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Basic Research Plan

February 1999

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DEPARTMENT OF DEFENSE

DEPUTY UNDER SECRETARY OF DEFENSE
(SCIENCE AND TECHNOLOGY)

OFFICE OF THE SECRETARY OF DEFENSE

1000 DEFENSE PENTAGON
WASHINGTON, DC 20301-1000

This third edition of the *Basic Research Plan* serves to focus, integrate, and describe the Department of Defense (DoD) investment in a world-class research program. It is a strategic plan to link long-term research to broad, revolutionary 21st century military capabilities. The plan describes the Department's *Basic Research* investment and integrated approach for achieving DoD objectives in ten Basic Research Areas. The plan also contains a section that describes selected basic research accomplishments. While it is impossible to predict with accuracy the breakthroughs and military capabilities we will gain from today's investment in *Basic Research*, we can look back in history and trace many of our current military capabilities and systems to the technologies and basic research that enabled their creation.

The plan sets forth our overall strategy for conducting a comprehensive research program to provide a strong foundation for subsequent technological advances and the development of revolutionary military capabilities and systems. It includes updated budget information, and details on areas of individual and common interests to the Military Departments. This *Basic Research Plan* also highlights our continuing emphasis on six Strategic Research Areas that define rapidly expanding research fronts with the potential for achieving high military payoff, rich with scientific opportunities that cut across multiple fields of science. The plan is the product of the Military Departments, the Defense Agencies, and the Basic Research Panel.

The *Basic Research Plan* is a dynamic document that is updated every two years. It is the product of corporate planning and provides guidance to the Military Departments and Defense Agencies to ensure that their combined research efforts will provide the warfighter with superior and affordable technology well into the future.

Delores M. Etter

Delores M. Etter
Deputy Under Secretary of Defense
(Science and Technology)

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EXECUTIVE SUMMARY

The DoD Basic Research Program is the cutting edge of the Defense Science and Technology Program. For more than 50 years, the Department of Defense has relied on its Basic Research Program to maintain U.S. military technological superiority. This objective has been realized primarily by DoD support for research into scientific and engineering areas of proven or potential importance to defense. DoD researchers also keep a watchful eye on research activities all over the world to prevent technological surprise. As the pace of technology quickens, it has become ever more important to maintain the world-class quality of the DoD research program, and to guide, coordinate, and integrate its many diverse activities. The *Basic Research Plan* (BRP) presents a comprehensive and reasonably complete overview of the whole DoD research program, presents the rationale for it, outlines its contents and organization, tabulates the funding (by program element as well as by discipline), and concludes with a few examples of its extraordinary accomplishments.

The bulk of the funding of the DoD research program supports 12 disciplinary areas, managed by 10 Strategic Planning Groups (SPGs). (Two pairs of related disciplines are grouped together under one SPG.) Each discipline is briefly described. Interdisciplinary research is encouraged and is specifically addressed under three program titles: *Strategic Research Areas* (SRAs), *Multidisciplinary University Research Initiative* (MURI), and *Government–Industry Cooperative University Research Program* (GICUR). The program also supports infrastructure through education and training in science and engineering, and university instrumentation under the *Defense University Research Instrumentation Program* (DURIP).

I. INTRODUCTION

For more than 50 years, the Department of Defense (DoD) has relied on its Basic Research Program to maintain U.S. military technological superiority. This objective has been realized primarily by DoD supporting research in science and technology (S&T) areas of proven or potential importance to national defense. DoD researchers also keep a watchful eye on any and all research progress throughout the world to look for new opportunities and to prevent technological surprise. As the pace of technology quickens, falling behind in S&T for defense could place us at a serious disadvantage. It has therefore become ever more important to maintain the world-class quality of the DoD research program, and to guide, coordinate, integrate, and plan its many diverse activities. In this, the DoD *Basic Research Plan* (BRP) makes two contributions: first, it provides an overview of where we are now, and second, it summarizes the planning process for future directions and areas of emphasis. Chapter II includes a brief description of the organization, structure, and context of the program.

A. CAPITALIZING ON BASIC RESEARCH

It is in the nature of basic research that it contributes to many aspects of national security, military as well as economic, which are often inseparable. Thus, only a technologically more advanced economy can provide technologically superior weapon systems at more affordable prices. To maximize the impact of basic research on national security, researchers cannot afford to isolate themselves in an "ivory tower." To quote from a recent economic report (Reference 1):

> A common misconception is that fundamental research is conducted in an ivory tower, with no regard for practical benefits. On the contrary, a consistent virtue of U.S. basic research has been the pursuit of fundamental knowledge with a sharp eye out for downstream applications. American entrepreneurs have been distinguished by their ability to capitalize effectively on new knowledge wherever it arises.

DoD scientific officers must have a record of personal experience in performing productive research, while reporting to superiors responsible for meeting military objectives, thus ensuring both the quality of the research and its relevance to national defense.

B. COMPOSITION OF DEFENSE BASIC RESEARCH

An important point not to be overlooked is that research programs supported by different federal agencies can differ greatly in their composition. Thus, a reduction in defense basic research falls heavily on areas of technology of vital importance especially– but not solely– to national defense. The amount budgeted for defense basic research has declined in real terms by 24 percent in 5 years (from 1993 to 1998), thereby disproportionately affecting research focused on engineering, computer sciences, and new materials, for example. This point was made clearly in an editorial in the prestigious journal *Science* (Reference 2):

> A shift in federal funding of R&D overlooks the vital role the Department of Defense (DoD) plays in funding academic basic research . . . for example, 69 percent of electrical engineering, 60 percent of computer sciences, 40 percent of materials sciences and engineering, and 27 percent of mathematical sciences. . . . The simplistic notion that R&D funding by DoD should not be increased would have a disproportionately negative impact on specific disciplines that are essential to the country.

The National Science Foundation (Reference 3) confirms this view with similar numbers for basic *and applied* research, as shown in Table I–1.

Table I–1. DoD Support for Basic and Applied Research

Field	DoD Percent of Federal Funding
Mathematics/Computer Science	22
Mathematics	30
Engineering	31
Electrical	75
Mechanical	71
Physical Sciences	6
Environmental Sciences	11
Psychology	12
Life Sciences	2

Source: National Science Foundation (Reference 3)

DoD research is organized into the following 12 disciplinary areas of critical importance for national security.

- Physics
- Chemistry
- Mathematics
- Computer Sciences
- Electronics
- Materials Science
- Mechanics
- Terrestrial Sciences
- Ocean Sciences
- Atmospheric and Space Sciences
- Biological Sciences
- Cognitive and Neural Science.

These disciplines are described in more detail in Chapter III, which lists topics of emphasis under each discipline. Funding for fiscal years 1997, 1998, and 1999 is shown there for each discipline separately. Table I–2 shows the funding for all program elements covering basic research for FY97, 98, and 99.

Table I–2. DoD Basic Research Funding, by Program Element, for Fiscal Years 1998, 1999, and 2000 ($ millions)

PE	Title	FY 1997	FY 1998	FY 1999
Services				
Army				
0601101A	In-House Laboratory Independent Research	14.0	13.3	13.5
0601102A	Defense Research Sciences	117.1	120.2	125.3
0601104A	University and Industry Research Centers	43.7	43.7	44.8
	Total Army	174.8	177.2	183.6
Navy				
0601152N	In-House Laboratory Independent Research	14.2	13.3	14.7
0601153N	Defense Research Sciences	331.4	318.2	346.8
	Total Navy	345.6	331.5	361.5
Air Force				
0601102F	Defense Research Sciences	182.1	188.2	209.7
Total Services		702.5	696.9	754.8
Defense Agencies				
Office of Secretary of Defense				
0601101D	In-House Laboratory Independent Research	3.1	1.5	2.2
0601103D	University Research Initiatives	209.4	214.6	228.4
0601110D	Gulf War Illness	0.0	0.0	23.7
0601111D	Government/Industry Cooperative Research	0.0	6.9	4.8
	Total OSD	212.5	223.0	259.1
Defense Advanced Research Projects Agency				
0601101E	Defense Research Sciences	89.4	66.7	64.4
Chemical and Biological Defense Program				
0601384BP	Chemical and Biological Defense	28.3	25.3	29.5
Total Defense Agencies		330.2	315.0	353.0
Total DoD		1,032.7	1,011.9	1,107.8

Note: Some columns do not add exactly to the totals due to rounding.

C. BASIC RESEARCH AND THE RELIANCE PROCESS

Basic research for the DoD focuses on technology ares of importance to the Department. It is guided by the DoD 's longer term vision of its 21st century missions. Thus, the *Basic Research Plan* supports the *National Security Science and Technology Strategy* (Reference 4), the *Defense Science and Technology Strategy* (Reference 5), and the Joint Chiefs of Staff 's *Joint Vision 2010* (Reference 6). It couples this vision-based guidance with the DoD *Reliance* process, whereby all DoD components engaging in S&T are organized to ensure balance of S&T investment across DoD. Started in the early 1990s, Reliance enables a DoD-wide approach to investment in science and technology, to control quality and assess productivity. Through Reliance the biennial Technology Area Reviews and Assessments (TARA) meetings monitor the state of the art as well as interactions among DoD components. In the case of 6.1– the budget category for basic research– the Reliance process focuses on the 12 disciplinary areas listed above, each of which is discussed in Chapter III of this document. Each discipline is coordinated by a Strategic Planning Group (SPG), except for two pairs of closely connected disciplines, namely Mathematics and Computer Sciences (one pair) and Terrestrial and Ocean Sciences (the other pair). Because of their close connection, each pair of disciplines is handled by one SPG, making 10 SPGs for 12 disciplines.

D. PLANNING THROUGH MULTIDISCIPLINARY RESEARCH PROGRAMS

Planning basic research is not like planning a product. Since the nature of scientific research is such that the outcome of any one investigation is unpredictable, the essence of planning among the disciplines is to minimize the risk by aggregating several research efforts into interdisciplinary research undertaken by multidisciplinary teams. (Define *interdisciplinary* as *interactive multidisciplinary.*) The task of each team is to develop new or improved technologies or capabilities. The lessons learned may lead to new or revised plans for the individual technologies. Three such multidisciplinary programs are listed below; each draws on a different set of performers from DoD, academia, and industry. Other research projects, notably those sponsored by DARPA, may also be multidisciplinary in nature.

- *Strategic Research Areas* (SRAs) combine projects from different disciplines under various DoD project leaders working cooperatively as a multidisciplinary team to meet a joint objective. The objective is determined by the Director of Research (reporting to the DUSD(S&T)) with the assistance of senior service representatives.
- The *Multidisciplinary University Research Initiative* (MURI) is carried out by multidisciplinary university teams to develop new technologies. Topics are selected by the Director of Research (reporting to the DUSD(S&T)) in consultation with the Service Research Offices (the "OXRs"). Awards are made based on an annual competition open to universities.
- The *Government-Industry-Cooperative-University-Research* (GICUR) program started in 1998 with the purpose of combining industry know-how and dollars with DoD interests and funding to guide and support university research. Two technology areas were initially selected under GICUR: Complex Networks and Systems, and Semiconductor Electronics.

These program could not exist without the many smaller single-investigator research tasks that are the foundation of the DoD basic research program. They in turn are influenced and may be redirected as a result of the outcomes of the multidisciplinary programs listed above. Since DoD scientific officers in the three Service Research Offices (the "OXRs") play the leading role in both single- and multidisciplinary programs, they as a group form the most influential link between DoD requirements, on the one hand, and the conduct of the basic research program, on the other.

E. EDUCATION AND INFRASTRUCTURE SUPPORT

The success of the basic research program depends very much on its human and physical infrastructure. It can only succeed through education and training of talented future scientists and engineers; moreover, they can carry out world-class research only with increasingly sophisticated (and expensive) instrumentation. Therefore, the University Research Initiative (URI), which started in 1983 with large multidisciplinary research projects (now identified as MURI), was later augmented with other components. One provides education and training fellowships to individual outstanding young scientists and engineers, and one, the Defense University Research Instrumentation Program (DURIP), aims at improving critical infrastructure support by providing badly needed modern research instrumentation.

F. ASSESSING THE PAYOFF FROM DOD RESEARCH

Discovery and innovation through basic research is not necessarily a linear process. Although the DoD model of the transition path from basic research (6.1) to applied research (6.2) to advanced development (6.3) implies a linear model (the model proposed by Vannevar Bush after World War II), this is often honored more in the breach than the practice. The "push" of the linear process is augmented in DoD by a feedback process, whereby changing operational requirements and new results from multidisciplinary research continually keep the Basic Research Program on target. This makes the DoD research program somewhat unique among federal research programs since DoD is a mission agency heavily dependent on leading-edge technology.

Advances ranging from algorithms to new materials may find use directly in a variety of mature products. An important line of transition for DoD research products is through industry. Advances are picked up, only to appear soon afterwards in systems being offered for sale to the services. An inherent benefit of basic research is that its results are widely shared– its use in one area of development does not lessen its value to, or availability for use in, other areas.

It is impossible to predict with certainty the outcome of basic research. DoD is proud of what has already been achieved. A retrospective approach is a reminder that many of the technologies we now take for granted were brought about by investing much earlier in basic research. Chapter IV includes a brief look at the pathway and timeline from basic research investments through technology to present-day systems. These are simplified views since many basic research products are enablers across a wide range of systems. The following examples all resulted largely from timely DoD investments in basic research:

- Owning the Night– night vision technology (Army Research Office)
- Precision Guidance for Air Defense Missiles (Army Research Office)
- The Airborne Laser (Air Force Office of Scientific Research)
- The Kalman Filter (Air Force Office of Scientific Research)
- The Global Positioning System (Office of Naval Research)
- Mine Countermeasures (Office of Naval Research).

Basic research supported by DoD is directed to maximizing the value that is likely to be created by the investment. Value in this context is represented by the enabling technologies that realize the operational concepts and mission goals of *Joint Vision 2010.* The *Basic Research Plan* attempts to maximize this value by contributing to informed choices of research areas.

Conversely, research can expand the military vision by introducing into it what science has newly made possible.

G. LONG-TERM FUNDING TRENDS

Figure I–1 shows the long-term funding trends in DoD basic research (budget cateogry 6.1) since 1962. The lower curve shows funding in then-year dollars. The upper curve is corrected for inflation and shows the funding in FY99 dollars.

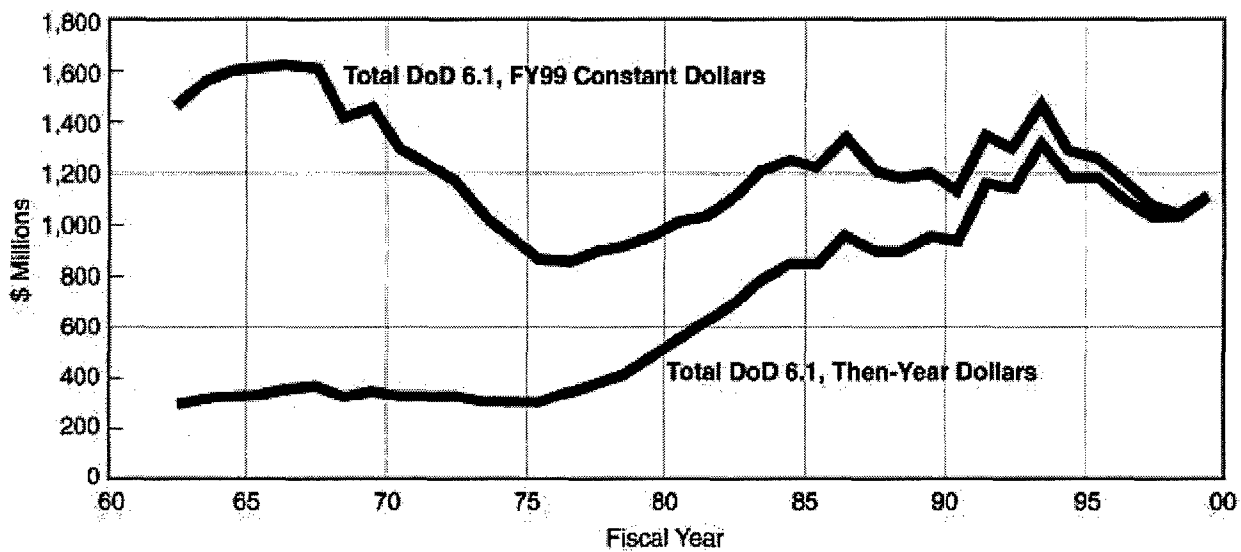


Figure I–1. Long-Term Funding Trends in DoD Basic Research

II. DOD BASIC RESEARCH PLANNING APPROACH

The purpose of the DoD Basic Research Program is to enable new technologies and capabilities to be developed and used by the warfighter in order to maintain the technological advantage of our forces. Defense-sponsored research creates future technology opportunities. These opportunities are then available to support new concepts of operations and to provide the new operational capabilities needed to field the forces that will meet our obligations. The following are key elements of the plan:

- Vision of the future—*National Security S&T Strategy, Joint Vision 2010*, and service visions and goals
- A flexible and balanced investment portfolio providing resource-constrained prioritization
- A superior quality, competitive, multidisciplinary research program
- Maintenance of essential education and research infrastructure for the future
- Assessment of the productivity of the investment.

A. VISION OF THE FUTURE

The BRP supports the vision and goals of the *National Security S&T Strategy*, the *Defense S&T Strategy*, and the Joint Chiefs of Staff's *Joint Vision 2010*. These documents also guide the *Joint Warfighting Science and Technology Plan* (JWSTP) (Reference 7), the *Defense Technology Area Plan* (DTAP) (Reference 8), and the *Defense Science and Technology Strategy* (Reference 5), which guide investments in applied research (6.2) and advanced development (6.3).

> New technologies have dramatically enhanced our ability to both prepare for and execute military actions. By supporting advances in information technologies, sensors, and simulation, we strengthen our ability to plan and conduct military operations, quickly design and produce military systems, and train our forces in more realistic settings. These technologies are also central to greater battlefield awareness, enabling our forces to acquire large amounts of information, analyze it quickly, and communicate it to multiple users simultaneously for coordinated and precise action. As [former] Defense Secretary William J. Perry has noted, these are the technological breakthroughs that are "changing the face of war and how we prepare for war" (Reference 4).

These strategies have four basic objectives:

- Deterring and defeating aggression in major regional conflicts
- Providing credible overseas presence
- Conducting contingency operations
- Countering weapons of mass destruction.

To achieve these objectives in the coming decades, the strategy commits the United States to:

- Maintain technological superiority in warfighting equipment
- Provide technical solutions to achieve the Future Joint Warfighting Capabilities

- Balance basic and applied research in pursuing technological advances
- Incorporate affordability as a design parameter.

Joint Vision 2010 defines the key military concepts of operation for the 21st century as:

- Dominant maneuver
- Precision engagement
- Focused logistics
- Full-dimensional protection.

Each of these concepts is explicitly based on continued technological innovation and on the ability to achieve information superiority. Together these documents set the goals for DoD and the services in looking to the future and in defining their investment in science and technology. Basic research is a vital part of the S&T program, providing technological opportunities and fundamental understanding of processes and materials on which to base future military technologies.

The services' visions have in turn been built from these bases: for the Army, *Army Vision 2010*; for the Air Force, *Global Engagement: A Vision for the 21st Century Air Force;* for the Navy, *Forward From the Sea—Naval Concept of Operations* and the *Navy Long Range Planning Objectives*; and for the Marine Corps, *Operational Maneuver From the Sea.* Together these documents describe the concepts of operations and define the capabilities needed to meet the challenges of the 21st century.

B. A FLEXIBLE AND BALANCED INVESTMENT PORTFOLIO

The services and the defense agencies develop their specific research investment plans based on the capabilities goals particular to each of them. These plans are then coordinated through the Defense S&T Reliance process. Defense S&T Reliance establishes and implements joint planning, co-located in-house work, or lead-service assignments among the military departments for the 12 technical disciplines of the *Basic Research Plan.* The Reliance approach to these disciplines is presented in Chapter III of this document. Each area has been examined closely by its participants to establish areas of common interest and opportunities for cooperative leverage. Such joint planning and coordination of programs precludes undesired duplication of individual service efforts.

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, chemistry and biological sciences for chemical and biological agent defense, and geosciences for terrain-related knowledge relevant to battlefield mobility prediction. The Navy has a full-spectrum program that places special emphasis on a wide range of ocean science activities, including predicting weather and currents, mapping the ocean floor, using acoustics to detect objects in the ocean, and conducting biotechnological research such as understanding and mimicking communications between mammals. Air Force expertise is concentrated in the aerospace sciences, materials, physics, electronics, chemistry, life sciences, and mathematics for application to air vehicles, space systems, and communications, command, control, computers, and intelligence (C^4I). 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.

This planning process is critical to the DoD investment strategy. The performance of the Basic Research Program with respect to inter-defense agency coordination and guidance from the DoD S&T strategy is evaluated by DDR&E, with feedback to the agencies after the annual program review. The Deputy Under Secretary of Defense for Science and Technology (DUSD(S&T)) chairs the Defense S&T Advisory Group (DSTAG). The Scientific Planning Groups, whose reports appear in Chapter III of this document, incorporate the DSTAG recommendations and decisions into the BRP. These reports provide detail on the division of effort among the services, areas of common interest, and levels of investment.

The *Basic Research Plan* looks both inward through the Reliance process and the reviews and planning processes of the individual services and agencies, and outward through coordination and leverage with the investments of other federal agencies. Figure II–1 shows the distribution of overall FY97 federal funding for basic research. The figure shows that DoD provides only about 7 percent of all federal basic research funding. However, it is important to realize that DoD support is focused in a number of critical fields, and that within these fields DoD is a major factor in the total national investment in basic research. DoD is a significant source of federal funding of R&D at universities in mathematics (22 percent) and computer sciences (30 percent), electrical and mechanical engineering (75 percent and 71 percent), optics, materials, and oceanography. Historically, DoD spends its research dollars supporting the scientific and engineering disciplines that can most significantly impact future warfighting capabilities. Within specific areas in some of these fields, DoD is the only source of research support (e.g., vacuum electronics needed for radiation-hardened systems). The specific percentages of DoD investments in 6.1 (basic research) for FY98 in various scientific fields are as indicated in Table II–1. Overall, DoD's investment in all of the areas shown in Table II–1 provided 7 percent of the total federal investment for basic research.

As already pointed out in Chapter I, DoD is the premier funder of certain disciplines critical for national security (electrical and mechanical engineering, mathematics and computer sciences, and materials science being prime examples). DoD will continue this pattern of investment to ensure that militarily critical technologies continue to see new technological opportunities and the introduction of fresh ideas for future systems.

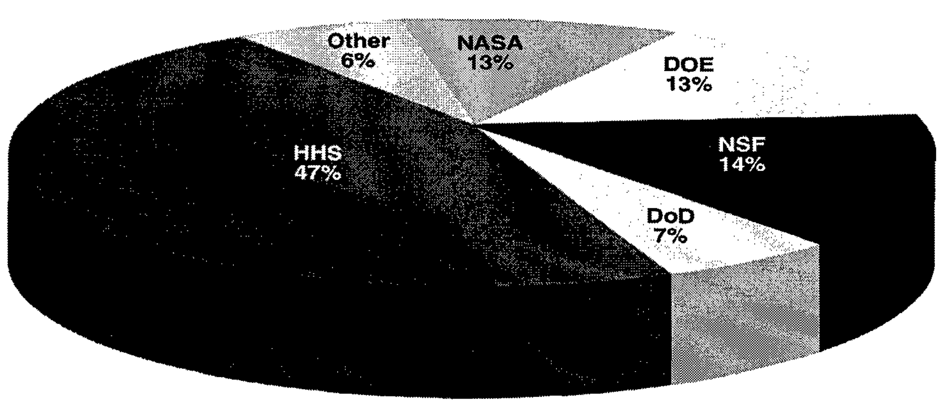


Figure II–1. FY97 Federal Funding of Basic Research by Funding Agency

Table II–1. Distribution of DoD Support for Basic Research (FY99)

Discipline	Percent of DoD Funding
Physics	8
Chemistry	7
Mathematics	5
Computer Sciences	8
Electronics	16
Materials Science	11
Mechanics	10
Terrestrial Sciences	2
Ocean Sciences	10
Atmospheric and Space Sciences	5
Biological Sciences	13
Cognitive and Neural Science	6

C. A SUPERIOR QUALITY RESEARCH PROGRAM

To ensure superior quality, the basic research strategy uses peer review and competition as an important tool in achieving DoD specific research goals. When seeking new ideas, DoD uses mainly the broad agency announcement (BAA) process, electronic media, and other mechanisms to reach the largest possible segment of the scientific research community. Awards are made based on competitive reviews using evaluation criteria stated in the BAA. When it is appropriate, DoD in-house research activities continue to be subjected to peer review, and projects are selected on a competitive basis.

In addition to the discipline-oriented research, DoD also promotes interdisciplinary basic science and engineering research, where multidisciplinary team effort can accelerate research progress in areas particularly suited to this approach by cross-fertilization of ideas. Each year, a select set of topics is announced in a BAA to solicit proposals from university research teams. These topics are selected on the basis that they address the strategic research areas and specific tri-service needs.

DUSD(S&T) establishes Technology Area Reviews and Assessments (TARA) as an oversight function to assess the quality of the research programs. The TARA review teams consist of technical experts from academia, industry, and not-for-profit research organizations. These teams evaluate the programs for quality, for advances in leading the state-of-the-art in research areas, and for their scientific vision.

D. SCIENCE EDUCATION AND RESEARCH INFRASTRUCTURE

About 55 percent of all DoD basic research funding for FY97 was invested at universities. Universities are key performers of research for DoD (Figure II–2). 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 are increasingly sought out as partners by industry for

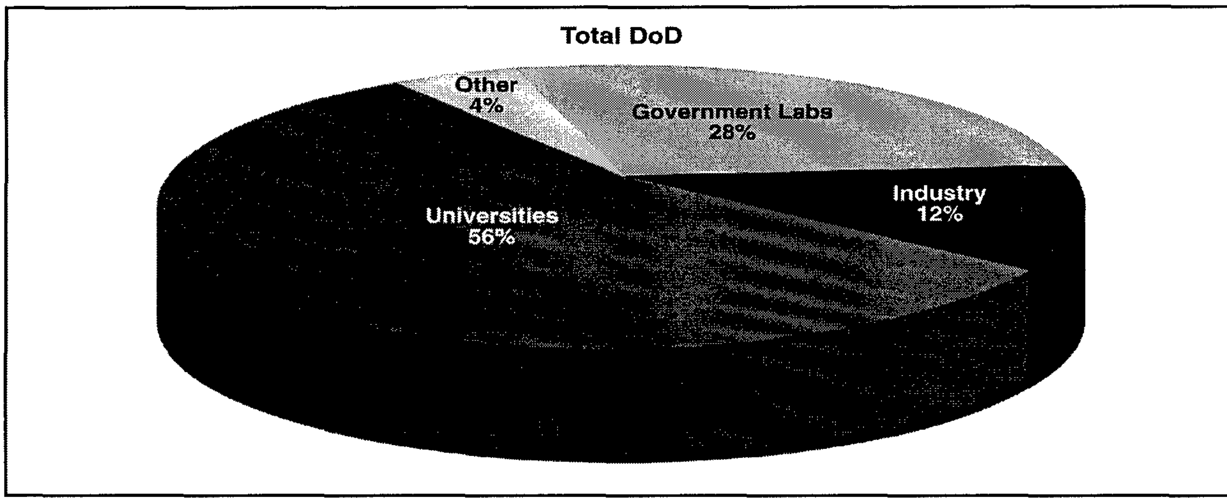


Figure II–2. FY97 Federal Funding of Basic Research by Performer

providing the innovation needed for the future generations of military technology. *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.

DoD in-house laboratories provide the technical expertise to enable the military services to be smart buyers and users. The DoD laboratories perform three critical functions: (1) identifying the connections between warfighters' needs and technological opportunity, (2) responding with high-quality research solutions to the warfighter's 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. Finally, the DoD basic research strategy leverages industrial and international research efforts through cooperative and joint programs. DoD continues to offer guidance and review industry independent research and development (IR&D) programs that offer potential military application.

Students, modern equipment, and facilities are necessary ingredients for scientific research. The Basic Research Program provides for the education and involvement of graduate students and young investigators through a variety of policies and programs designed to create a new generation of scientists and engineers who will perform research of importance to DoD in the future. Many individual research grants to universities and multidisciplinary university research grants often include financial support for graduate students and post-doctorates in addition to the research professors. In addition, DoD sponsors the National Defense Science and Engineering Graduate Fellowship program to provide fellowships to substantial numbers of graduate students majoring in science and engineering of interest to DoD. For DoD's own technically trained employees, who make up almost half of the scientists and engineers employed in the federal government, DoD maintains continuing education programs to keep up with the latest advances in science and technology. DoD is committed to support students and to ensure that its need for scientist and engineers will be met in the future. Special equipment programs link the purchase of modern research equipment in support of DoD relevant research. Research instrumentation is a critical part of the research infrastructure that enhances scientific progress and productivity. In some cases, unique and essential facilities may be upgraded or created to maintain the scientific base critical to DoD needs.

The DoD laboratories, like other elements of the DoD infrastructure, are participating in the processes of reinvention and acquisition reform. The DoD 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.

E. ASSESSMENT OF QUALITY AND FOCUS

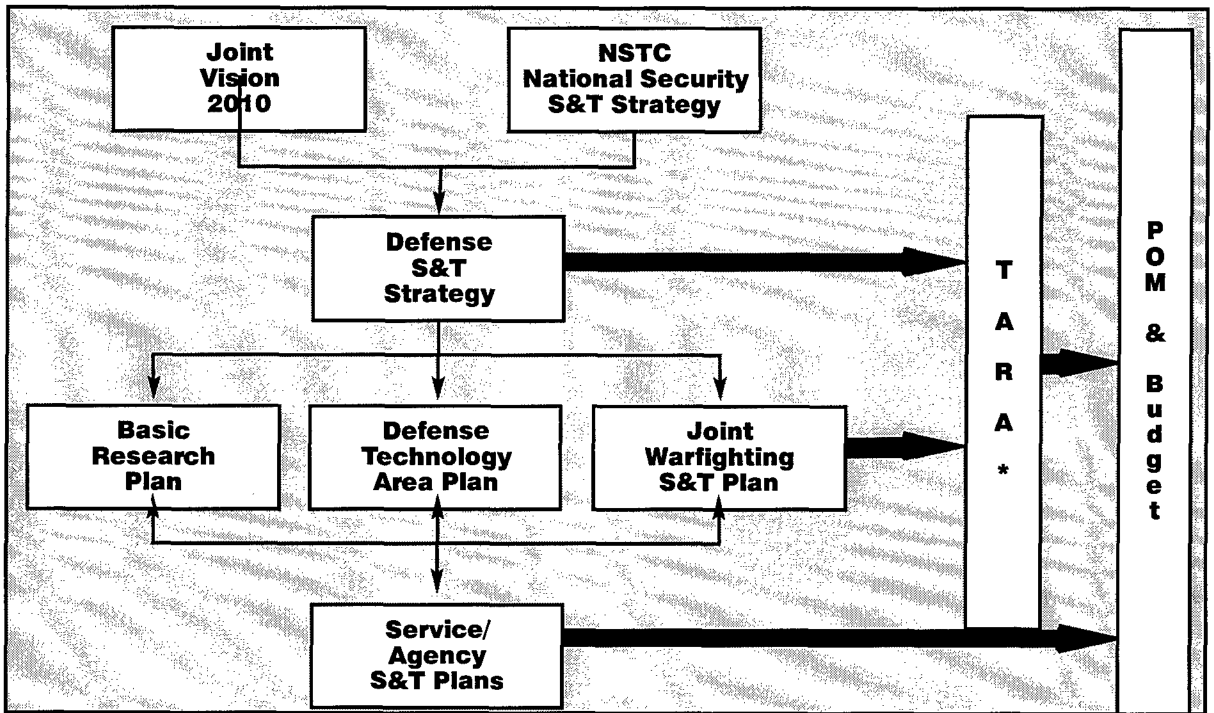
DDR&E uses the TARA process to review the quality and focus of the Basic Research Program. The review takes place in alternate years to assess the content of the discipline area programs for focus, state-of-the-art approaches and problems, and overall quality of the program.

The biennial basic research cycle starts with project-level reviews at the individual research agencies (Army Research Office, Office of Naval Research, Air Force Office of Scientific Research). These sessions are followed by a program-level review of the combined research agencies and preparation of the *Basic Research Plan*. 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 DoD S&T strategy is evaluated by the DDR&E, with feedback to the agencies after the annual program review. The services and defense agencies also conduct other periodic program reviews to assess quality, relevance, and scientific progress.

A significant aspect of the DoD basic research strategy involves the role of Reliance as discussed in Chapter III. In 1995 the DDR&E adopted the goals and structure of the DoD S&T Reliance initiative, and the DUSD(S&T) assumed the chair of the DSTAG. The DUSD(S&T)-led S&T strategy and planning process focuses on ensuring the transition of technology to address warfighting needs, strengthening the commercial-military industrial base, promoting basic research, and ensuring quality throughout the entire DoD S&T community.

Contingency planning is another common element in each service's approach to planning basic research. Budgetary and resource constraints, unplanned military situations, and dramatic scientific breakthroughs can impact any plan no matter how well thought out. Unplanned situations force adjustments to planned basic research activities by either reducing or increasing service investment in various areas. The services account for these contingencies by prioritizing their individual research efforts. When funds must be redistributed to either accelerate a promising research area or to support unexpected military operations, lower priority programs are eliminated or modified significantly.

The Basic Research Program is reviewed every other year by ODDR&E through the TARA process to provide guidance for Program Objective Memorandum (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 DTAP as an important source document for the TARA process. Figure II–3 depicts the S&T planning and review process for the DoD S&T program.



* Technology Area Reviews and Assessments

Figure II–3. Science and Technology Planning Process

III. BASIC RESEARCH AREAS

The Basic Research Program of the Department of Defense supports a broad range of activities spanning many scientific disciplines. The results of these extensive fundamental research efforts provide a sound technical foundation for meeting both the recognized current U.S. defense requirements as well as projected but less well defined future needs. To focus attention on a few of the most exciting research areas that offer significant and comprehensive benefits to our national peacekeeping and warfighting capabilities, the following six Strategic Research Objectives (SROs) were established in 1995 (these SROs are being reviewed and strengthened as Strategic Research Areas for 1999):

- *Biomimetics*– research to develop novel synthetic materials, processes, and sensors through advanced understanding and exploitation of design principles found in nature.
- *Nanoscience*– research to achieve dramatic and innovative enhancements in the properties and performance of structures, materials, and devices that have controllable features on the nanometer scale (i.e., tens of angstroms).
- *Smart Structures*– research to demonstrate advanced capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multielement, deformable structures used in land, sea, and aerospace vehicles and systems.
- *Mobile Wireless Communications*– research to provide fundamental advances enabling the rapid and secure transmission of large quantities of multimedia information (speech, data, images, and video) from point to point, broadcast, and multicast over distributed networks of heterogeneous C^4ISR systems.
- *Intelligent Systems*– research to develop advanced systems that can sense, analyze, learn, adapt, and function effectively in uncertain, changing, and hostile environments in achieving the mission.
- *Compact Power Sources*– research to exploit new concepts to achieve significant improvements in the performance of compact power sources through fundamental advances relevant to current technologies.

These SRAs were selected on the basis that (1) they support DoD missions, (2) they have the potential to result in significantly enhanced capabilities for the peacekeepers and warfighters, (3) they are highly visible and broad areas of substantial DoD investment, (4) they are cross-disciplinary and multidisciplinary in nature, (5) they require sustained investment over a long period of time, and (6) they have the potential for major scientific breakthroughs. The SRAs cut across the Reliance Basic Research Areas to provide focus on areas in which interdisciplinary work should have major payoffs for DoD.

The great majority of the scientific research work constituting the DoD Basic Research Program involves 10 technical disciplines:

- Physics
- Chemistry
- Mathematics
- Computer Sciences
- Electronics
- Materials Science
- Mechanics
- Terrestrial Sciences
- Ocean Sciences
- Atmospheric and Space Sciences
- Biological Sciences
- Cognitive and Neural Science.

As mentioned in Chapter I, each discipline is coordinated by a Strategic Planning Group (SPG), except for two pairs of closely connected disciplines, namely Mathematics and Computer Sciences (one pair) and Ocean and Terrestrial Sciences (the other pair). Because of their close connection, each pair of disciplines is handled by one SPG, making 10 SPGs for 12 disciplines.

The SPGs and the SRA Coordinating Committees provide coordinated tri-service oversight for research in these areas. Research activities in the technical disciplines tend to concentrate on the scientific disciplines involved, whereas the SRAs tend to focus on interdisciplinary approaches to enhanced DoD capabilities. The SRAs tend to be multidisciplinary, as shown in Table III–1.

Table III–1. Correlation Between SPG Disciplines and Strategic Research Areas

Scientific Planning Groups	Strategic Research Areas					
	Biomimetics	Nano-science	Smart Structures	Mobile Wireless Communica-tions	Intelligent Systems	Compact Power Sources
Physics		X	X			X
Chemistry	X	X				X
Mathematics				X	X	
Computer Sciences	X	X		X	X	
Electronics	X	X	X	X	X	X
Materials Science	X	X	X			X
Mechanics			X		X	
Terrestrial Sciences				X		
Ocean Sciences				X		
Atmospheric and Space Sciences				X		
Biological Sciences	X	X	X		X	
Cognitive and Neural Science	X				X	

Selected details regarding specific thrusts within each discipline, budget information, commonality and divergence of service interests, and representative basic research goals in each area are provided in the following sections.

A. PHYSICS

Physics is the scientific discipline devoted to discovering and employing the fundamental principles that underlie the laws of nature. Physics research investigates novel phenomena, formulates and tests new concepts and theories, develops new experimental tools and techniques, performs new measurements, develops new computational techniques, and applies all of the above to developing useful devices and novel or improved materials. DoD Physics research has the goal of transitioning scientific progress and breakthroughs into enhanced defense capabilities. These materials and devices have the potential to extend and enhance the operational capabilities of many different types of military equipment and systems in the areas of weapons, weapon platforms, sensors, communications, navigation, surveillance, countermeasures, and information processing. As such, the Physics SPG crosses all elements of the *Joint Warfighting Science and Technology Plan* by supporting S&T contributions to military needs: ground, sea, air, and space sensor research; sensor improvement research; guidance and control; lethality technologies; high-power microwaves that 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.

The definition of service-specific research in Physics clearly follows lines of respective mission applications. The Army focuses on soldier and land platforms; the Navy, on surface ships, including carriers and their aircraft, and submarines; 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 compact displays and detectors to support the combat soldier. The Army also has a program to develop the scientific underpinnings of image science issues related to aided target recognition, with an emphasis on the development of metrics for performance prediction in highly cluttered scenarios. The Navy pursues research to develop blue-green lasers for underwater communications and mine detection. Naval research in acoustics is focused on physical acoustics and underwater acoustics involving propagation and transducers. Application of nonlinear dynamics to signal detection and classification is of high interest to the Navy. The Air Force has an active program in optical compensation for the imaging of space objects through the atmosphere.

DoD Physics research falls into four general subareas: radiation, matter and materials, energetic processes, and target acquisition.

Radiation: Research in this area ranges from the x-ray to the microwave regime and beyond. Advanced radiation sources are needed to satisfy DoD requirements, including those for C^3I, radar, sensors, electronic warfare, and directed-energy weapons. In addition to radiation sources, this area involves the propagation of radiation and the detection of objects using radiation in different military environments. Research thrusts include ultraviolet and blue-green lasers, high-power microwaves, uncooled detectors, nonlinear optics, and optical compensation.

Matter and Materials: This research ranges from nanoscale (atom sized) systems to macroscale (e.g., high T_c superconductors) systems that impact many DoD systems, such as the Global Positioning System performance improvements (using atom traps and their impact on atomic clocks) and low observables (e.g., bandgap engineered materials). Atom optics and quantum effects are being used to develop ultrasensitive detectors and unprecedented computational and communication capabilities. In addition, nanoscience research is being pursued to develop ultra-small sensors and materials with unique properties for signature control, electronics, and armor.

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

Target Acquisition: The survivability of friendly and unfriendly platforms (e.g., ships, tanks, aircraft) and systems (e.g., C^3I, radar) depends on advances in the area of target acquisition. The area involves an element within the oceanographic and atmospheric arena. Research thrusts are focused on detection and displays, and the scientific underpinning of automatic target recognition (ATR). The Army needs to see through the dust of battle, a requirement calling for advances in imaging science. The Air Force must image space objects through atmospheric distortions. Naval research on acoustic and nonacoustic underwater detection and classification of submarines and mines has employed nonlinear dynamics signal processing methods and nonlinear stochastic resonance detectors.

Budget information for Physics research is provided in Table III–2. Table III–3 provides an outline of service-specific interests and commonality in this research area.

Table III–2. Basic Research Funding for Physics ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
PE 0601101A	In-House Lab Independent Research	Army	0.0	0.0	0.0
PE 0601102A	Defense Research Sciences	Army	8.0	8.8	8.3
PE 0601104A	University and Industry Research Centers	Army	2.0	0.6	0.5
PE 0601152N	In-House Lab Independent Research	Navy	3.1	2.3	2.5
PE 0601153N	Defense Research Sciences	Navy	31.6	33.4	36.2
PE 0601102F	Defense Research Sciences	Air Force	19.9	20.5	23.1
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	9.9	9.2	8.9
PE 0601103D	University Research Initiative	OSD	18.8	17.2	21.2
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Total			93.4	91.9	100.7

Table III–3. Service-Specific Interests and Commonality in Physics

Subarea	Army	Navy	Air Force
Radiation Sources Detection Propagation	Uncooled detectors Sub-MMW research Tunable IR lasers	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); nonlinear optics (A, N, AF); optical diagnostics and testing (A, N, AF); coherent free electron radiation sources (A, N, AF)		
Matter and Materials Optical Atomic Molecular Plasma	Atomic-scale systems Low observables Soldier displays	Physical acoustics Energetic and nonlinear IR materials	Visible lasers Semiconductor lasers
	Areas of Common Interest: ferroelectrics (A, N); nanostructures (A, N, AF); surfaces and interfaces (A, AF); atom optics (A, N, AF); high-T_c superconductors (N, AF); atom traps (A, N, AF); computational physics (A, N, AF); nonlinear control (A, N, AF)		
Energetic Processes High voltage Plasmas Power generation	Mobile power sources	Compact accelerators Pulsed power Ultra-high fields Beam plasma dynamics	Nonneutral plasma effects
	Areas of Common Interest: nonneutral plasmas (N, AF); collective phenomena (N, AF)		
Target Acquisition Oceanographic Atmospheric	Integrated sensory science Imaging science Unconventional optics	Nonlinear acoustics Sound/fluid/structure interactions Active and passive sonar Stochastic resonance detectors	Atmospheric discharges
	Areas of Common Interest: ionospheric modification and propagation (N, AF); nonlinear dynamics/chaos (A, N, AF)		

B. CHEMISTRY

Chemistry research directly affects a wide range of critical DoD systems and missions. Such research is central to developing advanced materials for specific DoD applications and to developing suitable processes for producing these 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 Chemistry research enables the design of components for military systems that exploit these properties for optimal performance.

Responsibilities for topics within the Chemistry area of the Basic Research Program are distributed in accordance with service mission considerations. 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, and novel cooling technologies and energetic materials (there is no civilian effort on which to depend). The Air Force emphasizes materials that maintain their integrity in extreme environments, corrosion chemistry related to aging aircraft, chemical lasers, and processes that affect operations in the atmosphere and in space. Topics of common interest continue to be: optical polymers for rapidly disseminating and displaying information to the warfighter; power sources for specific DoD applications; 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 the design of optimal material systems. In addition to the applications cited above, other widespread applications of Chemistry research include developing materials for marine and aerospace environments, strong and lightweight composite materials, electronic materials, semiconductors, superconductors, and barriers for chemical and biological weapons.

Chemical Processes: *The ability to control 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. Ongoing research is addressing the destruction of munitions and the catalytic oxidation and hydrolysis of chemical agents and toxins, as well as techniques for detecting 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 expected to continue to eventual development of medium- to large-scale energy conversion systems. The Navy leads work in development of carbon nanotube and organic composites for electronic and structural material applications. Activities in surface processes and interface reactivity for electronic device technologies operating in harsh environments are being pursued. The Air Force continues to develop new materials synthesis methods, particularly the novel work it is doing on inorganic polymers, which holds promise of a new class of versatile materials that operate in extreme environments. Air Force work to understand, detect, and prevent corrosion of aircraft is increasing. The Air Force is also actively pursuing approaches to develop lightweight chemical laser systems. Common efforts within the SPG in chemical synthesis address energetic materials, supramolecular chemistry for biomimetics and detection, and optical materials. Research on optical polymers for information processing applications is continuing to make great progress important to meeting many DoD needs. Research in tribochemistry is developing an understanding of the role of surface chemistry in friction and wear, for example, to support synthesis of tailored lubricants.

Budget information for Chemistry research is provided in Table III–4. Table III–5 provides an outline of service-specific interests and commonality in this area.

Table III–4. Basic Research Funding for Chemistry ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
PE 0601101A	In-House Lab Independent Research	Army	1.9	0.7	0.8
PE 0601102A	Defense Research Sciences	Army	5.4	5.7	6.3
PE 0601104A	University and Industry Research Centers	Army	0.0	1.2	0.5
PE 0601152N	In-House Lab Independent Research	Navy	0.8	0.9	0.9
PE 0601153N	Defense Research Sciences	Navy	23.8	23.5	25.3
PE 0601102F	Defense Research Sciences	Air Force	27.7	27.1	28.8
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	6.0	5.7	5.4
PE 0601103D	University Research Initiative	OSD	22.6	17.0	17.1
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Total			88.2	81.9	85.1

Table III–5. 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/permselective polymers Dendritic molecules	Nanoelectronic materials Inorganic semiconductors Minimally adhesive surfaces Complex oxides Nanotubes/organic composites	Inorganic-based protective coatings and space materials Aircraft coatings Polymeric high-temperature materials
	Areas of Common Interest: nanostructures (A, N, AF); energetic materials (A, AF); power sources (A, N, AF); functional polymers (A, N, AF); sensors (A, N, AF); lubricants (N, AF)		
Chemical Processes Atomic and molecular energy transfer Transport phenomena Reactions Changes of state	Decon/demil chemistry CBW detection Organized assemblies Diffusion/transport in polymers Energetic ignition/detonation	Biomimetic catalysis (CBW) Combustion/conflagration in fuels Surface and Interface processes Self-assembled mesostructures Ion/charge transport Adhesion	Chemical lasers Atmospheric and space signatures and backgrounds Processing (ceramics, polymers, sol gels) Thin-film growth
	Areas of Common Interest: chemical dynamics (A, N, AF); tribochemistry (A, N, AF); sensors (A, N, AF); chemistry of corrosion and degradation (A, N, AF); power sources (A, N, AF)		

C. MATHEMATICS AND COMPUTER SCIENCES

Mathematics research contributes the analytical tools required to satisfy DoD needs in many diverse areas, including 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 depend on research achievements in a number of mathematical subdisciplines. For example, approaches to computer vision for ATR require research in constructive geometry, numerical methods for stochastic differential equations, Bayesian statistics, tree-structured method in statistics, probabilistic algorithms, and distributed parallel computation. Another example is the 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.

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 to create virtual environments for design and prototyping.

The services support basic research in mathematics on nonlinear dynamics and on multiscale phenomena. The results of this research are applicable both to the specific concerns of each service as well as to common issues. The Army leads in mathematics research pertinent to the development and performance of advanced materials for advanced armor and antiarmor systems. The Navy leads in ocean modeling and wavelet-based image processing. The Air Force leads in control and guidance.

A major interest in computational mathematics is in adaptive methods. In operations research, the prime topic of DoD interest is mathematical programming, reflecting 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; the Navy, in nonlinear filtering (for target tracking) and incompressible flows (for hydrodynamic design); and the Army, in probabilistic methods for automatic/aided target recognition.

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 dependably, the Army is driven by 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 services' 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, the atmosphere and space).

Within the DoD Basic Research Program, research in Mathematics falls into three general subareas:

Modeling and Mathematical Analysis: The fundamental knowledge provided by research in this area increases DoD's ability to develop advanced ground vehicles, aircraft and naval vessels, energetic materials, delivery systems, radar, sonar, sensors and actuators, and other military equipment.

Computational Mathematics: Research in this area impacts DoD capabilities in ballistics, target penetration, vulnerability, ground vehicles, aircraft, naval vessels, combustion, detonation, and stealth technology.

Stochastic Analysis and Operations Research: Research in this area impacts DoD capabilities in design, testing, and evaluation of systems; decision making under conditions of uncertainty; logistics; and resource management.

Similarly, research in Computer Sciences falls in three general subareas:

Intelligent Systems: The fundamental knowledge provided by research in this area directly affects DoD capabilities in automated C^3I systems, guidance and control of semiautomated and automated platforms, ATR, and real-time warfare management decision aids.

Software: Research in this area influences DoD capabilities in automation, decision support, combat systems, warfare management systems, distributed interactive simulation, digitization of the battlefield, training, and man–machine interaction.

Architecture and Systems: This area affects DoD capabilities in warfare management, real-time data acquisition, training, C^3I, geographic information systems, ATR, system automation, distributed interactive simulation, and vulnerability and lethality analysis.

Budget information for Mathematics and Computer Sciences research is provided in Table III–6. Table III–7 provides an outline of service-specific interests and commonality in this area.

Table III–6. Basic Research Funding for Mathematics and Computer Sciences ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
Mathematics					
PE 0601101A	In-House Lab Independent Research	Army	0.0	0.0	0.0
PE 0601102A	Defense Research Sciences	Army	5.1	5.0	6.3
PE 0601104A	University and Industry Research Centers	Army	0.3	0.1	0.4
PE 0601152N	In-House Lab Independent Research	Navy	2.6	2.4	2.6
PE 0601153N	Defense Research Sciences	Navy	16.0	11.8	13.3
PE 0601102F	Defense Research Sciences	Air Force	24.2	29.0	19.8
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	0.0	0.0	0.0
PE 0601103D	University Research Initiative	OSD	14.6	13.3	13.5
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Subtotal			62.8	61.6	55.8
Computer Sciences					
PE 0601101A	In-House Lab Independent Research	Army	0.0	0.0	0.0
PE 0601102A	Defense Research Sciences	Army	9.8	8.5	10.4
PE 0601104A	University and Industry Research Centers	Army	7.5	7.3	7.6
PE 0601152N	In-House Lab Independent Research	Navy	0.8	0.9	0.9
PE 0601153N	Defense Research Sciences	Navy	21.2	14.3	16.0
PE 0601102F	Defense Research Sciences	Air Force	6.1	7.3	18.6
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	17.8	16.4	15.9
PE 0601103D	University Research Initiative	OSD	12.9	15.2	16.0
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	2.9	0.8
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Subtotal			76.0	72.8	86.2
Total			138.8	134.4	142.0

Table III–7. Service-Specific Interests and Commonality in Mathematics and Computer Sciences

Subarea	Army	Navy	Air Force
Mathematics			
Modeling and Mathematical Analysis Physical modeling and analysis	Mathematics of materials science Reactive flows	Ocean modeling and mixing	Control and guidance Nonlinear optics
	Areas of Common Interest: inverse problems (N, AF); multiscale phenomena (A, N, AF); nonlinear dynamics (A, N, AF)		
Computational Mathematics Numerical analysis Discrete mathematics	Computational mechanics Data representation Discrete mathematics	Computational acoustics Computational statistics Computational logic	Computational control Compressible and hypersonic flow
	Areas of Common Interest: adaptive methods (A, N, AF); computational electromagnetics (N, AF)		
Stochastic Analysis and Operations Research Statistical methods Applied probability optimization	Statistical modeling Simulation methodology	Random fields Nonlinear filtering	Intelligent search Discrete event systems
	Areas of Common Interest: stochastic image analysis (A, N); stochastic PDEs (A, N); mathematical programming (A, N, AF); network and graph theory (A, N, AF)		
Computer Sciences			
Intelligent Systems Control Learning NLP Motion planning Virtual environments Languages	Intelligent control Natural language processing Machine intelligence	Case-based reasoning Machine learning Motion planning	Intelligent real-time problem solving Intelligent tutoring Intelligent accents
	Areas of Common Interest: data fusion (A, AF); machine vision (A, N, AF); virtual environments (A, N); novel computing paradigms (A, N, AF)		
Software Software engineering Software environments Languages	Heterogeneous database Formal languages Automation of software development	Hard real-time computing Structural complexity Programming logic	Information warfare high-performance knowledge bases
	Areas of Common Interest: software environments (A, N, AF); programming languages (A, N, AF); formal design and verification (N, AF)		
Architecture and Systems Compilers Operating systems	Scalable parallel combat models Hybrid system architectures	Ultradependable multicomputing systems Secure computing	Distributed computing for C^3
	Areas of Common Interest: compiler optimization (A, N); operating systems (A, N, AF); man–machine interface (A, N)		

D. ELECTRONICS

Electronics is considered a dominant force multiplier in DoD systems. Basic research in Electronics supports all elements of the JWSTP and is both need and opportunity driven. The Electronics SPG plans and conducts a forward-looking, well-integrated research program that addresses many of the currently defined mission deficiencies and operational requirements, including aiming and position accuracy of weapons, unmanned robotic vehicles and aircraft, and reliable (minimum downtime) global communications and real-time global surveillance as needed for information dominance and network centric warfare. These requirements are driven by *affordability* and *a continuing need for operational superiority.* Operational superiority requires systems possessing higher accuracy and vastly greater information throughput capacity to influence real-time situation assessment or systems performing autonomously over land, at sea, or in the air or space.

The Basic Research Program in Electronics has established a national leadership position and has initiated, advanced, exploited, and leveraged research results in many fields that impact technologies of military importance. Representative examples are research efforts on infrared detectors for various military operations under realistic battlefield conditions; wide-bandgap semiconductor research, which is critical for high-temperature jet engine controls and high-power RF and shipboard switching devices; 100-GHz logic for digital RF and beamsteering; and RF and optical computing devices needed to achieve major weight/size reductions 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 vehicles and soldier support; Navy programs are driven by considerations derived from multifunctional RF, ocean, and submarine operational needs; the Air Force research efforts are dictated by requirements for high-performance aircraft and space platforms. In addition to service-specific programs, the Electronics SPG plans for multiservice and multidisciplinary efforts to more effectively focus resources on recognized high-priority DoD topics.

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 radiation-hardened, low-power, low-voltage applications for soldier or space support; ultra-high-frequency devices to be applied in secure communication or radar; versatile, multifunctional RF technology; 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. Other optical research is directed to IR threat bands outside commercial spectra.

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. Coding schemes for secure communication and robust communication networks are being investigated. Unique cellular arrays are being investigated for image processing to bypass software and algorithm bottlenecks.

Optimum control of distributed information processing and transmission is also receiving substantial attention. 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 electromagnetics 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 electromagnetics research program is focused on fundamentals of antenna design, dispersion-free beamsteering, scattering and transmission of EM signals, and efficient RF components for use predominantly in multifunctional 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. Basic research issues in landmine detection, demining, and neutralization have been receiving increased attention.

Budget information for Electronics research is provided in Table III–8. A more detailed outline of service-specific interests and commonality in this area is given in Table III–9.

Table III–8. Basic Research Funding for Electronics ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
PE 0601101A	In-House Lab Independent Research	Army	3.1	1.8	2.0
PE 0601102A	Defense Research Sciences	Army	14.8	17.0	19.1
PE 0601104A	University and Industry Research Centers	Army	14.6	22.2	22.5
PE 0601152N	In-House Lab Independent Research	Navy	0.5	0.2	0.3
PE 0601153N	Defense Research Sciences	Navy	34.4	32.5	36.6
PE 0601102F	Defense Research Sciences	Air Force	24.8	24.8	26.1
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	34.2	18.0	17.5
PE 0601103D	University Research Initiative	OSD	36.3	36.5	38.2
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	4.0	4.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Total			162.6	157.0	166.3

Table III–9. Service-Specific Interests and Commonality in Electronics

Subarea	Army	Navy	Air Force
Solid-State and Optical Electronics Detectors Superconductors Nonlinear circuits	IR and UV detectors Power switches Terahertz electronics Low-power and low-voltage analog electronics	Wide-gap semiconductors Magnetic thin films All-digital RF electronics Magneto-electronics 6.1-angstrom materials	Radiation-hard electronics Nonlinear optical materials High-temperature electronics
	Areas of Common Interest: lithography (A, N); quantum transport (A, N); nanoscale and mesoscale electronics (A, N, AF); heterostructures (A, N, AF); multifunctional devices and micro-optics (A, N, AF); device reliability (N, F); superconductors (N, AF)		
Information Electronics Modeling Simulation	Mobile, wireless multimedia distributed communications IR target recognition and image analysis Human cognitive processing	Sensor array processing Distributed networks Soft/fuzzy logic/neural networks Reliable, fault-tolerant VLSI	None
	Areas of Common Interest: modeling/simulation of circuits, devices, and networks (A, N); sensor fusion (A, N, AF); digital signal processing (A, N, AF); adaptive arrays (A, N, AF); target acquisition (A, AF); array processing (A, N, AF)		
Electromagnetics Antennas Transient sensing Tubes	Wireless and radar propagation Advanced MMW circuit and antenna integration Mobile tactical wireless and printed antennas	Dispersion-free beamsteering	Transient electromagnetics Secure propagation Distributed aperture radar
	Areas of Common Interest: integrated transmission lines (A, N, AF); EM numerical techniques (A, N, AF); discontinuities in circuits (A, N, AF); EM scattering (N, AF); vacuum electronics (N, AF); optical control of array antennas (A, N, AF); power-efficient RF components (A, N, AF)		

E. 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 by providing access to higher performance and superior weapon systems together with improved readiness, decreased need for logistic support, increased reliability, and lower lifetime cost.

Navy programs are driven by operational considerations such as ocean surface and subsurface vehicle designs as well as naval air, space, and missile system 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/antiarmor 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 Materials Science 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.

The DoD Basic Research Program in Materials Science includes two subareas: structural materials and functional materials. Research in both 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 subarea 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 high performance, low cost spacecraft materials; and lightweight, tough, corrosion-resistant hulls of naval ships.* Structural materials of principal interest are metallic materials, ceramics, composites, and polymers. The structural aspects pertain primarily to service under mechanical loads. Research in this area is focused on designing and processing advanced materials to achieve higher performance and improved reliability at lower costs, developing new materials with unique microstructures, providing improved understanding of material behavior under a variety of complex loading and environmental conditions, optimizing interface chemistry and mechanics, and developing innovative nondestructive techniques for characterizing materials and investigating the interrelationships that couple material processing and performance. Some of the research areas of growing importance pertinent to these thrusts include computational design, aging systems, biomimetics, and nanoscience. The area of aging systems is of particular concern for all three 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 affected 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 products and reliable performance, attaining materials-by-design capability to provide new materials with unique properties, investigating the principles of defect engineering, and exploring the potential of nanoscience. Areas of growing importance include nanoscience, smart systems, and thermoelectrics. For example, in the area of thermoelectrics, novel material approaches that include lead-telluride (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 for high-temperature applications for shipboard cooling and power generation.

Budget information for Materials Science research is provided in Table III–10. An outline of service-specific interests and commonality in this area is included in Table III–11.

Table III–10. Basic Research Funding for Materials Science ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
PE 0601101A	In-House Lab Independent Research	Army	2.7	0.2	0.2
PE 0601102A	Defense Research Sciences	Army	7.3	13.0	16.1
PE 0601104A	University and Industry Research Centers	Army	2.9	1.4	1.8
PE 0601152N	In-House Lab Independent Research	Navy	1.8	2.1	2.2
PE 0601153N	Defense Research Sciences	Navy	27.7	30.5	31.9
PE 0601102F	Defense Research Sciences	Air Force	13.3	14.0	13.6
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	10.1	9.4	9.1
PE 0601103D	University Research Initiative	OSD	32.2	36.6	42.9
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Total			98.1	107.2	117.8

Table III–11. Service-Specific Interests and Commonality in Materials Science

Subarea	Army	Navy	Air Force
Structural Materials Synthesis Processing Theory Properties Characterization Modeling	Manufacturing science (land/rotorcraft systems, armaments) Armor/antiarmor materials Diesel engine materials Gun tube liner materials	Marine corrosion, oxidation, and fatigue Advanced materials for ships and submarines Acoustically damped structures Layered designed materials	High-temperature fatigue and fracture Airframe and engine materials Aging aircraft Functionally graded materials Space plane, spacecraft, and launch vehicle materials Material properties integration
	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 Optical components IR detector materials CBD materials Smart materials	Ferrite films Ferroelectrics Diamond Acoustics/active materials Superconductivity	(Topics addressed under Chemistry, Electronics, Physics, and Mechanics basic research areas)
	Areas of Common Interest: optoelectronics (A, N); magnetic materials (A, N)		

F. MECHANICS

DoD-sponsored basic research 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 capabilities 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 service lives of major system acquisitions increase demands for major performance improvements with predictable affordability constraints.

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. Research in Mechanics is focusing on understanding relationships between microscale phenomena and macroscale response; submicroscale mechanical response devices for obtaining service-history data; inventing new concepts for predicting and controlling strongly nonlinear/dynamic phenomena; conducting interdisciplinary work with synergistic ideas from analysis, simulation, and diagnostics; and determining the appropriate level of complexity relevant to engineering. These characteristics, alone or in combination, are present in all DoD research in Mechanics. 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.

Mechanics research supported by the DoD Basic Research Program can be conveniently divided into three general subareas: solid and structural mechanics, fluid dynamics, and propulsion and energy conversion. Each service performs research responsive to its particular system drivers. In a number of areas, the services have common interests. In general, each service performs research in an area of commonality, with specific nonoverlapping technology targets. For example, in structural dynamics and smart structures, the Army emphasizes stability and control of rotorcraft structures, the Navy focuses on underwater explosion effects and 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 and 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., smart helicopter rotor blades). Opportunities exist for optimizing lift-to-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 tailoring 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 turbulent flows with high Reynolds numbers. 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 aeroacoustic fields and structural deformation, the understanding of compressibility, and 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 supercavitation phenomena for high-speed undersea weapons.

Propulsion and Energy Conversion: *Research in this area is crucial to the performance and 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 weapon applications. Research on the physical, chemical, and 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 III–12. Service-specific interests and commonality in this area are cited in Table III–13.

Table III–12. Basic Research Funding for Mechanics ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
PE 0601101A	In-House Lab Independent Research	Army	2.3	1.2	1.2
PE 0601102A	Defense Research Sciences	Army	16.8	17.9	17.0
PE 0601104A	University and Industry Research Centers	Army	17.0	11.0	11.4
PE 0601152N	In-House Lab Independent Research	Navy	3.2	2.8	2.9
PE 0601153N	Defense Research Sciences	Navy	28.3	23.6	25.7
PE 0601102F	Defense Research Sciences	Air Force	31.3	34.0	37.5
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	0.0	0.0	0.0
PE 0601103D	University Research Initiative	OSD	20.9	18.9	17.4
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Total			119.7	109.4	113.1

Table III–13. Service-Specific Interests and Commonality in Mechanics

Subarea	Army	Navy	Air Force
Solid and Structural Mechanics Structural dynamics Composites Aeroelasticity Acoustics	Finite deformation, impact, and penetration	Structural acoustics Thick composites Micromechanics of electronic devices and solids	Hypersonic aeroelasticity Mechanics of high-temperature materials Particulate mechanics
	Areas of Common Interest: structural dynamics and control (A, N, AF); damage and failure mechanics/quantitative nondestructive evaluation (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 hydro-acoustics	Turbomachinery aerothermo-dynamics Fixed-wing aerodynamics Hypersonic aerothermo-dynamics
	Areas of Common Interest: unsteady separated flow (A, N, AF); turbulence (N, AF)		
Propulsion and Energy Conversion Gas turbines Explosives Soot formation	Reciprocating engines Gun propulsion Small gas turbines	Underwater propulsion Missile propulsion Explosives	Large gas turbines Supersonic combustion Spacecraft and orbit propulsion
	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)		

G. TERRESTRIAL AND OCEAN SCIENCES

The DoD requirement for a core competency in Terrestrial and Ocean Sciences arises from the fact that the oceans and their borders are the Navy and Marine Corps' main operating environment, while the Army operates on the land surface and has mission interests with the Navy and Marine Corps in joint logistics-over-the-shore (JLOTS) and coastal engineering. The impact that these physical environments have on virtually every aspect of Army, Navy, and Marine Corps activity requires a robust competency in Terrestrial and Ocean Sciences.

DoD research in Terrestrial Sciences encompasses study of the broad spectrum of land-based phenomena that affect the Army. In particular, it is concerned with the impact of the surface and near-surface environment on Army activities and is directed at those particular elements that may have significant bearing on the planning, rehearsal, and execution of military campaigns. Additional aspects of importance are the management and stewardship of Army installations, particularly as regards the sustainability of Army training and testing lands and the remediation of Army contaminated sites. Current research comprises work in three interrelated subareas:

Terrain Properties and Characterization: An ability to understand and utilize the variable topographic and physical characteristics of the landscape is critical to mobility/countermobility, communication, survivability, and troop and weapon effectiveness. A major goal of this effort is a capability for the rapid post-acquisition generation, analysis, and utilization of remotely sensed terrain data about short-term battlefield conditions and dynamics.

Terrestrial Processes and Landscape Dynamics: Improved understanding of terrestrial processes affecting Army operations in different physical environments is the focus of this area.

Terrestrial System Modeling and Model Integration: The ultimate objective of the efforts described above to characterize the natural environment and study surficial processes is to develop or enhance integrated system models and simulators. Research in this area is aimed at integrating advances in fundamental theory and process understanding into existing environmental process and material behavior models.

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, optical, and electromagnetic features from the bottom to the surface. The domain for this advance extends from the open ocean to the beach. Current DoD research falls in three interrelated subareas:

Oceanography: The fundamental knowledge provided by research in oceanography impacts naval capabilities to operate in the ocean, and the ability to use its sensors and weapons effectively. The littoral zones of the world (e.g., marginal shelves, shallow water coastal regions) require much finer resolution than that developed for open ocean models in order to nowcast/forecast the four-dimensional ocean environment in support of operations such as amphibious assault, special operations, and mine countermeasures (MCM).

Ocean Acoustics: Oceanography affects the Navy's capabilities to detect, classify, and neutralize undersea enemy systems and activities. The ocean is effectively transparent to sound propagation, so fundamental knowledge of ocean acoustics is key to system design, operating strategies, and tactical decisions. The Navy has identified ocean acoustics as an area of national responsibility for Navy investments.

Ocean Geophysics: This area affects both Navy and Army capabilities to work in the ocean and at its boundaries, and ongoing research provides part of the essential knowledge base required by the other two subareas.

Budget information for Terrestrial and Ocean Sciences research is provided in Table III–14. Service-specific interests in this area are described in Table III–15.

Table III–14. Basic Research Funding for Terrestrial and Ocean Sciences ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
Terrestrial Sciences					
PE 0601101A	In-House Lab Independent Research	Army	0.8	7.3	7.2
PE 0601102A	Defense Research Sciences	Army	18.1	1.2	2.4
PE 0601104A	University and Industry Research Centers	Army	0.0	0.0	0.0
PE 0601152N	In-House Lab Independent Research	Navy	0.0	0.0	0.0
PE 0601153N	Defense Research Sciences	Navy	0.0	0.0	0.0
PE 0601102F	Defense Research Sciences	Air Force	0.0	0.0	0.0
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	2.7	0.0	0.0
PE 0601103D	University Research Initiative	OSD	0.0	2.6	3.8
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Subtotal			21.6	11.1	13.5
Ocean Sciences					
PE 0601101A	In-House Lab Independent Research	Army	0.0	0.0	0.0
PE 0601102A	Defense Research Sciences	Army	0.0	0.0	0.0
PE 0601104A	University and Industry Research Centers	Army	0.0	0.0	0.0
PE 0601152N	In-House Lab Independent Research	Navy	0.5	0.4	0.4
PE 0601153N	Defense Research Sciences	Navy	88.2	86.8	97.9
PE 0601102F	Defense Research Sciences	Air Force	0.0	0.0	0.0
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	0.0	0.0	0.0
PE 0601103D	University Research Initiative	OSD	11.6	9.6	9.3
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Subtotal			100.3	96.8	107.6
Total			121.9	107.9	121.1

Table III–15. Service-Specific Interests and Commonality in Terrestrial and Ocean Sciences

Subarea	Army	Navy	Air Force
Terrestrial Sciences			
Terrain Properties and Characterization	Terrain data generation and analysis Properties of natural materials Site characterization	Continental terraces	None
Terrestrial Processes and Landscape Dynamics	Surficial processes and geomorphology Hydrometeorology and hydrology Coastal erosion and engineering Groundwater flow and mass transport	Near-shore sediment processes	None
Terrestrial System Modeling and Model Integration	Tactical mobility and LOTS Sustainable testing and training lands Contaminant remediation		None
Ocean Sciences			
Oceanography	None	Physical, chemical, biological, optical modeling, and prediction	None
Ocean Acoustics	None	Shallow-water acoustics High-frequency acoustics Long-range propagation	None
Ocean Geophysics	LOTS Coastal engineering Coastal erosion	Continental terraces Sediment processes	None

H. ATMOSPHERIC AND SPACE SCIENCES

Research in Atmospheric and Space Sciences develops the basic technical foundations in these areas primarily for use in many applications important to DoD. Research in meteorology (dynamical, physical, and modeling), space science (ground-, air-, and space-based), and remote sensing (active and passive) is conducted to support a broad range of DoD interests and activities. The products of these 6.1 basic research efforts and accompanying 6.2/6.3 work undergo transition to operational commands for use in weapon and surveillance platforms; planning of peacetime and warfighting operations; live and simulated training; and forecasting, mitigation, and modification of the battlespace environment.

For DoD to plan and conduct a comprehensive program of research across the broad spectrum of air and space science topics, however, is fiscally and technically not feasible. Therefore, DoD provides products to other agencies and cooperates with them to enhance the knowledge. Examples of cost-sharing and leveraging of work by other agencies include tropical storm research (ONR and NOAA), high-resolution modeling (ARO, ONR, NSF, and NOAA), atmospheric aerosols (ONR and NASA), and boundary layer modeling (ARO and NOAA). In the international community, DoD sponsors scientific conferences such as the DoD Battlespace Atmospherics Conference. These conferences attract government, university, and industry researchers from all over the world and help to ensure that this area of DoD basic research is highly leveraged and well coordinated with others in the field.

Mission assignments for each service serve as focal points for supported research. For example, the Army emphasizes research in continental boundary layer dynamics, remote sensing of atmospheric state and content, and atmospheric effects on sensor systems. The Navy has responsibility for global- and theater-scale meteorology focused on the marine environment, including tropical cyclones, marine cloud processes, air–sea interactions, and coastal zone predictions. The Navy space program emphasizes space-based exoatmospheric physics, while the Air Force counterpart tends to emphasize remote sensing of space objects, detection and tracking of missiles, and on-orbit satellite operations and survivability. If appropriate, interservice collaborations and many complementary research programs are used when common interests are served.

Basic research in Atmospheric and Space Sciences comprises work in three subareas:

Meteorology: In many military operations, weather determines the order of battle and meteorology is its associated force multiplier. Safety of operations, logistical planning and execution, deployment of forces in and out of theater, and sensor and weapon performance are all influenced by weather conditions. The DoD's atmospheric research effort seeks to provide the basic understandings of global and theater weather needed to construct reliable prediction models used by operational commands. Understanding the basic nature of atmospheric turbulence and cloud boundary layers affects the ability to predict the transport and diffusion of airborne effluents, aerosols, heat, and moisture. For blue-water operations, special attention is directed toward understanding the behavior and evolution of tropical cyclones in general and in the Western Pacific in particular, where DoD has the lead forecast responsibility for the United States. Plans are to improve our knowledge about motion (track), structure (size), and intensity (wind speed) of these important phenomena. The research program balances theoretical modeling, analytical case studies, and experimental observations while exploring the limits of forecast predictability. The overall goal of these research efforts is to provide the highest quality mission-tailored weather information, products, and services to our nation's combat forces in peace and war– anytime, anyplace.

Space Science: As demonstrated during recent and current operations, U.S. forces are increasingly dependent on the capabilities of DoD space assets. GPS navigational capabilities, critical in high-technology warfare, are the direct result of long-term and ongoing basic research in precision timekeeping. Precision time-interval and time-transfer technology are also required for precise targeting and synchronization of secure communications and other systems. Ionospheric and upper atmospheric neutral density research will address needs for improved GPS accuracies, precision geolocation of RF emitters, and RF communications. A new naval optical interferometer may provide positional accuracies of astronomical sources below the milliarc-second level. These advances, combined with improved astrometric reference frames and continuing improvements in compact electronics, will support operational requirements for systems with increased precision guidance and autonomous satellite navigation. The high bandwidth and secure communications features of the MILSTAR satellites are the result of large 6.1 investments in rad-hard electronics, broadband communications, ionospheric specification, and power generation. Continuing efforts in these areas, coupled with ongoing developments in mobile wireless band communications, will result in a new generation of smaller, lighter, and more affordable satellites.

The next generation and block upgrades of DoD missile early-warning satellites– the Space-Based Infrared System (SBIRS)– will not be possible without continuing investment in focal plane technology, onboard signal processing capabilities, and the ability to acquire and track very dim targets against highly cluttered backgrounds. The potential ability to exploit basic understandings of plume signatures and varying background radiance in the design of spectrally agile electro-optical sensor systems may even enable the detection of cruise missiles from space-based platforms. Solar and heliospheric research is directed toward understanding the mechanisms for generation of solar extreme electromagnetic fluxes, solar flares, coronal mass ejections, and the propagation of these phenomena from the sun through the magnetosphere and ionosphere. The resulting ionospheric variability affects RF communications over a very wide range of frequencies. A better understanding of solar and space physics, and the ability to predict sooner the effect of solar activity, will enable commanders to switch to the other assets and to turn off those systems susceptible to damage, temporary or permanent, until the space environment has returned to acceptable limits. Upper atmospheric neutral density is also a function of solar activity, and future research will result in improved specification of satellite drag, orbital tracking, and vehicle reentry– providing the U.S. Space Command greater capability to maintain and upgrade the Space Object Catalog.

Remote Sensing: Remote sensing characterizes environmental parameters and target signature characteristics critical to the performance of surveillance, acquisition, tracking, and home-to-kill sensors and weapons. It also supports critical needs in chemical/biological warfare. In meteorology, wind profiler technology will provide details regarding the 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. The development of the Airborne Laser is highly dependent on basic research directed toward measuring and mitigating the effects of natural and induced atmospheric turbulence. Remote sensing for missile warning and subsequent track and kill will be greatly enhanced with the planned development of hyperspectral imagery techniques and associated automatic target recognition algorithms. The ability to use space-based electro-optical sensors to see through the lower atmosphere and clouds is increasingly important as the theater ballistic missile threat requires better all-weather capability and improved warning times for cueing tracking sensors. The threat of chemical and biological agents against military and civilian populations has led to increased emphasis on the development of biosensors with very special responsivities.

Budget information for basic research work in Atmospheric and Space Sciences is given in Table III–16. Service-specific interests and commonality in this area are presented in Table III–17.

Table III–16. Basic Research Funding for Atmospheric and Space Sciences ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
PE 0601101A	In-House Lab Independent Research	Army	0.0	0.0	0.0
PE 0601102A	Defense Research Sciences	Army	4.7	5.2	5.0
PE 0601104A	University and Industry Research Centers	Army	0.0	0.0	0.0
PE 0601152N	In-House Lab Independent Research	Navy	0.1	0.1	0.1
PE 0601153N	Defense Research Sciences	Navy	21.4	21.4	24.1
PE 0601102F	Defense Research Sciences	Air Force	13.8	10.6	13.8
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	0.0	0.0	0.0
PE 0601103D	University Research Initiative	OSD	10.3	8.6	8.9
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Total			50.4	45.9	51.9

Table III–17. Service-Specific Interests and Commonality in Atmospheric and Space Sciences

Subarea	Army	Navy	Air Force
Meteorology	Continental boundary layer Small-scale meteorology Transport, diffusion, obscuration Chemical/biological defense	Marine boundary layer Maritime and coastal meteorology Heterogeneous flows Major storms, worldwide Synoptic to mesoscale modeling Aerosol models	None
	Areas of Common Interest: aerosol effects (A, N); coherent structures (A, N); subgrid scale parameterization (A, N); large eddy simulation (A, N); atmospheric transmission (A, N); radiative energy transfer (A, N); nested models of all scales (A, N); surface energy balance (A, N); cloud formation and processes (N); contrast transmission (A, N); 4D data assimilation (A, N)		

Table III–17. Service-Specific Interests and Commonality in Atmospheric and Space Sciences (continued)

Subarea	Army	Navy	Air Force
Remote Sensing	Fine resolution of wind, temperature, and humidity fields within boundary layer Chemical/biological detection	Marine refractivity profiles	
	Areas of Common Interest: atmospheric profiles of temperature, humidity, winds, aerosol concentration (A, N, AF)		
Space Science	None	Precision time Space-based solar observation Wave–particle interactions Astrometry	Ground-based solar observations Energetic solar events Ionospheric structure and transport Optical characterization
		Areas of Common Interest: neutral density (N, AF); ionospheric C^3I impacts (N, AF); celestial background (N, AF); geomagnetic activity (N, AF)	

I. BIOLOGICAL SCIENCES

Research in Biological Sciences provides the fundamental understanding required to use 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; to inhibit or prevent the deleterious effects of chemical, biological, and physical agents from interfering with military warfighting and peacekeeping operations; and to ensure that force health protection and safety standards are based on solid scientific evidence. With the exception of biomedical programs, which are closely coordinated through the ASBREM Committee, a single service now conducts the basic research for all three services in areas where it is the technology leader for related 6.2 or 6.3 programs, or where that service has the largest investment and program expertise. The Army is the DoD executing agency for chemical and biological defense technology, and ONR and AFOSR rely on the results of Army-executed research in this area in meeting their own specific needs. The Air Force was designated through Reliance agreements to host the Tri-Service Toxicology Center at Armstrong Laboratory at Wright-Patterson AFB, as well as co-located S&T programs in nonionizing radiation and laser radiation bioeffects at Brooks AFB. The Navy is the only service that supports work in the marine environment.

DoD basic research in Biological Sciences comprises three major subareas:

Molecular/Cellular: Basic research on antibodies, characterization of surface biomolecular interactions, receptors, and cell-based sensing has enabled the development of biochemical detector technology that has, in turn, provided the U.S. military with its first automated capability for detecting biological agents. Meanwhile, ongoing research promises to improve greatly on the selectivity component of future detectors, enhancing their capability to warn of threats from biological agents present in battlefield, counterterrorism, or counterproliferation scenarios. Likewise, research on olfactory sensing offers novel biologically inspired approaches for the design and eventual production of engineered systems capable of detecting trace amounts of explosives and toxic chemicals. In addition, this research will provide the military with unique advanced capabilities for sensing contamination of food, clothing, material, the individual warfighter, and the environment.

Systems/Organisms: Exposure of the warfighter to hazardous military chemicals (e.g., fuels and propellants) and to novel forms of electromagnetic radiation (e.g., laser pulses and high-power microwaves) can negatively impact military missions and result in serious long-term costs for DoD. The capability to develop and use nontoxic military agents will promote health and enhance the performance of the warfighter. Studies are ongoing to understand mechanisms by which these novel military agents may produce deleterious biological effects and to explore safe exposure levels. Research in this area will enable the development of scientifically derived safety standards, the design of protective equipment, and the improvement of experimental and computational approaches for rapidly assessing toxic properties of future agents. Recently, studies exploring the interaction of single ultrashort laser pulses with the eye have been completed and used to establish new national ocular safety standards for laser exposure. The new standards will not only safeguard the warfighter's vision but also help to establish baseline specifications for developing advanced laser-protective eyewear.

Biomedical: The fundamental knowledge provided by research in this area will dramatically improve DoD's capabilities to prevent injury and disease, to sustain the health of the force, and to provide efficient and effective combat casualty care when necessary. Advances in immunology, toxicology, physiology, neuroscience, biochemistry, psychology, and molecular biology– all of which are directed toward the understanding of disease and injury processes– will provide the warfighter with new options for increasing survivability and mission effectiveness on modern battlefields. The knowledge will be used to enable applied research for the development of novel drugs, vaccines, medical devices, health promotion and prevention procedures, medical diagnostics, and treatments for trauma and disease. Today military personnel are protected from epidemic hepatitis as a result of knowledge gained from basic research on the biology and immunology of the hepatitis A virus. In addition, basic research into the physiology of thermoregulation has produced mathematical models that are used in the Army Mercury System deployed at Army Ranger training sites to protect trainees from thermal injury (e.g., hypothermia).

Budget information for Biological Sciences research is provided in Table III–18. Table III–19 identifies service-specific interests and commonality for this area.

Table III–18. Basic Research Funding for Biological Sciences ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
PE 0601101A	In-House Lab Independent Research	Army	3.9	2.0	2.0
PE 0601102A	Defense Research Sciences	Army	22.6	31.4	27.7
PE 0601104A	University and Industry Research Centers	Army	0.0	0.0	0.0
PE 0601152N	In-House Lab Independent Research	Navy	1.4	1.4	1.5
PE 0601153N	Defense Research Sciences	Navy	25.5	24.1	23.3
PE 0601102F	Defense Research Sciences	Air Force	10.1	13.9	14.6
PE 0601101D	In-House Lab Independent Research	OSD	3.1	1.5	2.2
PE 0601101E	Defense Research Sciences	DARPA	5.6	5.2	5.0
PE 0601103D	University Research Initiative	OSD	11.2	20.0	12.7
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	23.7
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	29.3	25.3	29.5
Total			112.7	124.9	142.2

Table III–19. Service-Specific Interests and Commonality in Biological Sciences

Subarea	Army	Navy	Air Force
Molecular/Cellular Processes and materials Sensors Biodegradation Chemical and biological defense	Macromolecular structure, function, and assembly Nanoscale biomechanics Olfactory and integrated multifunctional sensing Sensing and respond processes Microbial degradation of aromatic compounds	Marine molecular biology Bioadhesion Bioluminescence Fast biosensor arrays Cell-based sensing Computational biology Enzymatic synthesis of energetic materials	Molecular mechanisms of infrared biosensing Novel molecular and computational tools for toxicity prediction
	Areas of Common Interest: biomimetics (A, N, AF); biocatalysis (A, N, AF); chemical and biological defense (A, N)		

Table III–19. Service-Specific Interests and Commonality in Biological Sciences (continued)

Subarea	Army	Navy	Air Force
Systems/ Organisms Physiology Toxicology	Adaptation and survivability Sustaining and enhancing soldier performance Noncircadian processes and genetics of sleep Hibernation	Marine mammal physiology Biomimetic sonar Environmental impacts of loud sound Marine environmental micro-biology	Toxic mechanisms of military chemicals Bioeffects of non-ionizing radiation
	Areas of Common Interest: none		
Biomedical Infectious dis-eases Combat casualty care Military opera-tional medicine Medical chemi-cal-biological defense	Pathobiology of CBW agents Nutrition and thermo-regulation	Immunophysiology Diving physiology	None
	Areas of Common Interest: molecular biology of animals and infectious agents; immunobiology for clinical management; vaccine and drug design; medical physiology, biochemistry, and toxicology; and psychobiology of human health effects (A, N)		

J. COGNITIVE AND NEURAL SCIENCE

The DoD-wide program of research in Cognitive and Neural Science 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. Joint agreements in 6.2 and 6.3 programs apply to manpower, personnel, and training issues. The defense-wide SPG in Cognitive and Neural Science has been responsive in aligning 6.1 programs in those areas.

DoD basic research activities in Cognitive and Neural Science involve two subareas:

Human Performance: Research in human performance 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 research on teams and organizations, the Army concentrates on group-leader processes, the Navy on coordination in distributed groups and models for evaluating organizational design, and the Air Force on communication strategies and interfaces important to maintaining situational awareness. In the areas of cognition, learning, and memory, the Army concentrates on training principles that underlie acquisition, retention, and transfer of soldier skills. The Navy emphasis is on artificial intelligence and AI-based models of cognitive architecture. The Air Force focus is on intelligent tutoring systems and identifying individual differences in cognitive and psychomotor abilities.

In stress and performance research, the Army focuses on performance issues, while the Air Force focuses on the circadian timing system underlying fatigue, performance, and the change from sleep to arousal. 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 image communication and sound localization 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: vision, touch/manipulation, locomotion, acoustics/biosonar, and learning. The Air Force examines biological sensor system specificity and sensitivity to provide, for example, new technologies for ambient-temperature, lightweight, low-cost infrared sensors by examining the mechanisms used by animals to detect IR signals.

Budget figures for basic research work in Cognitive and Neural Science are given in Table III–20. Table III–21 provides an outline of service-specific interests and commonality in this area.

Table III–20. Basic Research Funding for Cognitive and Neural Science ($ millions)

Program Element	Title	Agency	FY97	FY98	FY99
PE 0601101A	In-House Lab Independent Research	Army	0.1	0.0	0.0
PE 0601102A	Defense Research Sciences	Army	4.4	6.5	7.2
PE 0601104A	University and Industry Research Centers	Army	0.0	0.0	0.0
PE 0601152N	In-House Lab Independent Research	Navy	0.5	0.4	0.4
PE 0601153N	Defense Research Sciences	Navy	13.4	15.7	15.7
PE 0601102F	Defense Research Sciences	Air Force	10.9	7.9	14.0
PE 0601101D	In-House Lab Independent Research	OSD	0.0	0.0	0.0
PE 0601101E	Defense Research Sciences	DARPA	3.0	2.8	2.7
PE 0601103D	University Research Initiative	OSD	18.0	18.5	27.4
PE 0601110D	Gulf War Illness	OSD	0.0	0.0	0.0
PE 0601111D	Government-Industry Cooperative Research	OSD	0.0	0.0	0.0
PE 0601384BP	Chemical and Biological Defense	Biomed	0.0	0.0	0.0
Total			50.4	51.8	67.4

Table III–21. Service-Specific Interests and Commonality in Cognitive and Neural Science

Subarea	Army	Navy	Air Force
Human Performance Personnel selection Training Human–system integration Teams and organizations	Leadership Societal linkages	Tactile information processing Sensory-guided motor control	Chronobiology Neuropharmacology
	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 Machine vision Autonomous vehicles Automatic target recognition Telerobotics	None	Autonomous undersea vehicle/manipulators Neural computation plasticity Automatic sonar classification	3D audio displays Infrared biosensors
		Areas of Common Interest: machine vision (N, AF)	

IV. BASIC RESEARCH INVESTMENT– THE PAYOFF

Basic research is an investment in the future– a future that we cannot predict. The dividends of our investments will accrue to the next generation. Thus it is difficult to justify these investments by anticipating payoffs and planning for breakthroughs. The best that one can do is to provide the flexibility to take advantage of breakthroughs and to harvest serendipity. However, we *can* look back in time to determine the impact of discovery and development and the rate of return. These frames of reference provide a good indication of what we can expect in the future.

The recent *Defense Science Board Task Force Report on the Defense Science and Technology Base for the 21st Century* (Reference 9) examined the problem of investing for the future. The report included a table that presents a history of militarily critical technology developments over the past 90 years. This table shows the approximate date of the first demonstration of a technology as well as the first significant military application of the technology. There is an average of 9 years from first demonstration to application.

Table IV–1 is a modified version of the DSB table that includes a column for the early basic research foundations of the technology. This adds from 15 to 40 years to the development cycle. As many have noted before, the precision weapons used in the Gulf War had their genesis in research conducted in the 1960s.

Table IV–1. History of Militarily Critical Technology Developments of the Past 90 Years

Technology	Basic Research	First Demonstration	First Significant Military Application
Radio		1901	1914
Airplane	1846/1853	1903	1916
Vacuum Tube	1859	1906	1915
Radar	1903	1925	1939
Digital Computer	1832/1937	1943	1945
Nuclear Weapons	1896	1945	1945
Transistor	1926	1948	1957
Inertial Navigation	1940	1950	1955
Nuclear Propulsion	1896	1950	1960
Integrated Circuit	1926/1954	1960	1970
Laser	1953	1961	1967
Stealth	1903	1970	1990
Modern Unmanned Air Vehicles	1940s	1980	1990

Source: Reference 9.

The added column in Table IV–1 is open to interpretation since all these technologies really have multiple foundations in basic research. For example, does basic research on the airplane begin with airframes or aerodynamics or power plants? All were necessary, all had separate roots, and all led to other products associated with their development.

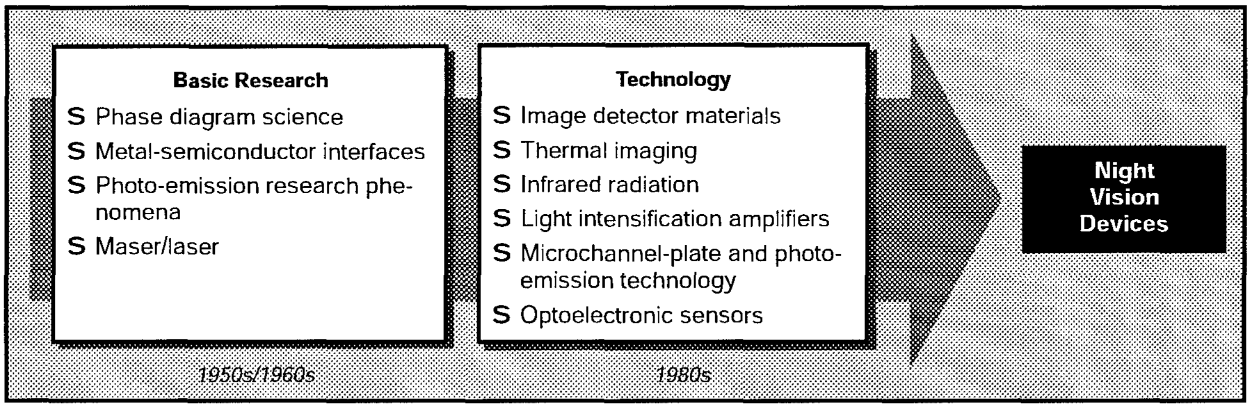
The Basic Research Panel has prepared a set of what we have termed *inverse road-maps*– charts that enable us to look back from a current capability or system to the technologies and basic research that enabled their creation. These inverse roadmaps simplify many relationships, since much basic research has applications in a myriad of systems. Conversely, a single technology so developed may also have numerous system applications. For example, the proliferation of the Global Positioning System has enabled the development of affordable navigation systems for automobiles and boats, instrumented landing approach systems for aircraft, and guidance systems for precision munitions.

The innate value of the basic research investment shines through clearly. The course of the investments spans 20 to 30 years. The results in terms of military capabilities are not readily apparent in the research topics that enabled them.

All of this serves to remind us that predictions are very difficult to make– especially about the future.

Owning the Night

The Army is widely regarded as the "father" of night vision devices. The first generation of night devices in the 1950s and 1960s used light intensification amplifiers. Light intensifiers have since moved from Army application to the civilian markets. Today, everyone from law enforcement officials to recreational boaters have found a use for these devices. A more sophisticated night vision technology is based on thermal imaging.



Thermal imagers function independently of light and detect heat in the form of infrared. The development of thermal imaging systems benefited from general advances in microelectronics and signal processing, but the major breakthrough that enabled the Army to "own the night" came from advanced materials technology. In the late 1960s, Dr. Ryoichi Kikuchi, a Hughes Research Laboratories physicist sponsored by the Army Research Office, was among several major contributors who discovered that the bandgap of mercury cadmium telluride (MCT) could be engineered with sufficient sensitivity to detect the natural thermal emission of targets that have substantial contrast to the background. Dr. Kikuchi described the equilibrium relationships of mixtures of elements, known as *phase diagrams*, which are fundamental to the fabrication of the alloys.

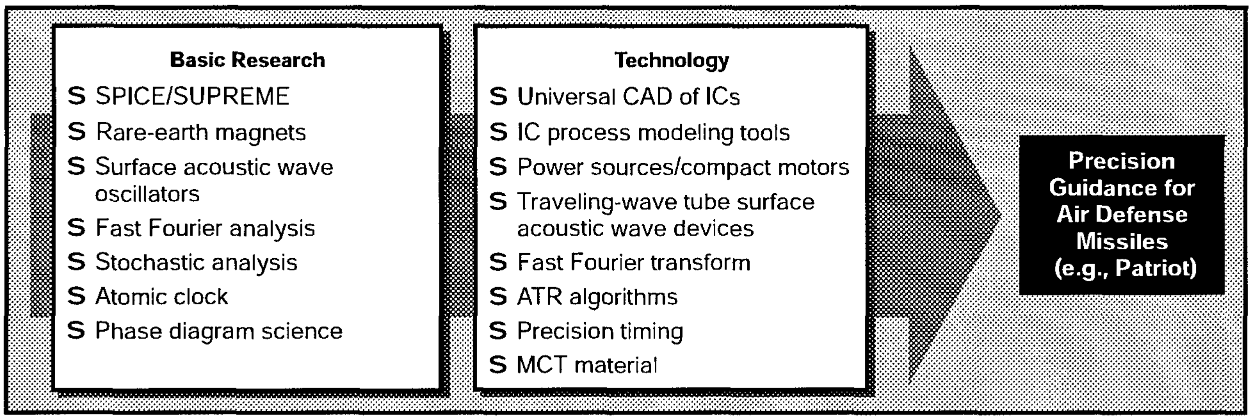
Although Dr. Kikuchi first proposed the theoretical techniques to develop infrared materials technology in 1951, it was not until the 1970s that a close working relationship between Dr. John Pollard and Mr. Charles Freeman at the Army's Night Vision Laboratory catalyzed the research effort of Dr. Kikuchi. Dr. Pollard's research involved materials to support the Common Module Program, which was based on photoconductive mode detectors. Dr. Pollard stimulated contractors to apply the liquid phase epitaxy (LPE) process as a way of filling the needs for the second-generation forward-looking infrared (FLIR) systems, which would operate in a photovoltaic mode. LPE from mercury-rich solution became the choice for volume production of night vision systems.

Night vision systems depend on modern image intensification. With support from ARO, Professor William Spicer of Stanford University conducted research leading to an understanding of the electronic properties of metal-semiconductor interfaces and semiconductor surfaces. High-efficiency image intensification devices used by the Army are based on the principles discovered by Professor Spicer.

Coupled with night vision sensors, lasers evolving from the ARO-supported research of Dr. Charles Townes, Dr. Arthur Schawlow, Dr. Peter Sorokin, and others provide capabilities of rangefinding and target designation. In the early 1990s, the understanding of MCT-phase diagrams enabled companies to produce detectors in economic quantities, thus enabling the production of an advanced generation of focal plane arrays. The Hughes Santa Barbara Research Center is one of the few remaining companies with the materials fabrication process to produce the second-generation FLIR in large scale. Approximately 550 patents have been awarded concerning the MCT alloy and infrared detection. An unanticipated outcome of this research was the development of the cluster variation method, which is a basic tool in first-principles design of a wide variety of materials used in applications ranging from electronics to armor. Several scientists have expressed the opinion that the value of this research has yet to be fully realized and will ultimately extend far beyond the development of infrared detectors. Recent thermal imaging research has increased performance, foiled countermeasures, and incorporated target tracking capabilities. Thermal imaging units have also been used to detect breast cancer and to record residential heat loss. Continued discoveries point to decreased size, weight, and cost of the next generation of devices.

Precision Guidance for Air Defense Missiles

Army air defense systems such as Patriot II utilize a phased-array radar to locate enemy targets and to control a missile launched to intercept the target. During the midcourse phase of flight, the missile is guided by commands from the ground radar. During the terminal phase, semiactive, proportional navigation is used. Target-angle tracking information obtained by the missile is transmitted to the ground, where guidance information is generated and transmitted back to the missile.



The missile's radar is based on traveling-wave tube technology developed at Stanford University's Ginzten Laboratory in the 1950s with support from the Army, Navy, and Air Force under the Joint Services Electronics Program. The services funded the pioneering research on magnetic materials at Carnegie–Mellon University by Professor H. E. Wallace, which led to the rare-earth permanent magnets that are so critical to reducing the weight of the microwave tubes so that they could be placed on the missiles. Professor Wallace's work was extended and coordinated with the in-house R&D at Ft. Monmouth, resulting in the rare-earth-based permanent magnets that are now fielded in many Army missile systems.

The rapid processing of the radar information at the radar site would not be possible without the fast computer algorithms based on the fast Fourier transform developed by Professor John Tukey at Princeton University with support from the Army in the 1960s. Once the missile reaches its target, it uses a conformal antenna based on technology developed, in part, through several Army research and developmental programs. The missile also includes vibration-immune timing circuits developed through research conducted by Professor Harry Tiersten at Rensselaer Polytechnic Institute under Army sponsorship during the 1970s and through Army scientists led by Dr. Arthur Ballato at the former Electronic Devices and Technology Laboratory.

The importance of the vibration-insensitive surface acoustic wave (SAW) resonator technology became critical for the radar tracking of high-velocity targets and was picked up by Raytheon, the prime developer for the Patriot missile system. The innovation of the all-quartz SAW package by Raytheon demonstrated the necessity for research leading to devices that could be fabricated and operate reliably over long periods of time.

As important as this advance was to the development of air defense missiles, it is only one of many other components of the missile system. Another central element is the technology for processing the massive array of radar data. Various tradeoffs that are invoked govern the computational limits under the press of time. Improvements to missile defense systems are heavily influenced by advances in computational processing power, which in turn are driven by electronic and electro-optical components that offer higher performance with less weight and volume.

The control of air defense missiles such as Patriot II depends on a tiny acoustic resonator or clock that must be able to perform under extremes of acceleration. Missile control also depends on advanced computational techniques.

The Airborne Laser

The Airborne Laser (ABL) is a cost-effective, high-energy airborne laser system designed to provide a credible deterrent and lethal defensive capability against boosting theater ballistic missiles. The ABL uses an active tracking system that relies on the reflection of an illuminator laser from the target to provide a signal from which the target position is precisely determined.

Basic Research

- Chemical reaction dynamics (1964)
- Molecular energy transfer (1970)
- Chemical kinetics (1975–85)
- Molecular spectroscopy (1985–90)
- Molecular energy transfer (1990–95)
- Laser engineering
- Adaptive optics increased laser intensity on target
- Atmospheric compensation and correction (1985)
- Vibration elimination (1988)

Technology

- Infrared chemical lasers (1964)
- First COIL demonstration (1977) and improvements: mechanisms, modeling, sensors
- Laser disabled five AIM–9B Sidewinder missiles over China Lake (1983)
- Order-of-magnitude increase in laser intensity on target enabled ABL missions
- Great improvements in pointing and stability verified in KC–135 flight test

Airborne Laser

Several technologies have enabled the ABL system. One key technology of the ABL is the chemical oxygen iodine laser (COIL). The COIL device converts the energy of chemical reactions into a powerful, infrared laser beam that can travel through the atmosphere and destroy targets at very long distances. An extensive legacy of AFOSR-sponsored basic research to understand, control, and optimize the kinetics of molecular interactions led to the invention and development of the COIL. Professors George Pimentel and J. V. Kasper at the University of California, Berkeley, demonstrated the first iodine laser in 1964 under AFOSR support. The first COIL device was demonstrated in 1977 at the Air Force Weapons Laboratory by McDermott, Pchelkin, Benard, and Bousek.

Continuing AFOSR-supported efforts to understand the laser mechanism and advances in laser engineering over the last two decades have enabled COIL technology to mature to the point where high-power output with excellent beam quality and long duration run times will meet ABL requirements. The performance requirements of the ABL are established by operational scenarios and support requirements defined by the user, Air Combat Command, and measured target vulnerability characteristics provided by the Air Force lethality and vulnerability community.

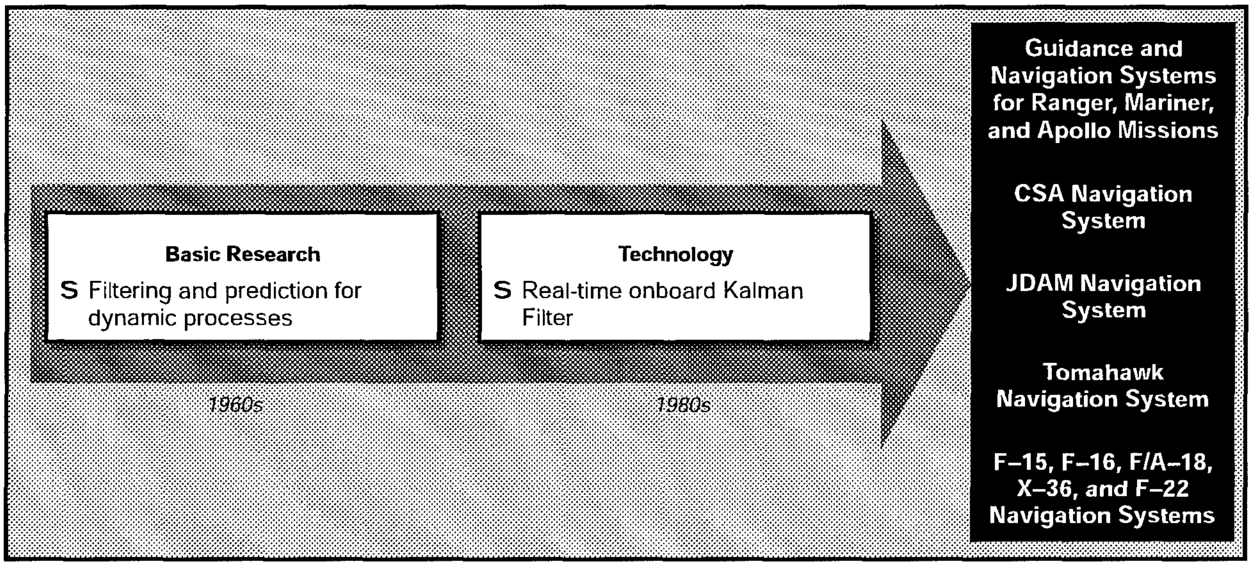
Another key technology critical to the ABL is adaptive optics, a control strategy that compensates for atmospheric turbulence effects on the laser beam. Advanced compensation techniques extend the lethal range of the ABL by 50 percent. This technology has been under development at the Air Force Research Laboratory (AFRL) Directed Energy Directorate for approximately 20 years.

Currently, AFOSR-funded research is being conducted within the AFRL in the area of atmospheric characterization. Understanding of the atmosphere—including high-altitude cloud ice crystal formation, moisture content, winds, and other factors—will be used to optimize ABL performance.

The ABL program successfully completed the OSD authority to proceed (ATP 1) milestone in June 1998, in which four specific technical accomplishments had to be completed. One major accomplishment was the successful and accurate characterization of atmospheric turbulence conditions using innovative scintillometer measurements sponsored by AFOSR. As a result of passing this milestone, the ABL program will continue the acquisition process, anticipating that an ABL engineering, manufacturing, and development program could begin as early as 2003.

The Kalman Filter

AFOSR sponsored an extensive effort in control theory research during the 1950s and 1960s to help obtain solutions to a range of difficult and important problems in the guidance, navigation, and control of advanced aerospace vehicles. The AFOSR-sponsored research of R. Kalman in the early 1960s produced a revolutionary new recursive filtering capability for dynamical systems, which quickly swept across the aerospace industry so that today Kalman filtering technology can be found on virtually all current Air Force weapon systems and space assets.



Some typical uses include the navigation and guidance systems of aircraft and missiles, radar tracking, and satellite orbit determination. H. W. Sorenson, former chief scientist for the United States Air Force, has said "The Gaussian concept of estimation by least squares, originally stimulated by astronomical studies, has provided the basis for a number of estimation theories and techniques ... probably none as useful in terms of today's requirements as the Kalman Filter."

Kalman filtering deals with an age-old question of how to get accurate information out of inaccurate data. More precisely, the filter solves the problem of how to update a "best estimate" for the state of a system as new, but still inaccurate, information pours in.

The Kalman filter is designed to strip unwanted noise out of a stream of data. The critical insight that led to this discovery was that the best estimate for the state of a system, together with the covariance matrix for the error in the state estimate, could be obtained recursively from the previous best estimate and its covariance estimate. The significance of this is that the filter does no more work on the millionth estimate than it does on the first. Moreover the covariances do not depend on the values of the incoming observed states, but involve only the covariance matrices of the noise, and are often computed offline for real-time, onboard applications. Newly developing computing capabilities and this new filtering technology were ideally suited to the dynamic-state estimation problems of the dawning space age.

The use of Kalman filtering is now pervasive in the aerospace industry. Indeed, William Lehmann, a former AFOSR director, attributed a role in the Desert Storm victory to the Kalman filter when he noted that the "guidance systems [in Coalition Forces aircraft] used the data smoothing that comes from Kalman filtering." The diagram above cites but a relative few of its many applications in DoD.

The Global Positioning System

Through a combination of atomic clock technology and advancements in satellite tracking methods, the Global Positioning System (GPS) emerged. Specifically designed for military use, GPS is now an almost essential navigational tool, allowing civilians—including boaters, pilots, hikers, and trucking and shipping companies—to locate their precise positions with the use of a small GPS receiver.

Basic Research

- Idea of using atoms to create a more accurate clock (1945)
- Norman Ramsey develops the separated oscillatory field method (late 1940s)
- NBS uses the ammonia molecule to build the first atomic clock (1949)
- NBS builds atomic clock with cesium atoms (1952)
- Minitrack system to detect satellites and plot their paths (mid 1950s)
- Maser, a keystone for the creation of GPS (late 1950s/early 1960s)
- Hydrogen maser clock (1960)

Technology

- America launches its first satellite, Vanguard I (1958)
- Transit Program (1963)
- First Timation satellite (1967)
- Navigation Technology Satellite One; first space-based atomic clock is tested (1974)
- First operational NAVSTAR GPS satellite (1978)

GPS

First GPS satellite launched (1989)

Last (24th) GPS satellite launched (1993)

More accurate GPS guidance made available to civilians (1996)

The creation of GPS began in the mid 1940s with a Columbia University physicist's idea that a more accurate clock could be created using atomic-beam magnetic resonance. In the late 1940s, ONR-supported research in atomic spectroscopy led to advancements in the development of atomic clocks and resulted in Harvard University researcher Norman Ramsey's discovery of the separated oscillatory field method, creating greater accuracy with available magnets.

In the late 1950s and early 1960s, ONR-supported researcher Charles Townes created the maser (microwave amplification by the stimulated emission of radiation), which amplifies electromagnetic waves and became a keystone for the creation of GPS.

In 1960, Ramsey and students developed technology for a hydrogen maser clock. This technology was improved in 1985, resulting in smaller and more efficient clocks for use in GPS satellites.

The satellite technology for GPS began in the 1950s. After the launch of the Russian satellite Sputnik in 1957, MIT researchers discovered they could locate the satellite's orbit by tracking its signal and noting the change in frequency as it passed overhead.

In the mid 1950s, Naval Research Laboratory (NRL) scientist Roger Easton and colleagues developed the Minitrack System to detect satellites and plot their paths. The satellites sent out timed signals to be received at ground stations. The differences between the time the ground stations received the signal and the time it was sent were calculated to determine the position, altitude, and velocity of the satellite.

The Transit Program, or Navy Navigation Satellite System, developed at the John Hopkins University Applied Physics Laboratory, allowed surfaced submarines to find their position by receiving timed transmissions from a passing satellite. By 1963, submarines using Transit technology could locate their position in a mere 20 minutes compared to the hours that previous methods required.

In the next few years, NRL scientists began working on the Timation Program, theorizing that satellites equipped with ultraprecise clocks would improve navigation calculations. Clocks in ground receivers were matched with satellite clocks, and the signals received from multiple satellites could be coordinated to find the receiver's location. Beginning in 1967, three Timation satellites were launched.

The Navy leveraged work done by the Air Force in 1964, when the Air Force initiated a program to develop and test a coded transmission technique that would provide precise ranging and timing data using a signal modulated with a pseudo-random noise code. This feature, which became known as *code division multiple access*, allowed all satellites in the constellation to broadcast on the same frequency without interfering with each other.

In 1973, the idea for GPS, a network of navigational satellites, originated during a DoD conference in the Pentagon. Twenty-four satellites, each broadcasting a continuous radio signal relaying its position and the exact time synchronized with internal atomic clocks, would be launched. On the ground, a specialized GPS receiver would take the information broadcast from any four of the satellites within range to approximate the receiver's location. During 1967–69, studies by the Air Force for a DoD tri-service navigation system resulted in the launch of the Navy Timation 1 and 2 timing/navigation system satellites. In 1973, the Air Force and Navy programs were combined into the Navigation Technology Program, which later evolved into the NAVSTAR GPS program.

The first of 10 prototype GPS satellites, built by Rockwell International, was launched in 1978, and GPS technology became available to civilians in 1983 under orders from President Reagan.

In the years between 1989 and 1993, the current GPS network, consisting of 24 satellites, was launched. Until recently, DoD followed a selective availability policy for protection against GPS use by forces opposing the military and the government. Two signals were broadcast from GPS satellites, allowing civilian use of one signal and military use of another, more precise signal. In 1996, the White House announced an end to this policy, and a more accurate level of GPS was made available to everyone.

Mine Countermeasures

Advancements in mine countermeasures (MCM) warfare made possible the creation of unmanned underwater vehicles equipped with sensors and navigation systems to locate mines, sparing the lives of divers and marine mammals historically used for such work. Developments in acoustic and optical sciences provide the foundations for MCM technology.

Basic Research

- S Navy introduced an underwater "telephone" (early 1950s)
- S ONR-sponsored Columbia researcher Charles Townes develops the maser, a microwave molecular amplifier (1951)
- S Under ONR sponsorship, Townes and his students achieve continuous maser oscillation (1954)
- S The first ruby laser is used at the Hughes Research Laboratory, and underwater "telephones" are improved. ONR-sponsored scientists conduct acoustic telemetry experiments using simple code modulation techniques (1960)
- S Practical, digital IC technology is developed following the increased availability of inexpensive, commercial transistors (early 1970s)
- S The Navy uses industry-developed "acoustic releases" in experimental digital acoustic communication (1971–73)

Technology

- S Development of advanced, application-specific, digital signal processing ICs made possible the invention of acoustic telemetry systems incorporating FDMA designs using low-cost FFT signal processors (1981–83)
- S ONR-sponsored MIT researchers developed relatively high-data-rate (1.2 kilobits per second) digital acoustic telemetry system called DATS (1984–86)
- S First successful laboratory test of an LLS underwater imaging system completed (1989)
- S Underwater acoustic telemetry with the invention of a high-data-rate (10–20 kilobits per second), phase-coherent modulation scheme employing joint, adaptive equalization and synchronization

Advanced, noncoherent, acoustic telemetry technology

High-frequency/ low-frequency aperture sonar

Laser visual identification sensor

SSI and laser identification and ranging

Underwater imaging approaches for identification of partially buried and moored mines in shallow and very shallow water

In the 1950s, the Navy introduced the first underwater "telephone," known to sailors as "Gertrude." Using straight amplitude modulation techniques and a frequency compatible with submarine echo-ranging sonars, sub-to-sub and sub-to-ship voice links were possible.

In the early 1960s, improvements to the underwater telephone allowed for a greater operating range, production in large quantities, and installation on nearly every naval platform. About the same time, ONR-sponsored scientists conducted acoustic telemetry experiments using simple code modulation techniques.

In the 1970s, the commercial availability of inexpensive transistor chips led to the development of practical digital integrated circuitry (IC) technology. More sophisticated underwater acoustic modulation schemes using frequency-shift-keying and error correction coding appeared. Industry used this technology to develop underwater "acoustic releases," which allowed for the release and recovery of moored buoys by sending acoustic signals. The Navy used these in experimental digital acoustic communication initiatives.

In the 1980s, the development of advanced, application-specific digital signal-processing ICs made possible acoustic telemetry systems incorporating the frequency-division multiple-access (FDMA) designs. Low-cost fast Fourier transform (FFT) signal processors were used. Commercial companies, such as Sonatech, used FDMA/FFT technology to design deep-water acoustic transponders, which the Navy used on 3D underwater tracking ranges and naval gun accuracy scoring systems.

Also in the 1980s, ONR-sponsored Massachusetts Institute of Technology (MIT) researchers, led by Prof. A. Baggeroer, developed a digital acoustic telemetry system (DATS) capable of a relatively high data rate. The DATS acoustic modems were designed to overcome the interference caused by underwater acoustic multipath and reverberation that severely limited previous data rates and reliability.

Sponsored by ONR, the Defense Advanced Research Projects Agency (DARPA), and the National Science Foundation (NSF), signal processor and ocean engineering researchers from MIT, Northeastern University, and Woods Hole Oceanographic Institution invented a high-data-rate, phase-coherent modulation scheme using joint, adaptive equalization and synchronization in the 1990s.

Recently, ONR researchers at the Naval Ocean Systems Center, now known as SPAWAR San Diego Center, developed advanced, noncoherent, acoustic telemetry technology. Though the technology is still being tested by the Navy's Distributed Autonomous Deployable Surveillance System, it was designed to operate at lower signal-to-bit ratios than the adaptive equalizers and is suited for multiuser applications.

Today, ONR is testing the high-frequency/low-frequency synthetic aperture sonar (HF/LF SAS), designed for shallow and very shallow water and developed with ONR funding at the Coastal Systems Station and Northrop Grumman.

Development of the optical technology that led to MCM began in the 1950s with research on lasers—devices that generate light with a purity of color, a degree of directionality, and a concentration of radiant energy many times greater than any other source.

With ONR funding, Columbia researcher Charles Townes invented the maser, a microwave molecular amplifier, in 1951. In 1954, Townes and his students, again under ONR-sponsorship, achieved continuous maser oscillation in ammonia at 24 GHz.

In 1958, Townes and Arthur L. Schawlow analyzed the conditions necessary for gaining oscillation in the optical region, and 2 years later, T. H. Maiman reported the first ruby laser at the Hughes Research Laboratory.

The Navy began using laser line scanning for MCM in 1989 with the first successful tests of the laser line scan (LLS) underwater imaging system. ONR funded laboratory tests in 1993 to compare synchronized scan imaging (SSI) and laser identification and ranging underwater imaging approaches. SSI proved superior.

ONR's Environmental Optics Program is furthering the understanding of how light interacts with the ocean, including the ocean boundaries and the atmosphere within tens of meters of the ocean surface. This research falls into one or more of the following categories:

- *Radiative transfer modeling*—developing and testing state-of-the-art numerical models of radiance propagation within the ocean.
- *Instrument development*—developing the devices and techniques required to measure the inherent optical properties of ocean water and the ocean floor.
- *Optical process studies*—quantifying the interactions of light in the ocean with physical, biological, and chemical ocean processes.
- *Coastal remote sensing*—quantitatively assessing in-water inherent optical properties, bathymetry or bottom type, from high spectral- and spatial-resolution aircraft or satellite data.

The products of these basic research thrusts support the development of ocean prediction models, new ocean remote sensing systems, and associated image analysis algorithms. Applied research is funded in areas of underwater imaging and hyperspectral remote sensing in support of mine warfare and special operations in light detection and ranging (LIDAR) in support of submarine warfare.

ONR's Electro-Optic Identification Sensors project is developing a laser visual identification sensor (LVIS) to identify partially buried and moored mines in shallow and very shallow waters. LVIS will be used in small-diameter underwater vehicles, including unmanned underwater vehicles. Since the mission is mine identification, LVIS must be able to deliver high-quality images in turbid coastal waters, while being compatible with the size and power constraints imposed by the intended deployment platforms.

APPENDIX A

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APPENDIX B

GLOSSARY AND REFERENCES

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AAN	Army After Next
AASERT	Augmentation Awards for Science and Engineering Research Training
ACI	accelerated capability initiatives
AFB	Air Force Base
AFOSR	Air Force Office of Scientific Research
AI	artificial intelligence
AlGaAs	aluminum gallium arsenide
AlGaN	aluminum gallium nitride
ARO	Army Research Office
ASBREM	Armed Services Biomedical Research Evaluation and Management Committee
ASW	antisubmarine warfare
ATM	asynchronous transmission mode
ATR	automatic target recognition
BAA	broad agency announcement
BMDO	Ballistic Missile Defense Organization
BOAS	blade-outer-air-sea
BRP	Basic Research Plan
C^3I	communications, command, control, and intelligence
C^4I	communications, command, control, computers, and intelligence
CBD	chemical/biological defense
CAV	composite armored vehicle
CBW	chemical and biological warfare
CMOS	complementary metal oxide semiconductor
CO_2	carbon dioxide
COIL	chemical oxygen iodine laser
CONUS	continental United States
DARPA	Defense Advanced Research Projects Agency
DCOR	Defense Committee on Research
DDDR&E	Deputy Director, Defense Research and Engineering
DDR&E	Director of Defense Research and Engineering
DEMIL	demilitarization
DEPSCoR	DoD Experimental Program to Stimulate Competitive Research
DEW	directed energy weapon
DoD	Department of Defense
DOE	Department of Energy
DRAM	dynamic random access memory
DRB	Defense Resources Board
DRS	Defense Research Sciences
DSTAG	Defense Science and Technology Advisory Group

DTAP	Defense Technology Area Plan
DURIP	Defense University Research Instrumentation Program
DUSD(S&T)	Deputy Under Secretary of Defense for Science and Technology
EEG	electroencephalogram
ELF/VLF	extremely low frequency/very low frequency
EM	electromagnetic
EO	electro-optics
EW	electronic warfare
FED	field emission display
FET	field effect transistor
FFRDC	Federally Funded Research and Development Center
FIFO	first-in, first-out
FRI	Focused Research Initiative
GaAs	gallium arsenide
GaN	gallium nitride
GaSb	gallium antimonide
Ge	germanium
GEO	geosynchronous earth orbit
GHz	gigahertz
GICR	Government/Industry Cooperative Research
GMR	giant magneto-resistance
GPS	Global Positioning System
HBCU/MI	Historically Black College and University/Minority Institution
HFET	heterojunction field effect transistor
HHS	Health and Human Services
HP	heteropolymer
HPM	high-power microwave
HSLA	high-strength low alloy
HTFA	High-Temperature Flowing Afterglow
IFSAR	interferometric synthetic aperture radar
IHPTET	Integrated High Performance Turbine Engine Technology
ILIR	In-house Laboratory Independent Research
InGaN	indium gallium nitride
InP	indium phosphide
IR	infrared
IR&D	Independent Research and Development
IS	intelligent system
ISDN	Integrated Services Digital Network
JCS	Joints Chiefs of Staff
JLOTS	joint logistics-over-the-shore
JSEP	Joint Services Electronics Program
JWSTP	Joint Warfighting Science and Technology Plan

LANL	Los Alamos National Laboratory
LED	light-emitting diode
LIDAR	light detection and ranging
LLS	laser-line-scan
LO	low observable
LOTS	logistics over-the-shore
MCM	mine countermeasures
MEMS	microelectromechanical systems
MeV	million electron volt
MHD	magnetohydrodynamics
MIMIC	microwave/millimeter wave monolithic integrated circuit
MIT	Massachusetts Institute of Technology
MMW	millimeter wave
MOD	metal-organic decomposition
MOS	metal oxide semiconductor
$MoSi_2$	molybdenum disilicide
MURI	Multidisciplinary University Research Initiative
NASA	National Aeronautics and Space Administration
NASA-LeRC	NASA Lewis Research Center
NDE	nondestructive evaluation
NdFeB	neodymium iron boride
NLO	nonlinear optics
NOAA	National Oceanographic and Atmospheric Administration
NRL	Naval Research Laboratory
NSF	National Science Foundation
ODASA(R&T)	Office of the Deputy Assistant Secretary of the Army, Research and Technology
ODDR&E	Office of the Director, Defense Research and Engineering
ONR	Office of Naval Research
ONREUR	Office of Naval Research, Europe
OSD	Office of the Secretary of Defense
PBL	planetary boundary layer
PbTe	lead-telluride
PDE	partial differential equation
PEBB	power-electronic building block
PEM	polymer electrolyte membrane
POM	Program Objective Memorandum
PPS	polyphenylsulfone
PRET	Program for Research Excellence and Transitioning
PRG	Program Review Group
PZT	lead zirconate titanate
RAM	random access memory
RAP	radio access point

RF	radio frequency
RTD	resonant tunneling diode
S&E	science and engineering
S&T	science and technology
SAM	self-assembled molecules
SAR	synthetic aperture radar
SATCOM	satellite communications
SBIRS	Space-Based Infrared System
SCF	supercritical fluids
Si	silicon
Si_3N_4	silicon nitride
SiC	silicon carbide
SNR	signal-to-noise ratio
SPG	Scientific Planning Group
SRO	Strategic Research Objectives
STM	scanning tunneling microscope
STOL	short takeoff and landing
SUNY	State University of New York
TARA	Technology Area Review and Assessment
T_c	critical temperature
TCP/IP	Transmission Control Protocol/Internet Protocol
TSRAM	transistorless static random access memory
UA	University of Arizona
UAV	unmanned aerial vehicle
UCLA	University of California, Los Angeles
UCSB	University of California, Santa Barbara
ULSI	ultra-large-scale integration
URI	University Research Initiative
URISP	University Research Infrastructure Support Program
USC	University of Southern California
UT	University of Tennessee
UUV	unmanned underwater vehicle
UV	ultraviolet
VLSI	very large scale integration
WMD	weapons of mass destruction
YAG	yttrium aluminum garnet
YBCO	yttrium barium copper oxide

REFERENCES

1. *America's Basic Research: Prosperity Through Discovery,* Committee for Economic Development, New York, 1998.
2. "Balancing the Research Portfolio," editorial in *Science*, vol. 281, page 1803, 18 September 1998.
3. *Selected Data on Federal Funds for Research and Development,* National Science Foundation, NSF Report.
4. *National Security Science and Technology Strategy,* National Science and Technology Council, 1995.
5. *Defense Science and Technology Strategy,* Director of Defense Research and Engineering, May 1996.
6. *Joint Vision 2010*, Joint Chiefs of Staff, 1996.
7. *Joint Warfighting Science and Technology Plan (JWSTP)*, Director of Defense Research and Engineering, February 1999.
8. *Defense Technology Area Plan*, Director of Defense Research and Engineering, February 1999.
9. *Defense Science Board Task Force Report on the Defense Science and Technology Base for the 21st Century.*

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16 apr 2001

MEMORANDUM FOR ADMINISTRATOR, DEFENSE TECHNICAL INFORMATION CENTER (DTIC)

SUBJECT: Distribution of Defense Science and Technology Plans

As a result of the concerns raised by the Defense Science and Technology Advisory Group (DSTAG) regarding the unlimited distribution of unclassified, but potentially sensitive, technical information contained in the Defense S&T planning documents, I requested that the Defense Intelligence Agency (DIA) review the documents and provide specific distribution guidance. The DIA responded by stating that the *Basic Research Plan* (BRP) is suitable for unlimited public distribution. The BRP has also been reviewed by the Director for Freedom of Information and Security Review and cleared for open publication.

The DIA advised; however, that the distribution of the *Joint Warfighting Science and Technology Plan* (JWSTP), the *Defense Technology Area Plan* (DTAP), and the *Defense Technology Objectives* (DTOs) must be limited to U.S. Government employees and U.S. contractors on a strict need-to-know basis. A password protected web site will meet protection criteria for access via electronic media. Distribution of these documents to foreign nationals will require a foreign disclosure review conducted by my office on a case-by-case basis.

Please take the necessary precautions to protect distribution of JWSTP, DTAP, and DTO Volume in accordance with the above guidance. All documents and compact disks (CDs) have been marked accordingly. We appreciate the outstanding support DTIC has provided in the past, both in the preparation and distribution of the S&T planning documents. Mr. Bob Baker is the point of contact who will provide additional guidance if any questions arise.

Delores M. Etter

Delores M. Etter
Deputy Under Secretary of Defense
(Science & Technology)