representative Basic Research Goals: Cognitive and Neural Science

Subarea	Area of Military Impact	Relevant DTAP(s)	2000	2005	2010
Human Performance	Affordable, efficient training	Human Systems Information Systems	Cognitive models validated	Curriculum authoring shells	Embedded training
	Force leadership and troop morale	Human Systems Information Systems	Conceptual model of leader-team performance	Model extended to commitment	Leader development program
	Adaptive human-machine interfaces	Human Systems Information Systems	Virtual reality work stations	Principles for visual environment and multi-media integration	Dynamically reconfigurable control centers
Reverse Engineering	Precision guidance and targeting	Human Systems Sensors and Electronics	Models of biological vision	Extrapolation to wideband and IR	Adaption of biological models to multispectral image analysis
	Unmanned vehicles	Air Platforms Ground Vehicles and Watercraft	Adaptive control algorithms	Sensory-motor integration	Autonomous multifunctional robotics

4.13 University Research Initiative Program

The University Research Initiative (URI) sector of the DoD Basic Research Program is allocated to the Services and Defense Agencies for a variety of purposes. Programs such as the Defense University Research Instrumentation Program (DURIP), the University Research Infrastructure Support Program (URISP), the Augmentation Awards for Science and Engineering Research Training (ASSERT) program , and the National Defense Science and Engineering Graduate (NDSEG) Fellowships were discussed in Section 2.

The Multidisciplinary University Research Initiative (MURI) component of the URI program, also discussed in Section 2, supports research teams whose efforts involve more than one science or engineering discipline. Because of its multidisciplinary nature, the individual components of this activity have not been reported under individual SPGs; instead, certain additional details are provided here. The MURI program strongly supports the Strategic Research Objectives, and other complex defense opportunities and needs. Individual projects have typically been supported at $1M - $2M per year over a five-year period. Thus, prior-year obligations constitute the major part of the MURI budget. Examples of topics that are currently in the final stages of proposal preparation for support in the current competition include:

- Integrated Approach to Intelligent Systems
- Advanced Active Control of Rotorcraft Vibration and Aeroacoustics
- Ultra-Lightweight Metals

The overall funding for the URI program over a three-year period is:

FY 95: $235.7 M

FY 96: $222.0 M

FY 97: $209.2 M (projected)

A more complete discussion and analysis of the URI program will be provided in the next version of the Basic Research Plan.

5.0 NEAR-TERM PAYOFFS

A traditional research program follows the path from 6.1 (Basic Research) to 6.2 (Exploratory Development) through 6.3A (Advanced Development), etc. before it is tested and fielded by the military. This process can take from 7 to 20 years, depending on the nature of the discovery. It is not unusual, however, for intermediate results such as software, theoretical models, and new processes to provide near-term payoffs, with serendipitous events yielding transitions to manufacturing and fielded systems in less than 7 years. Examples of such occurrences can be found in all 12 of the research thrust areas. A brief discussion of a few illustrative cases is provided in the following paragraphs..

Mathematics and computer science research results can have a substantial and rapid impact on military operations because they do not require the production of any new “hardware.” For example, fast, rapidly maneuvering air targets represent one of the most challenging threats to our weapons platforms because they cannot be tracked accurately using conventional, linear filtering systems. Recent development of a computationally feasible method for calculating nonlinear track filters has provided new potential for developing significantly better tracking systems and improving, for example, ship self-defense. The steadying of pointing devices and weapons used to track and destroy incoming missiles is also critical to our ability to defend various types of assets against missile attack. Recently developed mathematical algorithms not only improve the pointing accuracy for missile defense from airborne platforms, they also impact other laser applications requiring extreme precision, including space communications, manufacturing, and medicine. Visualization of the battlefield is also critical to the enhancement of fast and accurate decision-making. Recently created algorithms and advanced software can manipulate data from a variety of sensors (e.g., radar and acoustic devices) "volumetrically" to rapidly display complete three-dimensional images of the theater of war on conventional, planar computer terminals.

Understanding and mapping land masses is critical to our ability to move ground forces into the battlefield. Recent research efforts have begun validating automated techniques for the rapid extraction of terrain data and the generation of terrain information from multispectral remote sensing imagery, investigating advanced digital techniques to improve terrain analysis, and developing first-principles models for predicting multispectral signatures of terrain surfaces and the appearance of surface features to imagery systems. Of more local importance are the geomorphological, hydrometeorological, hydrologic, and hydraulic studies to understand the fractal scaling character of 3-D terrain, to provide new insights into the control of extreme rainfall (floods), and the transport of soil sediment and pollutants in sub-aqueous systems. This latter effort is critical to the characterization and clean-up of contaminated DoD and commercial waste sites.

Materials and mechanics play crucial roles in the development of any new weapon system. For example, research on titanium aluminum alloys for low pressure turbine applications in jet engines can lead to a significant reduction in weight and to higher operating temperatures. These characteristics translate directly into more efficient jet engines and lower life-cycle costs. In addition, components fabricated from these materials can be retrofitted directly into existing engines. Recent success in the development of computer-based design methodologies for gas turbine combustors are essential to the creation of high-performance, low-emission gas turbine engines with an increased thrust-to-weight ratio, improved fuel economy, and reduced infrared and acoustic signatures. These research efforts are closely coordinated with NASA on issues where technologies are common to both civilian and military gas turbines.

Advancements in physics, materials science, and electronics are closely intertwined, as evidenced by the recent three-fold improvement in the figure of merit of lead telluride-based thermoelectric materials. These solid-state materials convert electricity directly to "cold" with no moving parts and no ozone-depleting chlorofluorocarbons. This materials breakthrough was made possible by using fabrication techniques from the electronics industry (the growth of multiple quantum well superlattices) and advanced solid-state physics theory. The result may enable a new generation of reliable, low cost coolers for high-speed electronics, remote detectors, and night vision equipment, and also provide a potential source of power for meeting individual soldier needs. Microelectronic fabrication techniques have also led to the development of a host of microfabricated electromechanical systems (MEMS). For example, tiny microflaps can now be manufactured and incorporated into aerodynamic lifting surfaces such as wings and stabilizers to control turbulence and vorticity generation. Using this approach, a substantial reduction in drag and enhancement of vehicle control might be achieved in combat aircraft..

Chemistry research is playing an increasingly important role in the improvement of weapon systems, from the synthesis of improved coatings for enhanced corrosion, wear, and biofouling resistance to the development of ensembles of nanoscale electrodes used to minimize radar reflections from ships. Advancements in polymer chemistry are leading to the creation of higher-energy-density rechargeable batteries and direct-oxidation fuel cells critical to the powering of next-generation battlefield electronics. Fundamental chemistry is also playing a critical role in the development of destruction technologies for chemical and biological warfare agents. For example, both hydroperoxide oxidation and hydrolysis have proven effective in the destruction of certain nerve agents. Enzymatic degradation is useful for the destruction of mustard agent hydrolysis products, and hydrothermal oxidation has proven effective for the destruction of a number of chemical warfare agents, in addition to a wide variety of DoD hazardous and toxic wastes.

Recent advancements in biology are finding their way onto the battlefield as well. An improved understanding of molecular-level cellular processes (in particular the temporal, spatial, and concentration-dependent correlation of exocytotic release of catecholamine and intracellular calcium) is enabling the development of new treatments for battlefield trauma and chemical and biological agent exposure. Finally, the replacement of noble metal electrodes with components based on enzymatic function provide an order-of-magnitude improvement in sensitivity, detectability, and cycling time, and they can be used to monitor blood flow for battlefield casualties.

These research results are but a few of the many examples of how recent advances in the sciences have transitioned to the field and helped our warfighters in the near term.

6.0 RECENT SUCCESSES

Defense Basic Research is the fundamental ingredient in the development and maintenance of a technologically superior military force. Conducted by the military Services and Defense Agencies of the Department of Defense, Defense Basic Research has had a profound impact on many capabilities of our Armed Forces, as well as in everyday life. Technical advances such as visual imaging, lasers, information processing, and global positioning have all been developed as a result of long-term and sustained investments in basic research.

This section provides examples of some of the more recent innovative accomplishments of Defense Basic Research. The examples were selected on the basis of overcoming unique technical challenges and the military importance of the accomplishments. Highlighted are accomplishments funded by the Air Force Office of Scientific Research (AFOSR), the Army Research Office (ARO), the Office of Naval Research (ONR), the Defense Advanced Research Projects Agency (DARPA), and the Ballistic Missile Defense Organization (BMDO). These accomplishments provide a varied sample of the types of future military technical capabilities that will be employed by our Armed Forces.

6.1 Air Force Office of Scientific Research (AFOSR)

6.1.1 Ultra-High-Temperature Silicon Carbide Fibers

Structural materials capable of working at ultra-high temperatures ranging from about 1500 °C to 2000 °C are required for operational improvement in both civilian and military aircraft engines. This requirement flows from a simple thermodynamic principle, which states that the efficiency of an engine that derives its power directly from combustible fuel increases with the temperature of combustion. Superior materials are therefore pivotal to improving the efficiency of aircraft engines.

The design and manufacture of ultra-high-temperature structural materials presents significant technical challenges. While there are a number of materials, both natural and man-made, that can withstand the combination of high temperatures and oxidizing environments required to achieve improved engine efficiency, few materials also possess the required properties of strength, density, stiffness and fracture toughness. After years of basic materials research, it has been found that fiber-reinforced ceramic-matrix composites may provide the desired combination of mechanical properties, reliability, and high-temperature stability.

Silicon carbide fiber was developed in the 1980s as the best candidate for high-temperature ceramic-matrix composites. Nicalon fiber, which is made in Japan, has impressive properties, but its strength deteriorates very quickly at temperatures above about 1000 °C. Apparently this reduction in strength is caused by oxygen trapped in the material during the manufacturing process. Recent efforts by the Japanese manufacturer to reduce the oxygen content have led to fibers that can retain their strength up to 1800 °C, but in an inert environment. However, research funded by AFOSR and performed by Prof. Michael Sacks at the University of Florida has led to a major breakthrough in the fundamental understanding of the relationships between processing, microstructure, and properties of silicon carbide fibers. Based on this understanding, silicon carbide fibers have been synthesized with high-temperature stability and mechanical properties greatly exceeding that of the best Nicalon fibers. This new manufacturing process has resulted in a patent application.

Fabrication of the ultra-high-temperature silicon carbide fibers constitutes a major step towards the introduction of these materials for exhaust nozzles in fighter planes and combustors in air-breathing turbine engines. The basic research investment enabling the use of these materials for producing superior rocket engines, gas turbines for land-based engines and internal combustion engines for passenger vehicles will provide an enormous return to our country in the form of millions of dollars of energy savings per year and a cleaner environment.

6.2 Army Research Office (ARO)

6.2.1. Smart Helicopter Rotor Blades

The development of smart rotor blades is an excellent example of the application of the results of Defense Basic Research in apparently disparate fields of science. In this case, the mathematics of feedback control systems, results of materials research on piezoelectric sensors and actuators, and the theory of aerodynamics were combined to provide a solution to noise and vibration control of rotor systems.

The critical challenge in developing improved rotor system performance for helicopters and tilt rotorcraft is to obtain system weight and cost reductions while simultaneously providing significant reductions in key vibration components and blade-vortex interaction noise. Studies have shown that such improvements can be realized with relatively small changes in the pitch angle of the rotor blade. Considerable research has been devoted to the concept of a “smart rotor blade,” one that responds to variable blade forces by automatically and rapidly adjusting the pitch of the blade during high-speed rotation. Employing this real-time dynamic technique can result in major reductions in noise and vibration levels (on the order of 50%) while also providing a slight improvement in performance in comparison to existing systems.

At present, the “twisted blade” and the “trailing edge flap” approaches appear to be the most promising. The twisted blade concept features piezoelectric ceramics embedded in the blade for strain actuation and sensing. Tests conducted over the last year have resulted in improved designs that have increased the twist performance of the blades by as much as a factor of two. The trailing edge flap approach is a composite blade that includes a piezoelectrically actuated trailing edge flap that changes the lift of the rotor blade. This approach offers new potential for overcoming the major weight penalty associated with conventional harmonic control systems.

As a result of the success of this research, McDonnell Douglas Helicopter Company is incorporating the trailing edge flap concept into an advanced composite, bearingless blade design for the Army's upgrade to the Apache helicopter.

6.3 Office of Naval Research (ONR)

6.3.1. Neural Network Monitoring System

Results from research on neural networks are now being used for solutions to a growing number of important problems. A recent accomplishment is a new neural network architecture based on the mammalian hippocampus that exhibits exceptional capability as a new class of detector. The hippocampus is that portion of the brain in man and animals that is key to long-term memory storage.

This novelty detection and classification technique, developed by current research grantee Dr. Mark Gluck (based on his work in neuroscience and cognition), recently proved its effectiveness when it confirmed a faulty transmission in a Marine Corps CH-46 helicopter. When an unknown anomaly first appeared in data gathered on what appeared to be a problem-free helicopter, initial analysis proved inconclusive. However, Gluck's neural-based algorithm suggested that a problem did exist. The helicopter, which had just participated in a major fleet exercise, was removed from service while its aft transmission was examined. An engineering analysis revealed three possible serious gear faults that had previously gone undetected.

The system that found the helicopter gearbox problem is part of a larger neural network monitoring system that includes accelerometers, signal processors, analog-to-digital converters, radial basis function classifiers, and other components. Whereas other network classifiers must be trained to respond by experiencing a particular, previously determined fault, the novelty detector comes to "learn" what a normal gearbox sounds like, which subsequently allows it to identify any abnormal vibrational pattern when it is received.

Gluck's hippocampal-based network has also been used to detect and classify faults in aircraft carrier fire pumps, and also to classify sonar signals. Insights gained from biologically-inspired models continue to support the Navy's emphasis for real-time, on-board diagnostics to act as maintenance "watch dogs" for aging ships and aircraft. Research on biologically-motivated neural networks was pioneered by ONR in the early 1980s.

6.3.2. Proximal Probe Nanolithography

As circuit designs and electronic devices try to meet the ever-present demand for more processing power, lower power consumption, and higher speed, improved information and data processing systems will depend on increased miniaturization; of interest are dimensions below 100 nanometers (nm), where a nanometer is one billionth of a meter. In 1980, ONR initiated the Ultra Submicron Electronics Research (USER) program, which has resulted in significant advances in lithographic technology and new materials for creating integrated circuits. Because optical lithography, the current technology, fails when devices are of such small dimensions, the Naval Research Laboratory and the University of Illinois have used proximal probe technologies such as the scanning tunneling microscope (STM) and the atomic force microscope (AFM) as tools for sub 100-nm lithography, or nanolithography.

Recent accomplishments at the 100-nm scale include development of a "resistless" AFM-based lithographic process that involves the anodic oxidation of a passivated surface using the local electric field of an AFM tip in air followed by selective etching. This process has been used to fabricate operating transistors with critical features as small as 30 nm. The advantages of this process include high write speeds, high spatial resolution, and compatibility with conventional device-fabrication procedures.

At or below about 10 nm, conventional silicon transistor devices do not operate efficiently and quantum effects start to dominate electron transport. As a solution to this problem, the AFM anodic oxidation process has been modified to include real-time, in-situ monitoring of device electrical properties, which provides important feedback needed to control the processing. In this way, devices of sub 10-nm dimension have been fabricated with precisely controlled electrical properties.

At 1 nm, the ultimate limit of atomic-level control of fabrication, researchers use an ultrahigh-vacuum (UHV) STM to selectively remove hydrogen atoms from a hydrogen-passivated silicon surface to produce a patterned surface as a template for metallization. Through nanolithographic research, we anticipate better performance and higher reliability at lower cost with greatly increased device density per circuit, integration of multiple functions on the same chip, smaller devices on a chip, and new possibilities for integrated optoelectronic circuits.

6.4 Ballistic Missile Defense Organization (BMDO)

6.4.1. High Speed Laser Communications

The fast-growing demand for accessible user-friendly information, as well as the broadening scope of international business, will undoubtedly affect technology needs for the satellite industry, as well as for rapid and secure military communications. Real-time telecommunications tasks, such as transmitting video images, geographical data, and 3-dimensional imagery, will require advanced technology so that massive amounts of different types of information can quickly and efficiently be sent from the data distributor to the final user.

Current systems use radio frequency (RF) waves to transmit information for television, telephones and computer networks-systems. Without further technology enhancements, these systems will become clogged as demand increases. A solution to this problem is the development of a next-generation satellite system that receives and broadcasts data with lasers for applications where information must be transmitted quickly across the world. This system, called Lasercom, is smaller, uses less power, and can cover a wider range of the electromagnetic spectrum than current technology. Successful demonstration of this new concept was a significant research accomplishment.

The Lasercom system works by using a combination of laser and RF communication techniques. To transmit data, an earth-based station first sends the information to the closest overhead satellite, typically via RF because the earth's atmosphere distorts laser signals. This satellite then relays the information via laser beam to an intermediate satellite. Laser beacons are used to ensure that intermediate satellites can quickly and precisely track the next satellite in line. An atomic line filter prevents reflected sunlight from interfering with the system's ability to detect the laser beacon. The final satellite link beams the signal down to another earth station via RF. For all-weather operations, as few as five ground stations would permit optical communications to the ground over 99% of the time.

This new technology offers many advantages. The Lasercom system can move one billion bits of data per second, which is 50 times faster than conventional data transmission rates and the transmission is more resistant to jamming and data interception. This method requires almost 400 times less peak power than conventional systems, and the system is also smaller and lighter, which reduces launch costs and allows for smaller satellites. For example, standard RF satellite communications systems use an antenna 3 meters in diameter, whereas the Lasercom system employs a small 0.1-meter telescope for detection and transmission.

The results of sustained basic research investment have enabled this high-speed laser communication system to be developed. It has obvious military importance for missile defense and for communication between airborne tactical surveillance platforms. But even components of the system have important stand-alone applications. For example, the atomic line filter can be used for the detection of plumes associated with helicopters, satellite and rocket launches, and forest fires. Coupled with a fiber optic probe, the atomic line filter can also be used to monitor the flow rate of blood and other biological fluids.

6.4.2 Diamond Thin Film Technology

BMDO has funded research on a new class of materials that will allow electronic equipment to operate faster, at higher power and in hostile environments. The materials, which include synthetically grown diamond and other very hard substances (certain carbides and nitrides), are being used in billions of dollars of new products because of their outstanding properties of hardness, optical transparency, and heat conduction. With films of these materials, companies are now manufacturing cheaper, brighter, and more rugged flat-panel displays, more durable machine tools, diodes that emit light at colors never before possible, and memory chips that store information even after the power has been turned off.

Research in this area has had two primary thrusts: one is to deposit single-crystal diamond on non-diamond substrates, and the other is to develop doping processes to make diamond semiconductors. Atomic layer epitaxy is being used for single crystal deposition because it can provide better controlled growth than conventional methods and thus ensure that growth occurs one atom-thick layer at a time. A new fast-atom doping process has been developed and patented wherein researchers shoot atoms at a diamond film during growth to add the impurities necessary for the eventual manufacture of n-type semiconducting diamond. To date, no other technology has been found to reliably dope diamond films without damaging the natural crystalline structure of the film. Testing of possible dopants for making both n- and p-type semiconductors is now in progress.

6.5 Defense Advanced Research Projects Agency (DARPA)

6.5.1. Methanol Oxidation Fuel Cell Technology

Currently available power sources for military platforms are severely hampered by high cost and a lack of energy/power density. This is particularly true for small (<100 W) power systems, which at present are limited to primary electrochemical batteries. A small, simple fuel cell, based on the direct oxidation of methanol (e.g., $CH_3OH + 3/2O_2 \rightarrow CO_2 + H_2O$) in a proton exchange membrane fuel cell, has the potential to replace lithium battery technology in many DoD applications. Methanol is chosen as a potential fuel due to its high energy density, safety, low cost, ease of handling and distribution, and high electrochemical activity. The energy density of an individual direct methanol fuel cell (DMFC) is estimated to be up to five times that of a primary lithium battery. This greatly reduces the weight that a soldier must carry into the field or, alternatively, significantly increases his power capability for the same weight. In addition, these fuel cells are not thrown away after each use, but can be “recharged” by simply adding a small amount of additional methanol to the fuel tank.

Basic research on advanced catalysts and improved membranes, and on the fabrication of optimized membrane electrode assemblies, has led to a more than ten-fold improvement in the performance of a direct methanol oxidation fuel cell in the last few years. Power outputs of nearly 350 mW/cm^2 have been achieved (for comparison, batteries typically operate at only a few mW/cm^2). Individual cells have run for more than 1700 hours (>200 h continuous) and 50-W stacks have operated for over 1300 h (more than 200 start/stop cycles) with no significant poisoning. Thus, the present state-of-the-art is close to being sufficient to build a DMFC that will match the output of the most widely used high-capacity DoD lithium battery (the BA-5590) at the same weight and volume. This performance enhancement could only be achieved through a strong, focused approach involving close interactions and frequent discussions among universities, federal laboratories, small businesses, and industry. Considerable work remains to be done, however, before the full potential of the direct oxidation fuel cell concept can be realized. For example, further basic research in the area of advanced catalysis is needed to improve the fuel utilization and to raise the overall system efficiency. Improved polymeric membranes are required to reduce the cross-diffusional loss of methanol from anode to cathode.