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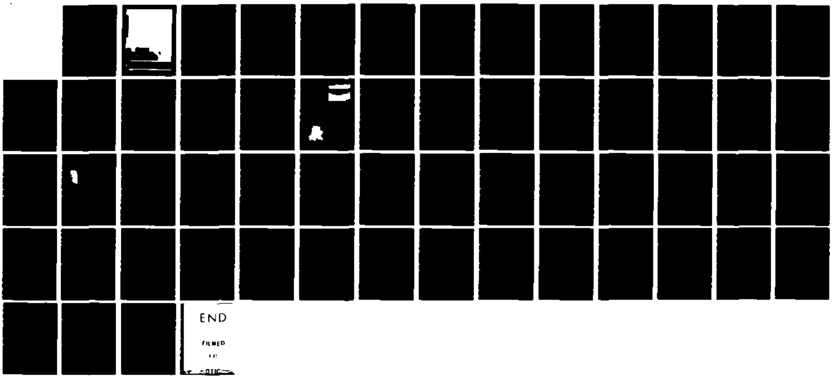

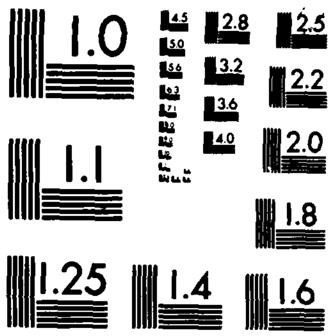
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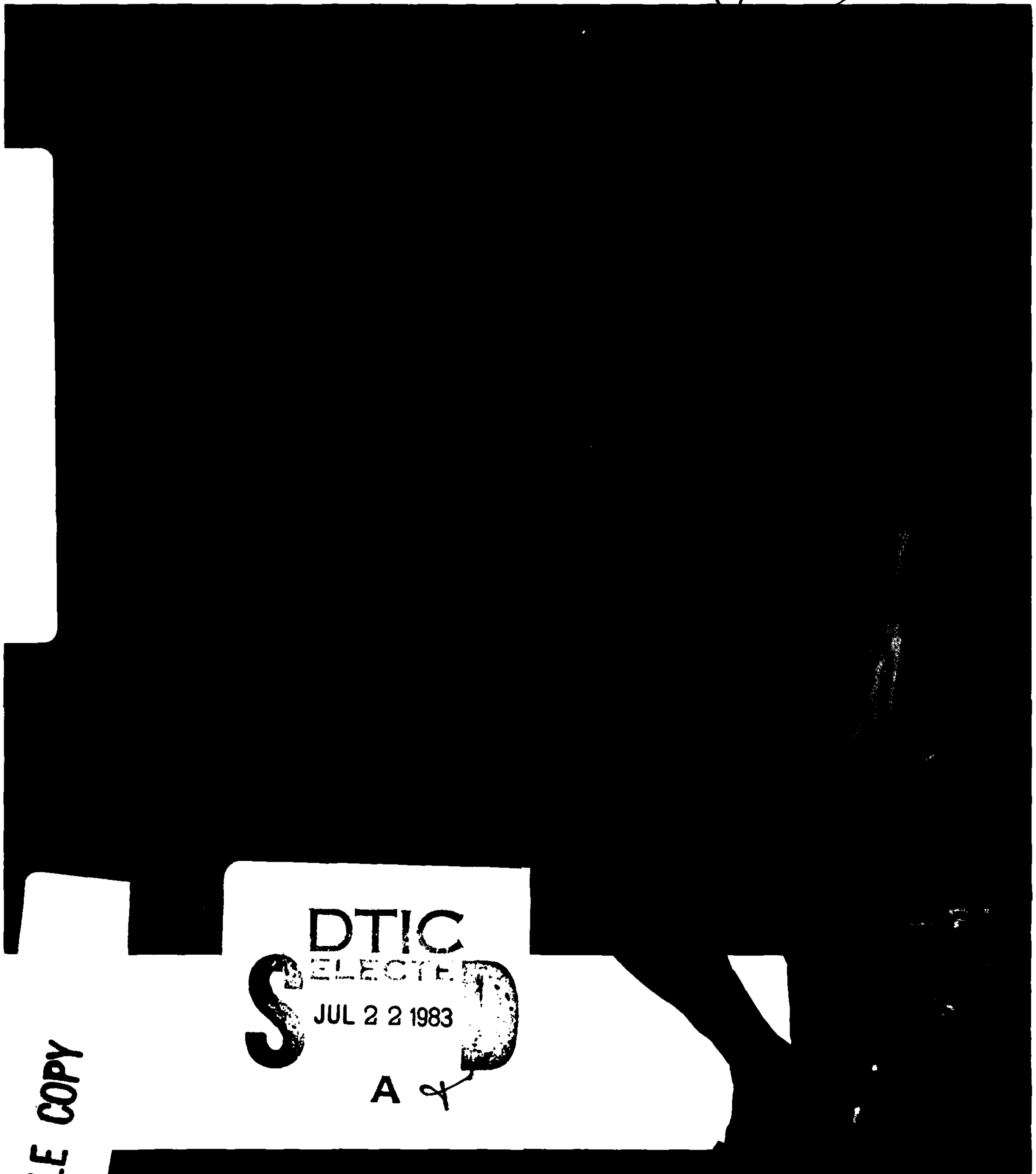

DEPARTMENT OF DEFENSE

UNITED STATES OF AMERICA

Contents

Foreword

This report, prepared in the Office of the Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology/Research and Laboratory Management), is an update of a previous volume written for the express purpose of describing the Department of Defense basic research program. The report is part of a continuing effort to improve communications with the national research community by increasing the visibility of our program and reaffirming the importance of basic research to the Department of Defense.

An effort has been made to present an overview of the DoD basic research program by sampling the entire range of disciplines of interest to DoD. Because space constraints permit citing only a few specific examples, many exciting parts of the program cannot be described in detail, but this should not be taken to indicate lack of interest or lower priority.

The DoD research program under the direction of my office has the overall responsibility for the program described in this book. We would like to acknowledge the assistance generously provided by the Army Research Office, Office of Naval Research and the Air Force Office of Scientific Research. Special thanks are due to Dr. Jimmie Suttle who had overall responsibility for this volume, and to Dr. Michael Stroscio and Mr. James Higgiston who assisted him ably in this task.

Leo Young

Leo Young
Director, Research and
Laboratory Management

Introduction

"Science is important to the preservation of our republican government and it is also essential to its protection against foreign power."

Thomas Jefferson, 1821

The present Administration is committed to advance, apply, and deploy—more successfully than in the past—those areas of science and technology that are essential to the restoration of our national defense capability. The science and technology programs of the Department of Defense (DoD), augmented by the efforts of other federal agencies and the private sector, provide the foundation for highly effective armed forces equipped with technologically superior weapons systems.

This is accomplished through a DoD research program that is, on one hand, responsive to the needs of the Defense establishment while, on the other hand, strongly linked to the traditional strengths of the academic and industrial sectors.

This document is intended to serve several purposes:

- To explain to researchers, both in and out of government, what the DoD research program is;
- To show how the program fits into the national research effort;
- To describe the structure of the program both in terms of technology efforts and relevance to the objectives of each Service;
- To summarize the major areas of emphasis, including some current research efforts and accomplishments;
- To solicit help from the research community in building a stronger research program for the future.

This report describes both the research program's technical composition and its management by the DoD. This ap;)roach should provide the reader with a full understanding of the DoD research program.

What is 6.1?

The annual defense budget is divided into 10 categories for accounting purposes. The R&D portion of the budget, or in DoD language, the RDT&E (Research, Development, Test and Evaluation) budget, is the sixth of 10 categories, and the activities within this budget category are numbered in the following way: 6.1 is research; 6.2 is exploratory development, 6.3 covers advanced development, 6.4 covers engineering development; and 6.5 includes management and support of R&D activities. The balance of the R&D programs fall into operational system development. The chart below shows the FY 83 allocations of funds for these categories.

The categories 6.1 and 6.2 taken together are referred to as the Technology Base or "tech base" part of the program. Efforts under the tech base part provide the means by which technical options may be found for the mid-term and long-term solutions to national security problems. The projects undertaken range from basic scientific investigations (basic research) by which new phenomenology is discovered, to demonstrations of promising technologies that may subsequently become building blocks for new weapon systems.

That portion of the tech base effort covered by budget category 6.1, the research portion, differs from the other categories in that it is not expected that a military product will necessarily result directly from it.

RDT&E BY BUDGET CATEGORIES

	FUNDING ($M)		
	FY 1981	FY 1982	FY 1983
6.1 Research	614.8	694.6	779
6.2 Exploratory Dev	1,985.3	2,212.5	2,434
6.3 Advanced Dev	2,806.3	3,475.9	3,881
6.4 Engineering Dev	6,394.6	7,683.3	8,611
6.5 Mgmt & Support	1,735.9	2,008.9	2,200
Operational System Dev	3,096.7	3,968.4	4,897
Total	**$16,633.5**	**$20,043.6**	**$22,805**

While DoD does not have a specific budget category named Basic Research, most of the effort funded under the 6.1 research category is by its nature basic research. The 6.1 activity supports fundamental investigations into the nature of basic processes and phenomena, selecting projects primarily on the basis of the quality of the work and the potential relationship to the DoD mission. Primary emphasis is on high-quality basic research which results in better understanding of the fundamental laws of nature. This understanding is necessary for the future development of military applications. When a 6.1 program is successfully completed, the results often lead to a 6.2 program to explore the use of the proven concept in a device with military relevance. One of the best and most often cited examples of this process is the development of the laser, which was largely supported by DoD from the time of its invention when it seemed a novel idea with long-range potential for the military. In fact, Prof. Nicholas Bloembergen of Harvard University, who shared the 1981 Nobel prize in physics for research leading to the development of the laser, was supported under the DoD Joint Services Electronics Program. Today, the laser is found in almost all aspects of military training and operations, and its use is expanding rapidly. Other examples of the impact of basic research on the nature of warfare will be given later.

How DoD Views its 6.1 Program

DoD has supported basic research for decades. In fact, the first government-sponsored research program was the 1804 Lewis and Clark expedition funded by the Army. When the Congress established the Office of Naval Research (ONR) in 1946, DoD became the first government organization to formally support basic research. (The National Science Foundation was not established until 1950.) The DoD commitment to fundamental research continued with the establishment of the Army Research Office (ARO) in 1951 and the Air Force Office of Scientific Research (AFOSR) in 1952. Later in the 1950s, the Advanced Research Projects Agency (DARPA) was started. However, support for 6.1 work fluctuated through the years. For example, in the late 60s, emphasis shifted toward near-term projects and funding was held more or less unchanged. But by the mid-70s, it was recognized that this approach to research management had cost DoD a 60-percent loss in purchasing power because of inflation and was risking the loss of one of its most valuable assets, its relationship with the scientific community and the ability to tap the innovative new ideas of scientists and engineers. In 1976, the Secretary of Defense, through the Defense Science Board, recognized that this pattern of supporting research was not likely to provide the necessary options for defense needs and sustained technological growth. A program of real funding growth and increased emphasis on high-risk, high-payoff, and long-term research was initiated.

In 1978, the President's Science Advisor appointed a working group (the so-called "Galt Committee") to review the policies and practices of the basic research program at DoD. The committee concluded:

"The DoD has supported basic research for decades, and it must continue to do so if it is to pursue its overall national defense objectives at the highest possible level of effectiveness, efficiency, and insight. There are three fundamental reasons. Many known technological problems stem from gaps in knowledge which only basic research can fill. Basic research is a source of new concepts which introduce major changes in technological and operational capability. And finally, it is a source of insight for DoD policy-makers and others in evaluating and reacting to the possibilities inherent in technical proposals and in technological developments anywhere in the world."

"The support of research has in the past benefited the DoD greatly, and will do so in the future since DoD's capabilities are based squarely on the technological strength of the United States. The use of high technology to preserve and insure our military posture and thereby to stay ahead of our potential adversaries may very well be the key element in our security in the years ahead."

In support of its conclusions, the Galt Committee cited examples of the impact that basic research has had on the conduct of warfare, and noted that the importance is not always recognized:

"The part played by basic research in the essential and continuous modernization of these military forces has not always been fully recognized. As recently as just prior to World War II, the Department of the Army and the Department of the Navy were doing almost no basic research. The Navy record, as an example, shows $8.9 million for all research and development in 1940. The result was a defense force not well informed of technical possibilities nor fully aware of the engineering and scientific opportunities available to it. Early in World War II, these shortcomings were painfully recognized, and heroic efforts to overcome them were undertaken. These efforts introduced a variety of new technologies—for example, radar, the proximity fuze, nuclear weapons, homing torpedoes, jet aircraft, rockets, and missiles—which changed the conduct of the war, and continue to have impact today on the military strength and readiness of the United States."

As a result of recommendations made by the Galt Committee and others who critically examined the DoD basic research program, numerous changes were made. New investment strategies were established along with commitments to increase funding. Additional efforts were initiated to renew and strengthen DoD relationships with the scientific community and especially the universities. A new management structure including the new position of Director for Research, now the Director of Research and Laboratory Management, was established. A new and simplified contract format was adopted in order to make the contracting process more responsive to the special needs of the research community.

Structure of the 6.1 Program

The DoD RDT&E program makes up approximately 50 percent of the entire federal R&D budget. Of the former, approximately 3.5 percent is devoted to basic research. This is estimated to be about $695M in FY82 and approximately $800M in FY83. In FY82, 44 percent was performed by universities and the remainder was carried out by in-house laboratories and industry, including nonprofit organizations.

The RDT&E program is vertically organized. A concept enters the system usually at the Research (6.1) level, where fundamental investigations into the nature of basic physical processes are conducted. Successful completion of a 6.1 program frequently leads to Exploratory Development (6.2) or applied research in which the proven concept is used in or applied to some device having potential military application. This is sometimes called the "breadboard" stage. The Advanced Development (6.3) stage follows, during which a prototype or "brassboard" of a specific system or subsystem is built and tested as a confirmation of the preceding 6.1 and 6.2 work. Finally, Engineering Development (6.4) reconfigures the successful prototype in preparation for production, should circumstances require it.

The obvious foundation for the overall process is the 6.1 program—hence the renewed emphasis on managing the program for greatest effectiveness. As a step toward this goal, the Defense Committee on Research (DCOR) which has members from the three Services, the Defense Advanced Research Projects Agency (DARPA), and is chaired by the DoD Director of Research and Laboratory Management, serves as a 6.1 coordinating and policy-making group in the Office of the Under Secretary of Defense for Research and Engineering. The group is concerned with interservice cooperation, the solution of managerial problems, and the consideration of urgent research needs.

Along the same general lines, but at the technical working level, interagency working groups operate in various research areas. The purpose of such groups is to coordinate the activities in a particular area of science which involve sectors beyond DoD. Such groups tend to eliminate duplication of effort, provide for a greater interchange of information, enable the sharing of facilities, and make more effective use of each agency's funds.

The performers of basic research pertinent to the needs of DoD are the scientists and engineers working within the DoD laboratories, industry, and universities. Thus the DoD research effort has two distinct parts: the in-house research program conducted within the military service laboratories and the extramural program funded by contracts and grants with industry and universities.

DoD in-house laboratories, more than 70 in number, are a vital and integral force in the defense R&D program that provides the technological foundation for our national security. They participate in and help guide the process from beginning to end, from the search for new knowledge and concepts to the design, development, and procurement of new systems. The in-house laboratories provide analytical advice and technical services in planning DoD's R&D program. They must maintain high scientific and technical competence so that outside technical advice can be evaluated and put into proper perspective in decision making. They provide the strong base of technical knowledge necessary for effective assistance in acquiring new systems; that is, to help make DoD a smart buyer. One of the laboratories' more basic responsibilities is the maintenance of a highly competent technical staff to keep DoD and the services informed of the latest scientific and technical opportunities pertinent to defense needs.

Research enables the laboratories to be at the forefront of the search for scientific knowledge, and through a program in research, laboratories provide their investigators with opportunities to keep abreast of new discoveries and to engage in meaningful interaction with the rest of the scientific community. The in-house research program serves to increase the technical abilities of the laboratories and to attract new and imaginative people into defense research.

The extramural research program of DoD involves support of basic research in both industrial and university laboratories. The research offices of the three services, the Army Research Office (ARO), the Air Force Office of Scientific Research (AFOSR), the Office of Naval Research (ONR), and the Defense Advanced Research Projects Agency (DARPA) support most of the DoD basic research in universities, while the military laboratories support significant effort within industry. The university program, as one might expect, tends to pursue research which offers long-term payoff while that funded in industry is often near-term and related more closely to the interests and needs of the sponsoring military laboratory.

As indicated earlier, universities are a major extramural performer of DoD research in the 6.1 category, conducting about one-half of the effort. This is not surprising since universities produce virtually all new members of the scientific community, and these are institutions in which basic research is a major function almost inextricably interwoven with advanced education.

Most of DoD's extramural research programs are supported through individual contracts and grants. However, a recent innovation in this support has been the establishment of multidisciplinary "cluster" programs focused on complex DoD problem areas. These programs, which provide at least three years or more of stable support, are carried out by groups of researchers at universities each managed by a senior scientist. They serve essentially as program managers, providing clear direction and coordination. Examples of such programs are the tri-Service Joint Services Electronics Program (JSEP) and the Joint Services Optics Program (JSOP), in which ARO and AFOSR participate cooperatively in supporting major projects. Although JSEP is not new, this concept of research management is now being emphasized more strongly. Most cluster programs are funded by a single Service, with other Services and agencies participating in review. In 1976 only 25 programs (under JSEP and oceanography) were of this nature. Today there are many more. This is indicated in table A-2 of Appendix A, which shows the distribution of projects by funding allocation. Note that the "Over $150K" category is substantial, reflecting the increased number of such larger projects. Over 130 such programs exist today.

Recently, ONR has initiated a special cluster program. The program, called Selected Research Opportunities (SRO), is designed to invest higher funding levels, between $200,000 and $500,000, in several specific, preselected topical areas of both general scientific and naval interest. The investigations may be multidisciplinary and the principal investigators are expected to communicate and coordinate with similar programs in industrial and in-house Navy laboratories.

The role of DoD management in the research program is to provide the fertile ground for the development of new research opportunities. Such opportunities come by way of unsolicited proposals, scientific liaison with other departments and agencies, professional surveillance (meetings, journals, personal contacts), scientific advisory panels, top-down requirements, research innovations and breakthroughs, and the evaluation of foreign intelligence. Once an opportunity is recognized, management then strives to exploit it. Signature suppression, less vulnerable communications, improved visibility in degraded environments, elimination of corrosion, advanced beam weapon technology, advanced data processing, and ultra-small electronics are examples of current research opportunities.

Measuring the success of this approach is not straightforward. One could count the number of published journal articles resulting from DoD-sponsored research, or the number of literature citations received, or the number of patent applications, or use any of a dozen other metrics, and then draw conclusions based on these statistics. One such metric might be the nearly 20 Americans who have received Nobel Prizes this past decade while working on DoD-supported programs.

More important than such measures as these, however, is the feeling of productivity and good will that has been engendered between the research community and the DoD research establishment. It is this feeling that DoD wants to preserve and amplify.

Because of the importance of the role of university basic research to the goals of DoD, several steps are being taken to improve the relationship between DoD and the university scientific community. This relationship deteriorated during the late 60's and the early 70's because of an unpopular war and decreased emphasis on the support of basic research by DoD. Also, in 1970 the so-called Mansfield Amendment to the Military Authorization Act placed restrictions on the type of research appropriate for DoD support. Although the wording of the amendment was changed the following year to recognize the need for DoD to support fundamental research, some residual effects of the amendment continued for several years and in effect caused the DoD effort to tend toward short-term research performed by universities. However, this trend has now been reversed, and the DoD and the academic sector have restored their productive partnership in pursuit of long-range, fundamental ventures in scientific inquiry.

Before proceeding to a description of some of the research directions for the current fiscal year and the future, it is appropriate to note some of the accomplishments resulting from the DoD basic research program. Already mentioned were those efforts during World War II which have had a tremendous impact on the nature of warfare: radar, nuclear weapons, homing torpedoes, rockets, jet aircraft, missiles, and the electronic computer. Research during the 1950s and 1960s led to the maser and laser, integrated circuits, intercontinental missiles, computerized weaponry, vastly improved communications systems, and advances in medical science.

The following are just a few examples of significant accomplishments made during the past two years:

- New Armor Penetrator Technology for Anti-Tank Warfare. Far more lethal armor penetrator warheads for use against tanks and other armored vehicles will result from a new theoretical shaped-charge model for designing anti-armor munitions.

● Improved Safety and Mission Effectiveness of Helicopters. A new nondestructive test method will locate previously undetectable helicopter rotor blade flaws which could, if undetected, lead to catastrophic failure.

● Low Cost Missile Seekers. Research in computer technology has led to a very small and inexpensive seeker which can autonomously acquire a target, track it, and provide guidance signals.

● New Submarine Detection Technology. Advances in optical sciences and electronics have led to development of a new kind of hydrophone based on optical fibers. The new hydrophone detector operates at low frequency with very low noise levels.

● High Brightness X-ray Source. A major problem anticipated in particle beam weaponry is a means to determine the position of the beam, since it does not radiate electromagnetic waves naturally. A new, high-brightness x-ray source developed with laser technology will be invaluable as an illuminator of neutral particle beams and will open a wide range of other technical applications. The new x-ray source, even on a laboratory scale, is brighter than synchrotron radiation from the world's biggest electron accelerators.

● Carbon-carbon Rocket Nozzle. Serious manufacturing problems exist in the production of carbon-carbon composite materials for rocket nozzles. These problems arise from the complexity of the process, which involves weaving fibers into bundles, impregnating with pitch, and additional operations of impregnation, graphization, and carbonization. A successful research effort has developed a method to determine cracked or unacceptable billets for nozzle fabrication. The applicability of this technique to MX nozzle materials is being explored.

The research program in FY 83 will continue to cover a broad range of science and engineering topics which are of critical importance to the defense mission. The funding increase in FY 83 will be used to strengthen areas to overcome serious inadequacies in the current level of effort. These include the following:

● Free Electron Laser (FEL). The FEL, which was first demonstrated at Stanford University in 1977 under an AFOSR contract, has the potential for efficiently producing high-power, coherent radiation which in principle can be tuned from the millimeter to the x-ray region of the spectrum. It has already demonstrated a megawatt of pulsed power at 400 micrometer wavelength, and further progress is expected.

● Microelectronics. It is vital to understand the fundamental limitations of the operating ranges of electronic devices, both semi-conductor and tube type. The extension of limiting parameters (such as frequency response, speed, power, sensitivity, dynamic range, and the like) is of immediate interest. Some exceptionally critical programs fall within this area, such as the entire field of near-millimeter wave (100 to 1000 GHz) sources and detectors, of which there is currently a severe shortage, especially in the atmospheric transmission windows at 140 and 230 GHz. An important aspect of the electronics program is a new tri-service 6.1 program on Ultra-Small Electronics Research (USER). With the advent of high-resolution electron, x-ray, molecular, and ion beam lithographic techniques we are quickly approaching an era of ultra-small devices in which individual feature sizes might well be fabricated on the molecular scale, the goal being 0.02 micrometer resolution.

● Hazard Protection and Performance Effectiveness. A major goal in this area is to determine the biological effects and human tolerance of such military environmental stressors as non-ionizing radiation, toxic emissions of weapons systems, physical forces (vibration, impact, and acceleration), and environmental extremes (heat, cold, high altitude, deep submergence). Another vital interest is the defense of the individual against chemical and biological (CB) weapons. These investigations deal with detection of CB agents, decontamination of exposed personnel and material, and treatment of casualties. This last topic requires understanding how the CB agent acts against the body. A typical nerve gas agent acts to inhibit the production of the nerve impulse transmitter acetycholine, and more research needs to be done to more fully understand the action of such transmitters.

● Computers and Information Processing. Topics of particular interest in information processing include computer architectures for efficient distributed processing, controls to improve memory-access techniques, reliable digital transmissions, software cost reduction, simplified operating systems, and improved methods for parallel processing, artificial intelligence, and robotics. An important effort has been established in artificial intelligence, directed at developing "smart" computer systems with capabilities for mimicking man's common-sense reasoning and physical dexterity. It includes fundamental research on machine representation of knowledge, language and speech comprehension, computer vision, machine-controlled manipulators, and reasoning by analogy and inference. Directly tied to the artificial intelligence project are efforts in robotics and industrial automation.

● Physical Oceanography. Physical oceanography includes descriptive, analytic, and modeling studies of the open ocean environment. Emphasis is on developing a predictive capability for the three-dimensional time-varying ocean structure and on filling gaps in the

National Physical Oceanography program that are of importance to the Navy. Programs include studies of the upper ocean, development of new oceanographic instruments, synoptic oceanography, and remote sensing including satellites and high-frequency over-the-horizon radars.

The budget for the DoD 6.1 Research program is comprised of two segments. The major portion of the program (92 percent) is in the program elements called Defense Research Sciences (DRS). The DRS programs include all the extramural efforts and most of the 6.1 tasks performed in the in-house laboratories. The objectives of the DRS program are to (1) ensure that the scientific and technological base related to national defense is the best in the world, (2) provide a broad and balanced foundation of fundamental information in scientific areas of interest to DoD, (3) identify today's scientific opportunities which address tomorrow's defense requirements, (4) counter the Soviet threat to our technological superiority, and (5) prevent or create technological surprise.

The remaining 8 percent of the 6.1 program is allocated to the In-House Laboratory Independent Research (ILIR) program. This unique program provides individual laboratory directors with discretionary funds for what might be called "high-risk venture capital" to enable them to take immediate advantage of technological opportunities that present themselves, and to maintain a research base in the DoD laboratories. ILIR funds are restricted to the in-house director's use, but can be contracted out by the laboratory. They may not be used merely to shore up regularly funded programs that have overrun their budgets, but are used to concentrate on daring new approaches to problems that might not ordinarily be supported since they fall outside the normal funding arena or funding cycle. The technical directors report on their ILIR programs directly to their Service Assistant Secretary for R&D with no review by any intervening layers of management. The programs are reviewed after the fact, with each year's funding dependent upon the results of the previous year's efforts.

To summarize, DoD views its 6.1 program as the source of its future technology. The Director of Research and Laboratory Management, in the Office of the Under Secretary of Defense for Research and Engineering, and the 6.1 managers in the various DoD agencies are responsible for optimizing the technology transfer process. Accomplishments in the 6.1 program must be quickly passed on to 6.2 programs. Because of the vertical R&D structure and the fact that many of the in-house organizations doing 6.1 work are also involved in 6.2 work, the time involved in applying the results of the 6.1 program should be minimized.

What are the responsibilities of the individual researcher? DoD expects participants in its 6.1 program to propose and perform the highest quality, most innovative, most creative research possible. Extramural researchers in particular are not expected to justify their proposals in terms of possible applications (not that such suggestions would not be welcome). In-house researchers, by virtue of their close association to specific military requirements, are charged with responsibility to focus their applications. However, the technical directors of the various Service organizations have the ultimate responsibility to effect and facilitate the technology transfer (under the guidance and review of the Director of Research and Laboratory Management) and thus to preserve the more fundamental nature of 6.1 programs (compared to the more applied 6.2 programs).

Quality is the most important criterion for the acceptance and funding of proposals. Next, is the potential relationship to the DoD mission. The weight given each of the criteria in the decision making process varies somewhat from case to case, depending on the availability and source of funds and the extent of support by other federal agencies. As might be expected, the focusing of fundamental research on mission areas increases from the extramural program (as administered by ARO, ONR, and AFOSR), to contracts from DARPA and the defense laboratories, to work performed in-house.

New research opportunities come from the research community. DoD is willing to provide the management, coordination, and funds necessary to turn new, high-risk, high-payoff concepts into reality.

DoD Research in the National Context

From the time of World War II, the DoD research program has strongly affected our nation in nonmilitary areas, radar and synthetic rubber are prominent examples. From a desire to improve the G.I.'s canned C-rations came new methods for freezing, drying, and preserving food; the printed circuit board found in every $10 portable radio evolved from the effort to make proximity fuzes for artillery rounds more gun-rugged; and, of course, there is the ubiquitous laser, whose full potential has yet to be tapped. The list could go on indefinitely. Research in tropical diseases, cryogenic preservation of blood plasma, improved construction techniques, resuscitators and heart pumps, goggles to aid the victims of retinitis pigmentosa, and even fluidic lawn sprinklers are just a few examples.

The DoD 6.1 research program, $779M in FY83, responds primarily to the military needs of the nation; however, through both formal and informal contracts, the research program has influence beyond its defense-related obligations. The Technology Transfer (T^2) program was formally established to allow the expertise and accomplishments of DoD laboratories to be made available to civilian governmental organizations at the local, state, and federal level. This program originated in 1971 when 11 DoD in-house laboratories joined together to form the DoD Technology Transfer Consortium in an effort to improve domestic T^2 processes. The program was endorsed in 1972 by the Deputy Secretary of Defense, subject to various conditions. (For example, the work must be compatible with existing DoD capabilities and facilities, and it must not impede the accomplishment of a laboratory's mission

Table 1. Cross Reference of Service Research Programs and DoD Disciplines[a]

DoD discipline	Names of programs within Service research offices		
	Army[b]	Navy	Air Force
Physics, Radiation Sciences Astronomy, Astrophysics	Physics—not including astronomy or astrophysics[c]	General Physics, Radiation Sciences Astronomy & Astrophysics	Physics, Astronomy & Astrophysics
Electronics	Electronics[c]	Electronics	Electronics
Chemistry	Chemistry[c]	Chemistry	Chemistry
Mathematics and Computer Sciences	Mathematics, Electronics[c]	Mathematical Sciences	Mathematics
Mechanics and Energy Conversion	Engineering Sciences	Mechanics, Energy Conversion	Mechanics, Energy Conversion
Materials	Metallurgy & Materials,[c] Chemistry	Materials	Materials
Aeronautical Sciences	Engineering Sciences[c]	Mechanics	[d]
Oceanography	—	Oceanography	—
Terrestrial Sciences	Geosciences[e]	Terrestrial Sciences	Terrestrial Sciences
Atmospheric Sciences	Geosciences[c]	Atmospheric Sciences	Atmospheric Sciences
Biological and Medical Sciences[f]	Biology[g]	Biological and Medical Sciences	Biological and Medical Sciences
Behavioral and Social Sciences	Biology[h]	Behavioral and Social Sciences	Human Resources

[a]The DARPA program is outlined in Appendix A.
[b]The Army program divison is from the Army Research Office (ARO) and pertains mainly to the extramural program. The technologies listed also pertain to the Divisions at ARO which monitor the work. Because of the large Army in-house laboratory program, the major Commands conducting resea ch in the vario disciplines are given in the footnotes. For a fuller explanation of the organization of the Army's 6.1 program, see nd apr x A.
[c]Programs in the area are also found within Departme of Army Materials Development and Readiness Command (DARCOM) laboratories.
[d]The Air Force does not identify Aeronautical Sciences separately since much of its research in the other disciplines concerns this area.
[e]Programs in this area are also found within the Corps of Engineers laboratories.
[f]There is also a small research program in this discipline being carried out at the Uniformed Services University of the Health Sciences (USUHS).
[g]Programs in this area are also found within the Surgeon General laboratories.
[h]Programs in this area are also found within the Army Research Institute for the Behavioral Sciences.

work). The Consortium has grown to more than 200 laboratories and centers representing 11 Federal agencies and is now managed by the National Science Foundation as an interagency organization. The DoD has been an active participant in the T^2 process, and under the Under Secretary of Defense for Research and Engineering has formally reaffirmed its commitment to the program every two years. Most recently, the process of technology transfer has been formalized and reinforced by DoD and other Federal agencies through mechanisms provided by the Stevenson-Wydler Technology Innovation Act of 1979 (*PL 96–480*).

Informally, the DoD R&D program weaves itself into the fabric of national life in a pervasive though not always obvious way. The very-high-speed integrated circuit (VHSIC) program now in progress will have a major effect on the electronics industry and will eventually enter our lives in ways that will make the wonders of talking children's toys and programmable microwave ovens pale by comparison. Similarly, the work in highly parallel arrays supported by the Navy may profoundly affect the next generation of large computers.

The National Research Council study "Science and Technology: a Five-Year Outlook," performed for the Office of Science and Technology Policy, discusses the current state of several aspects of our national technology base and highlights trends and areas for future emphasis. This study mentions many areas in which DoD is participating: earthquake hazards, ocean dynamics, synaptic transmission in nerve cells, amorphous solids, surface phenomena, graphite intercalated compounds, organic conductors, molecular beam epitaxy, robotics, superconductors, electronics displays, composite materials, powder metallurgy, computer-aided design/manufacture, and a host of others.

Such programs are not, for the most part, planned as part of an overall national program. They "happen" for several reasons: the military shares many similar problems with the civilian sector; the military researcher is well-connected to the civilian scientific community through journals, symposia, and the like; and a great deal of the DoD research program (well over half in FY82) is performed by contractors and grantees in the private sector.

This Report. To the outside community, DoD may appear to be an intimidatingly large organization, difficult for researchers to penetrate to find out "who is interested in my idea." To help the researcher find possible sponsors more easily, we have divided the body of this report into two parts: scientific disciplines in the first, and organizations in the second. Table 1 is a matrix showing the 12 classical disciplines as delineated by the Office of Research and Laboratory Management and the corresponding divisions within the Service research offices. This is often very important to the outside community, since many of our programs are multidisciplinary and may overlap; for example, solid state physics falls within the categories of physics and electronics in ARO, the category of electronics at ONR and AFOSR, and the category of materials at DARPA.

Rather than providing great detail, the report highlights the individual areas with examples of on-going programs and a few major accomplishments in each. Some of the requirements for the future are provided as an indication of the shape the program will assume in the years to come.

Appendix A presents a collection of statistical tables to give the interested reader a feel for the breadth and depth of the program. Appendix B provides a list of points of contact to assist those wishing to gain access to the DoD research community.

A final word on relevance: we find that all too often good ideas are never brought to DoD's attention because the researcher does not see an immediate "military application." This is unfortunate, since the extramural researcher is not usually the person who should make this determination. We in DoD are interested in all good ideas, and it is the responsibility of the scientific program managers, not the researchers, to decide on the applicability of a particular research project.

Scientific Disciplines

Physical Sciences

- ***Physics, Radiation Science, Astronomy and Astrophysics***
- ***Electronics***
- ***Chemistry***
- ***Mathematics and Computer Sciences***

Physics, Radiation Science, Astronomy and Astrophysics

Fundamental research in the physical sciences is the largest and most diverse area in the DoD research program. This is research into the properties and behavior of matter at the most basic level. As such, its individual programs span a greater range of types of investigation, from the more basic to the more applied, than do the other discipline areas of the DoD program.

History has demonstrated that significant changes in the concepts of physics are likely to lead to important advances in military technology and tactics. The demonstration of the maser in 1953 and the low-power laser in 1960 marked the beginning of a revolution in military tactics which rivals the impact of radar in World War II. The electronic dependence of current military systems is a direct consequence of applying basic principles of solid-state physics to electronic circuitry. The use of the high-power laser as a weapon may well be the most significant influence on military firepower since the origin of explosives.

The physical sciences are basic to the whole range of military science and technology; some examples are the phenomena of photoemission (for night vision), molecular kinetics (in combustion and explosives), and solid-state effects (upon which electronic devices depend). In a sense, physics is the parent of the other physical sciences, and its military applications are accordingly extremely diverse.

DoD's recognition of the far-reaching influence of breakthroughs in the physical sciences is the basis for its interest in supporting the best physics research possible, particularly within the critical fields described in this section. It is no accident that the Services have supported many milestones in physics (such as, for example, the development of the BCS theory of superconductivity, nonlinear optics, and lasers).

History also suggests the difficulty of predicting the ultimate military significance of a specific research task, so that it is futile to try to organize research programs according to military objectives. Consequently, the Military Departments and agencies that deal with the physics community have tended to organize their programs along traditional subdisciplinary areas, as described below.

Atomic and molecular physics. Atomic and molecular physics provides significant opportunities for military applications based on detailed knowledge of atomic and molecular structure, the interactions of individual atoms and molecules with electrons and other species, and interactions with electromagnetic fields. These interactions are basic to understanding the transmission properties of electromagnetic radiation in the natural and disturbed atmosphere, and to developing new laser candidates for high- and low-power applications. This research area is also applicable to the development of accurate navigational aids, infrared emitters and detectors, and energy systems.

Topics covered in this area include energy and charge transfer, electronic excitation and relaxation of excited states, state-to-state molecular dynamics, spectroscopic investigations and techniques, fluorescence, radiationless transitions, and optical pumping. Of particular interest is the investigation of the properties of Ryderg state atoms, i.e., atoms having an electron in a very high quantum level. Since the geometrical cross section scales as n^4, where n is the principal quantum number and polarizability goes as n^7, studies of Rydberg atoms with very high n may lead to applications such as efficient long-wavelength radiation detectors, sensitive electric-field detectors, and very long-wavelength lasers. In recent years, the techniques of many-body physics have been used within atomic and molecular physics for a wide range of applications such as determining the velocity dependence of vibrational excitation of molecules formed in rocket exhausts and computing the activation energies for complex explosives.

Optics and lasers. The Military Services have been very actively sponsoring research in optics and lasers, since the potential for range determination, weapons guidance, and communications was recognized immediately with the demonstration of maser and laser phenomena. Specific applications will continue to develop as various research problems are resolved. These applications include the development of (1) lasers in heretofore inaccessible regions of the spectrum such as the far infrared, ultraviolet, and x-ray regions, (2) widely tunable lasers, and (3) new approaches to high-power and high-efficiency laser action.

An outstanding example of DoD-supported work in this area is the free-electron laser (FEL), which was first demonstrated at Stanford University in 1977 under an AFOSR contract (fig. 1). This device has the potential for efficiently producing high-power, coherent radiation which in principle can be tuned from the millimeter to the x-ray frequency of the spectrum. It has already generated 1 MW of pulsed power at a 400-μm wavelength.

Recent research in this area addresses issues associated with recovery of electron beam energy and two stage FEL operation. This research portends more efficient FELs and greatly reduced electron beam energy requirements.

The rapid development of laser techniques has also presented many opportunities not directly concerning laser devices. For example, nonlinear optical techniques, such as up-conversion and conjugate-wave processing, suggest new ways of handling information.

Also being studied are optical components such as glass and windows for lasers; the effects of electric and magnetic fields on optical materials are of interest. The unique laser properties of monochromaticity, coherence, high intensity, and short pulse lengths are being applied to the study of various material systems and to the production of plasma radiation that is well-suited for use in lithography, chemical analysis and strain measurement.

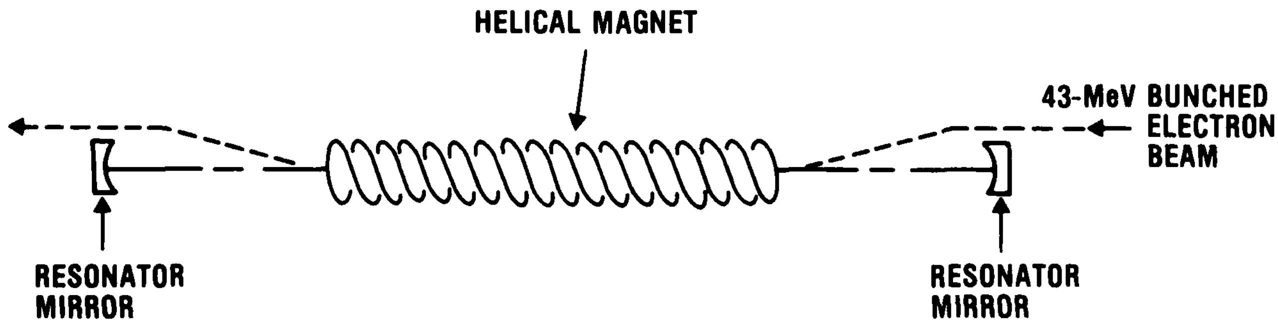

Figure 1. Schematic diagram of first free-electron laser

Electrical phenomena in gases and plasmas. The study of electrical phenomena in gases and plasmas includes the physics of electrical discharges and electromagnetic interactions with these discharges. The high-priority programs dealing with directed energy fall partially in this area (particle beams supported heavily by DARPA) and partially in the laser area.

The particle-beam program, being the newer of the two, has many problems requiring research. The program's needs have been divided into five areas.

- Pulse power—improved repetition rate, improved voltage and current capabilities for switches, materials having increased energy storage density at reduced size, weight, and cost, and prime power sources having increased power density and fuel efficiencies.
- Sources—diagnostics, scalability, improved repetition rate, increased monoenergetic character, and improved beam formation and extraction techniques of high-intensity ion/electron sources.
- Accelerators—improved focusing elements, greater understanding of dielectric breakdown, transport codes for multistaged systems, diagnostics, and high-flux swing magnet.
- Propagation—recombination rates and cross sections for atoms, molecules, and hydrated complexes, effects of ion-equilibrium vibrational and rotational populations on hydrodynamics, effects of "dirty air," and improved models of hose and two-stream instabilities.
- Beam-material interaction—low and high flux signatures, thermomechanical damage estimates, collective effects, multipulse effects, and effects on layered targets.

A further example of work supported by DoD in plasma physics is the research on collective plasma processes, in ionized media and in electron beams, that lead to the production of intense radiation at microwave and millimeter wave frequencies.

Condensed matter. The military interest in condensed-matter physics is extremely broad, including such diverse possiblities for applications as (1) explosive initiation and propagation, (2) surface phenomena relating to corrosion and wear, (3) fundamental forces governing the mechanical properties of metals and alloys under normal and unusual environmental conditions, and (4) the construction of man-made superlattices to press the limits of electronic device size and speed performance. Examples of work partially supported by DoD in this area are the research on superlattices by Leo Esaki, the Nobel laureate from IBM (fig. 2) and theoretical research on phonon-electron coupling processes central to explosive initiation.

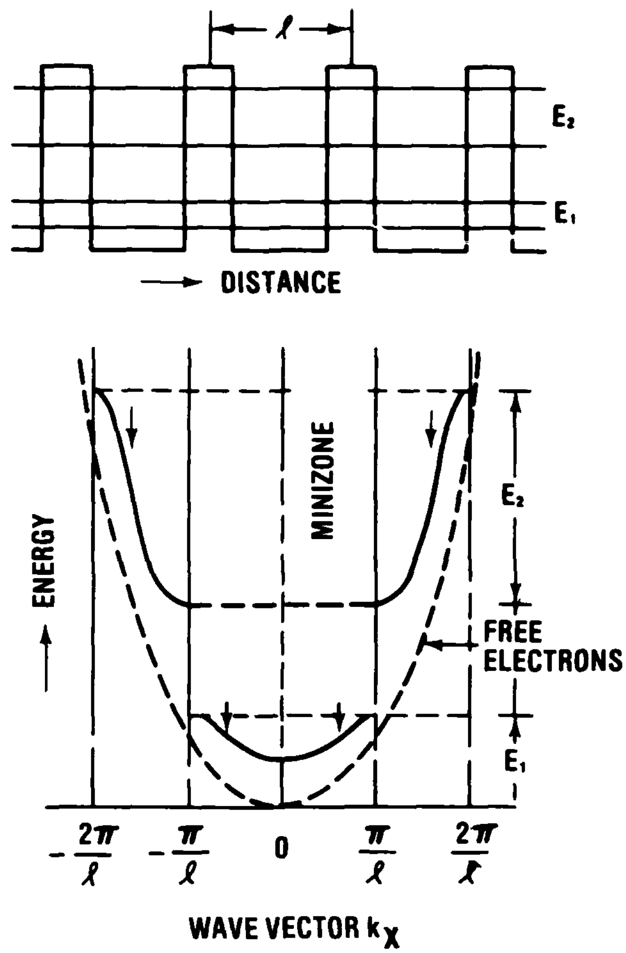

Figure 2. Superlattice struture gives rise to minizones in wave-vector space, dividing the E-k relation into a series of minibands.

The areas of physics research interest are correspondingly broad and include the total spectrum of properties of liquid, amorphous, and crystalline substances. There continues to be interest in specific issues concerning the mechanical, electrical, optical, and thermal properties of these material classes.

Much research tends to focus on novel approaches to devices of electronic significance. There are many other areas of thrust, however. For example, ONR has maintained an interest in low-temperature phenomena in connection with cryogenic and superconductive devices. Representative research is concerned with superconductive millimeter-wave detectors, Josephson junctions, coupled superconducting junctions, and magnetometers. Theoretical and experimental research related to superconductors that operate under extreme conditions is sponsored by AFOSR.

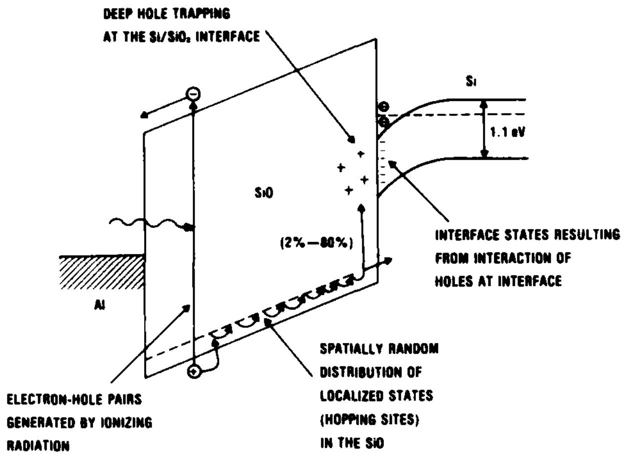

Figure 3. Schematic of radiation effects problem in metal-oxide-semiconductor structures.

Electromagnetic technology. Electromagnetic technology includes the physics of electron tubes, semiconductor devices, dielectric devices, and photoelectric and optoelectronic devices and systems.

Radiation sciences. Because of the emphasis that DoD places on the survival of equipment in a nuclear environment, research in radiation science concentrates on understanding the interaction of radiation with matter and devising methods to harden devices against the damaging effects of radiation. All three Services carry out major programs in both research and development, both in-house and on contract. An example of such a program is a widely acclaimed investigation whose goal is to explain the charge buildup caused by ionizing radiation at the interfaces in silicon-based electronic devices (fig. 3). Since manufacturers of electronic components do not evaluate a device's radiation hardness, many of these devices may not be able to survive even moderate radiation doses. Studies such as this one will suggest changes in material composition and manufacturing techniques that should yield more radiation-resistant devices.

Acoustics. Much of the DoD support for electroacoustics within the last several years has been by the Navy, in relation to physical and underwater acoustics for improved sonar and surveillance, underwater communications, signal-processing techniques, reduction of target strength, and investigations of the effects of ocean topography and variability on sound propagation.

The three Services are interested in acoustic research because of its application to diagnostics, for example, in nondestructive evaluation (NDE). Acoustic techniques are often employed as a probe; an example is the use of photoacoustic spectroscopy to understand radiationless transitions in doped electro-optic crystals. The Air Force has sponsored a major program in NDE and surface acoustic waves for signal-processing devices.

Primary research areas of current interest include nonlinear acoustics, basic studies in acoustic emission, interaction of sound with objects, and physical models for acousto-optic transduction. Interest will continue in extending ocean propagation models of related at-sea work, physical and chemical properties of media, and new device principles.

Astronomy and astrophysics. Because of such critical defense-related missions as surveillance, communications, time and position determination, and missile guidance, the physics of the upper atmosphere and of various astronomical and astrophysical phenomena is an area of significant emphasis. The radiation environment at very high altitudes is being studied both from the standpoint of equipment survivability and background effects on surveillance and comunication systems. With the continuation of the Space Shuttle during the eighties, this area of research can be expected to increase in emphasis.

Research in this area includes the observation and interpretation of radio, infrared, optical, ultraviolet, x- and gamma-ray, and particle emissions from earth, aircraft, balloon, rocket, and satellite platforms. As is typical for scientific investigations in this area, emphasis is placed on techniques and the development of instrumentation.

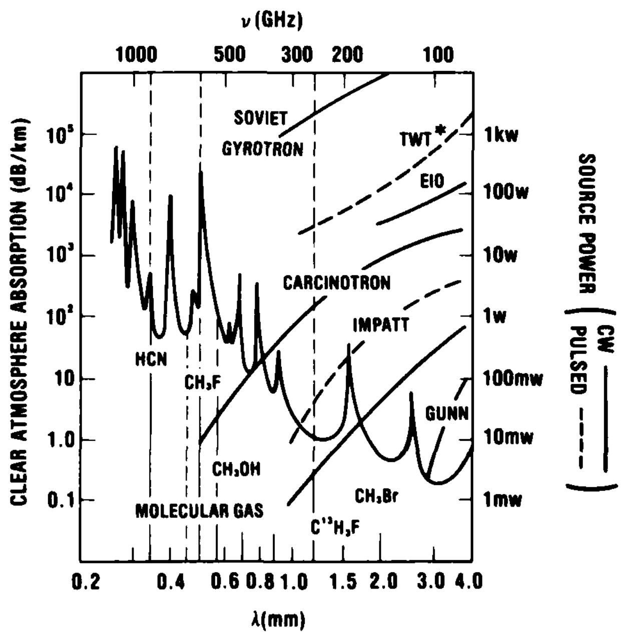

Figure 4. Clear-weather absorption and state-of-the-art source powers in near-millimeter wave region.

A major accomplishment in the astronomy area has been the completion of an x-ray skymap by staff members at the Naval Research Laboratory (NRL). NRL prepared one of the instrumentation sets on the HEAO 1 satellite, which was launched in August 1977 for a mission devoted to x-ray astronomy. The device has yielded data on radio pulsars, binary pulsars, black holes, extragalactic sources, BL Lacertae objects, and the x-ray background.

Another accomplishment in astronomy is the mapping of the background (nonzodiacal) starlight in both red and blue wavelengths over the entire sky under an AFOSR space research contract. Taking advantage of merged Pioneer 10/11 skymaps and the negligible zodiacal light beyond a distance of 2.8 AU, the zodiacal light was isolated and the maps of the two colors were developed.

Cross-disciplinary physics. Many of the greatest opportunities for military applications of science and technology arise from research in the boundary areas between physics and other scientific disciplines and technology. Physics research is a powerful stimulator of fresh ideas for technology. Technology responds by providing ways to implement new physics investigations. This mutual dependence of the growth of physics and technology is exemplified by the demonstration of the laser, its subsequent technological development, and the impact that advanced laser technology has made in many spectroscopic research areas.

A major area of interest relates to the generation, control, and detection of electromagnetic radiation. For example, the Army is actively engaged in the physics of coherent sources near 1 mm in wavelength for possible application to a high-resolution radar under obscured-visibility conditions (fig. 4). The research necessary to produce radiation at still higher power levels is supported by the Air Force for possible applications in electromagnetic warfare. Other areas of interest include the treatment of materials and its effects on microstructure and properties, high-current and high-voltage technology, electrical and magnetic devices for electronic applications, integrated electronics, and photo- and opto-electronic devices and systems.

Electronics

DoD requires electronic systems having characteristics for high-speed information processing, high reliability and availability, operation in hostile environments, resistance to jamming and interception, exploration of the total electromagnetic spectrum, coordination of interdependent functions, complex and unpredictable situation management, and ease of personnel training and maintenance. The Services have common needs in electronics research: microwave, millimeter, and electro-optical components and materials, high-speed information-processing devices and materials, and an understanding of processes affecting device, circuit, and system reliability. Thus, the research program in electronics has been structured in a logical progression of topics beginning with the study of electronic materials, through the way these materials behave in devices, to the design and construction of components, the combining of components into circuits, and finally, the building of systems based on these circuits.

Physical electronics. Investigations in this area are directed at understanding such phenomena as the generation, transport, and control of charge carriers in semiconductors, and the magnetic properties of materials. Specific research topics include the electronic and structural properties of binary, ternary, and quaternary semiconductors, semiconductor surface and interface effects, high field and nonequilibrium transport phenomena, transport physics in ultra-small dimensions, magnetic effects at high frequencies, and interfaces in optically integrated circuits.

Electronic devices. It is vital to understand the fundamental limitations of the operating ranges of electronic devices, both semiconductor and tube type. The extension of limiting parameters (such as frequency response, speed, power, sensitivity, dynamic range, and the like) is of immediate interest. Some exceptionally critical programs fall within this area, such as the entire field of near-millimeter wave (100 to 1000 GHz) devices (both sources and detectors), of which there is currently a severe lack, especially in the atmospheric transmission windows at 140 and 230 GHz.

One of the more exciting technology base programs in DoD today is the very-high-speed integrated circuit (VHSIC) program. The enormous potential of these devices has been barely comprehended at this time. The VHSIC program, now in the developmental stage (6.3), deals with the fabrication of circuit elements on a chip having a resolution in the region of 0 5 to 1.0 μm. Since the propagation time of an electrical impulse is directly dependent on distance, this new technology will yield devices that operate faster by at least a factor of two than the present devices. In addition, the available "real estate" on a chip will go up by the square of that number, or conversely, the same chip will be able to be reduced in size by that same factor. The current thrust behind the VHSIC program for the military is higher reliability and higher speed. The commercial counterpart of the VHSIC program is VLSI (very-large-scale integration) where the thrust is for higher density of elements on a chip. Currently, 10^4 gates per chip is feasible. The design goal of the program is 10^6 gates per chip. Although the technology to fabricate these devices is coming into view, the main problems to be attacked involve the application of the technology. The acronym DAST, which stands for Design, Architecture, Software, and Testing, summarizes the direction that the VHSIC program will take.

As one of the programs supporting VHSIC, Ultrasmall Electronics Research (USER) is pushing the frontier of solid state electronics toward a generation of devices with critical dimensions no larger than a molecule. Such small dimensions allow an increase in the density of transistors on a single semiconductor substrate and provide an increase in data-processing speed. As the critical dimensions of solid state devices are reduced, the time and space domain become so small and electric fields so large that new concepts and theories of operations need to be developed. An idea of the sizes involved here can be gained from figures 5 and 6. Figure 5 shows an LSI circuit which is current technology. Superimposed on the circuit is an amoeba giving a size scale of about 100 μm. Figure 6 shows the state of the art: a heterojunction laser of the quaternary compound InGaPAs grown by liquid-phase epitaxy. The circular objects superimposed on the structure are leukemia viruses, ranging in size from 0.05 to 0.1 μm, indicating a resolution of the layers of the heterostrucutre of about 0.015 μm. In recognition of these needs, the USER program is centered around the physics, chemistry, and metallurgy of the geometrically constrained semiconductor structures of the next generations of integrated circuits.

Some structures that have been proposed are so small that the bulk properties of the host semiconductor may be significantly less important than size-related effects such as tunneling, size-quantization, range order, and fluctuation phenomena. In these devices, preliminary studies indicate that the temporal and spatial scales become so short and the electric field so large that new physical regions are reached, where the precepts of present-day semiclassical device physics are inappropriate and indeed may be misleading. For instance, in devices whose size approaches the long-range order of the material, phenomena such as defects, chemisorption, segregration/agglomeration, and microinclusions, normally negligible in larger devices, may be of critical importance in this submicrometer range. Current transport theory based on the Boltzmann transport equation is almost certain to be invalid. Additionally, interactions between neighboring structures must be considered. Structural renormalization, synergetic self-organization, collective or coherent operations, dissipative relaxations, etc. have only begun to be examined. The USER program began during FY81 and promises to be one of the most exciting research efforts in the DoD program.

Antennas and electromagnetic detection. The transmission and reception of electromagnetic radiation are becoming increasingly necessary for the performance of military missions. Navigation, radar, electronic warfare, communication, direction finding, and electronic countermeasures depend on the full understanding and efficient use of antennas, atmospheric and ground propagation, and sensitive, optimized detection schemes. Examples of current emphasis are electrically small and conformal antennas, effects of proximity to complex structures, radar-resolution enhancement, research in the near-millimeter region dealing with low-cost, high-performance antennas, and an improved data base in atmospheric propagation and target/background characterization.

Over the last five years the Services have been supporting research in conformal antenna technology. Because these antennas are physically very thin they can be flush mounted to the aerodynamic surfaces of missiles, rockets, Remotely Piloted Vehicles, and projectiles without degrading electrical or aerodynamic performance. Also, because they are monolithic and fabricated by simple photolithography, they are inexpensive. The investment in conformal antenna research is now beginning to pay dividends.

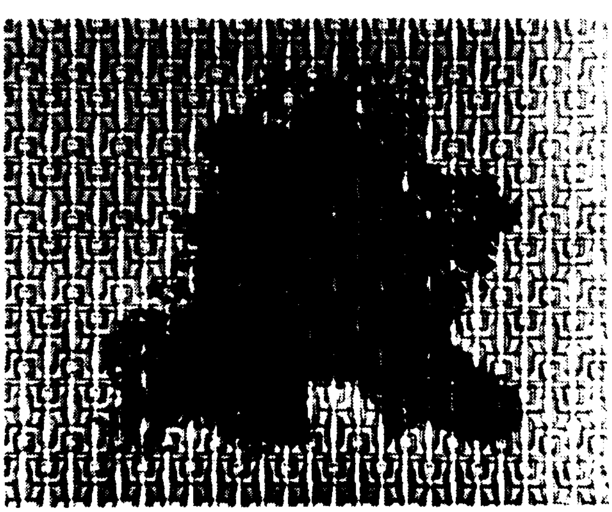

Figure 5. Amoeba superimposed on LSI circuit.

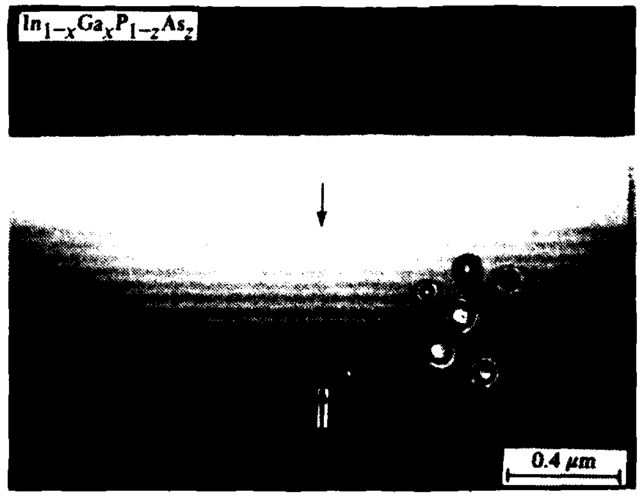

Figure 6. State of the art in ultra-small electronics technology: leukemia viruses superimposed on heterojunction laser.

This high electrical performance at low cost, compared to 20-year old, conventional waveguide antenna technology, has been made possible by basic research. Element resonance effects, fringing electric fields, interelement coupling, element directivity variations, insertion phase shifts and radiation resistance variations are some of the phenomena that needed to be understood before an antenna of this type could become practical. The analytical results of numerous researchers have been pulled together by a small group at the Harry Diamond Laboratories and used to develop a synthesis algorithm. A comprehensive interactive computer code, which exercises the appropriate analysis and synthesis subroutines, accepts performance parameters (e.g., main beamwidth) as input data, synthesizes the metalization patterns, predicts electrical performance, and directs a photolithographic computer to produce a mask. The actual antenna is then produced by simple chemical etching. Because of the investment in research, computer design of high-performance, low-production cost monolithic antennas is now possible.

Circuits, networks, and related systems. The major thrust of this area is improved techniques for the design, production, testing, and simulation of integrated circuitry, optical circuits, and high-frequency networks.

Signal processing, communications, and related systems. Research is concentrating on improving system performance and reducing the size, weight, and cost of systems that transmit, receive, and process information in the form of speech, radio frequencies, image, radar, or other modes. Research is being supported in the areas of image processing; multidimensional digital signal processing in the multisignal, interference, and jamming environments; and adaptive, optimal, and nonlinear signal processing. There is also interest in hybrid analog/digital processor systems, possibly involving optical/superconducting elements for use with VHSIC type systems.

Chemistry

Chemistry is a diverse and wide-ranging area of research. Some programs are closely related to work going on in other disciplines, such as materials and solid-state physics. The following is only a partial list of topics of current interest to DoD.

Chemical/Biological defense. This program provides fundamental information and new concepts in support of new or improved defensive systems against the chemical and biological (CB) warfare threat and a sound deterrence system of chemical munitions. It also provides research in aerosol and obscuration sciences in support of the Army requirements for smokes and obscurants. The development of an integrated CB defense system is required to cope with the hazards of any potential CB threat environment. New concepts and a stronger scientific basis are needed from which to establish novel approaches to exploratory development related to individual and collective protection, detection and warning, decontamination and contamination avoidance, and training systems. Research is also needed in chemical deterrence to examine new agents, both lethal and incapacitating, and to evolve new concepts for delivery of chemical agents from a variety of munition systems. Improvements in smokes are required, including obscuration in infrared and millimeter wavelength regions of the spectrum, faster emplacement for quick-reaction protection, reduced toxicity, methods for eliminating smokes, and improved logistics of smoke agents and dissemination devices.

Laser chemistry. Research in this area concentrates on laser chemistry as a revolutionary means of conducting chemical synthesis, purification, separation and characterization. It was found that lasers can accelerate chemical reaction rates by orders of magnitude and that the purity of laser light can be used to selectively control the course of chemical reactions.

Electrochemistry related to rechargeable lithium batteries. DoD has supported research in lithium batteries for several years. Recently, patents have been awarded for lithium batteries which are rechargeable at room temperature, have high specific energies, and of course are much lighter than comparable lead-acid secondary batteries. Other research directions include ion-transport processes in fused and solid electrolytes as well as the basic mechanism of charge transfer at electrode surfaces.

Electrically conductive polymers. Electrically conductive polymers, such as polyacetylene, $(CH)_n$, are nonmetallic materials which display high conductivity and anisotropic electrical and optical properties. Along with piezo- and pyro-electric polymers, these materials are of interest for potential applications as sensors and detectors, and for applications in electronics.

Other topics in chemistry research are briefly described below.

- Rapid techniques for sensing, detection, and identification of explosives, chemical agents, and trace elements (with emphasis on using combustion diagnostics and advanced spectral methods to reveal space- and time-resolved temperatures and compositions)
- Quiet, efficient power sources with low thermal emission, including work on electrode processes and materials, electrolytes, and electrocatalysis
- New, more effective energetic materials including more efficient production techniques (It is noteworthy that a DoD-sponsored program in the area of boranes resulted in the 1976 Nobel Prize in Chemistry for W.N. Lipscomb of Harvard. Likewise, DoD support for H.C. Brown of Purdue in boronhydride chemistry resulted in his receiving the Nobel Prize three years later.)
- Investigations into the chemistry underlying the effectiveness of propellants and explosives
- Chemiluminescent reactions characteristic of upper atmospheric airglows and aurora
- Direct chemical means to produce coherent radiation, especially new chemical laser systems which will emit in the visible spectral region
- The chemistry of surface erosion of metal components such as turbine blades and gun barrels by hot gases; localized and rapid molecular reorientation characteristic of elastohydrodynamic lubrication; the mechanism of corrosion-inhibiting lubricant additives
- New fibers and fabrics affording greater protection against weather, flame, chemical agents, and electromagnetic radiation
- New antifouling materials for improved fuel efficiency and decreased maintenance of ships and submarines
- Chemistry of electronic materials including microstructural characterization and synthesis of high-purity, low-cost semiconductors
- Chemistry of electrochromic materials for new display devices

- Characterization of epoxies and high-temperature resins for new composite materials, especially durable, low-cost, processible thermosetting resins of high environmental resistance
- Chemistry and processing of ultra-high-strength polymeric materials; advanced molecular composites based on rigid rod-like ordered polymers dispersed in a randomly coiled polymer matrix. (AFOSR has supported the work of P.J. Flory of Stanford University on the physical chemistry of macromolecules for which he was awarded the Nobel Prize in chemistry in 1974.)
- Water-activated chemiluminescent materials for marking and rescue operations
- Enclosed-atmosphere monitoring and purification (e.g., for submarines)
- Formulation and characterization of high-strength-to-weight polymers for weight-critical vehicles
- New fire-retardant chemical materials for shipboard survivability
- Photochemical holeburning for high-density optical storage of information
- Photoelectrochemical energy production and storage devices for remote installations

Mathematics and Computer Sciences

Mathematics and computer sciences play increasingly important roles in solving military problems of engineering and management. Specifically studied are such functional areas as logistics, manpower planning, reliability and maintainability, remote sensing, vehicle and weapon control, decision making, command and control, communication, surveillance, and information processing. These areas are covered in a broad spectrum of scientific disciplines, described below.

Applied analysis. This area develops and applies the necessary analytical and computational tools to study, fundamentally, the basic equations of mechanics and mathematical physics. Particular attention is devoted to topics such as acoustics, structural mechanics, fluid flow, aerodynamics, control theory, C^3I (command, control, comunications and intelligence), and distributed processing in networks.

Statistics and probability. Statistics and probability are related to the broad issues of signal-processing, reliability, quality assurance, availability, maintainability, logistics, and computational issues in a non-deterministic environment. Concern is with methods of analysis which reduce costs and enhance reliability of equipment; within the broad area of communications and surveillance are included problems of C^3I and sonar signal processing. Work also is done on image processing for remote sensing and the statistical modeling of complex systems.

Operations research. Operations research has applications at various levels from policy planning and weapons system investment choices to tactical doctrine and efficient design of logistics systems. The techniques of war gaming, large-scale simulation, mathematical optimization, transportation problems, multicriteria decisionmaking, and risk analysis are used to improve such specific functions as combat planning, manpower scheduling, procurement, spare parts transportation, and allocation.

Computers and information processing. Some topics of interest in information processing are computer architectures for efficient distributed processing, controls to improve memory-access techniques, reliable digital transmissions, software cost reduction, simplified operating systems, large-scale scientific computing, and improved methods for parallel processing, artificial intelligence, and robotics.

Rising software costs, high error content, and the emergence of new technologies (such as mini- and micro-computers and distributed processing) are problems which the computer software community is facing. Through the formalization of software development, the search for new approaches to software problems and more intensive educational programs, DoD hopes to develop a scientific foundation for supporting the improved design, construction, operation, and maintenance of computer programs. This scientific foundation is expected to facilitate many developments of high priority to the DoD such as rapid software development and the design of custom integrated circuits.

A program has been established in artificial intelligence directed at developing "smart" computer systems with capabilities for mimicking man's capacities of common-sense reasoning and physical dexterity. It includes fundamental research on machine representation of world knowledge, language and speech understanding, computer vision and machine-controlled manipulators, and reasoning by analogy and inference. Directly tied to the artificial intelligence projects are efforts in robotics and industrial automation (see the description of the robotics program under *Mechanics and energy conversion*, p. 20).

A quantum advance in computer technology has been made in the area of highly parallel arrays. Although digital computers have been rapidly decreasing in size and cost, the increase in speed has been modest. A major breakthrough in this area was the use of synergism between algorithms and hardware to divide the computational load for many important mathematical operations among very large numbers of very simple computing modes with no overhead cost. Many previously intractable problems are now solvable.

Mathematics Research Center. As part of the mathematics program, the Army Research Office supports the Mathematics Research Center (MRC) at the University of Wisconsin. This provides a reservoir of talent to support the Army's mathematics needs as they occur in the in-house laboratories. MRC carries on programs in response to Army requirements, holds seminars on pertinent mathematical topics, and conducts residence programs for Army scientists at MRC and reciprocal residence programs for members of the MRC staff at Army Labs.

Engineering Sciences

Mechanics, Energy Conversion and Aeronautical Sciences

Within the disciplines of mechanics, energy conversion and aeronautical sciences are grouped both structures and fluid mechanics, as well as various aspects of power generation and conservation. In general, the engineering sciences may be considered to concentrate on the technologies dealing with the construction and operation of mechanical devices and structures. In this respect, engineering research is somewhat more applied in nature than some of the more fundamental work described in the previous sections. Mechanics and energy conversion is the second most heavily funded discipline within DoD.

Structures

Mechanics of solids. The mechanics of solids deals with constitutive relations, analysis of stress and strain, the development of experimental methods of examining materials, and the analysis of fracture, fatigue, deformation, and wear. During this past year, a complete analysis of the stresses in metal-forming processes was carried out for the first time. This work was made possible by developments in plasticity theory, large-deformation finite-element techniques, and increased computer size and speed. In general, however, additional work is needed in elastic-plastic three-dimensional analysis under static and high strain-rates of loading.

Structural mechanics and dynamics. Included within structural mechanics and dynamics are the analysis and design of structures which will support or withstand static and/or dynamic loads. In general, the goal for this area is the development of lighter, safer, more reliable structures. Among the diverse programs under way are investigations to improve machinery mounts for reducing vibration and studies examining the response of submarine hulls to underwater explosions.

An area needing additional work is the understanding of the rotor dynamics of helicopter blades. Problems in rotor dynamics include the understanding of the forces and moments produced on rotorcraft in both hovering and forward flight. The general problems of turbulence in boundary layers, flow patterns, unsteady aerodynamics, vortex dynamics, and wakes are of concern, as are such topics as vibration, balancing, and interaction of the rotor with the fuselage. A major problem in rotorcraft performance is noise, which threatens military operations by alerting enemy observers to approaching units, as well as causing pilot distraction and fatigue.

Figure 7 indicates some of the factors which would be considered in an analysis of a guyed tower. Such implanted ocean structures are affected by the loading conditions typical of the ocean environment and the ocean bottom soils. This type of analysis is necessary to predict the *in situ* life of ocean structures required for surveillance or logistical purposes.

Shock, vibration, wave propagation, and noise. The shock of gun firing, the vibration response of structures such as bridges and aircraft frames, and in general the whole problem of acoustical excitation as it relates to the failure of structures are of utmost importance.

There are also major programs currently under way dealing with submarine response to underwater explosions, as well as the radiated sound from, and echo reduction of, coated and uncoated submarines. Other investigations deal with the static, dynamic, and creep instability and fracture of shell structures in general (and pressure hulls in particular), the effects of laser pulses on structures, and advanced techniques in structural analysis by computer.

Tribology. Surface mechanics and tribology includes studies of lubrication, friction, and wear, which have obvious relevance to all mechanical devices.

Robotics. While this area is interdisciplinary, it does relate to solid mechanics and, therefore, it is included in this section. DoD has all the cost/productivity/morale problems of industry, plus a few special problems of its own. Not only must DoD manufacture systems, but it must support and maintain these systems across a far-flung theater of operations, frequently in hostile operating environments, using a largely unskilled labor force with a high turnover rate. Thus, the demand for intelligent, flexible automation (robots) is obvious.

The requirement for robots within DoD is matched by a national need for research and technology that supports the development of robots. For example, it is estimated that Japan currently has about three and a

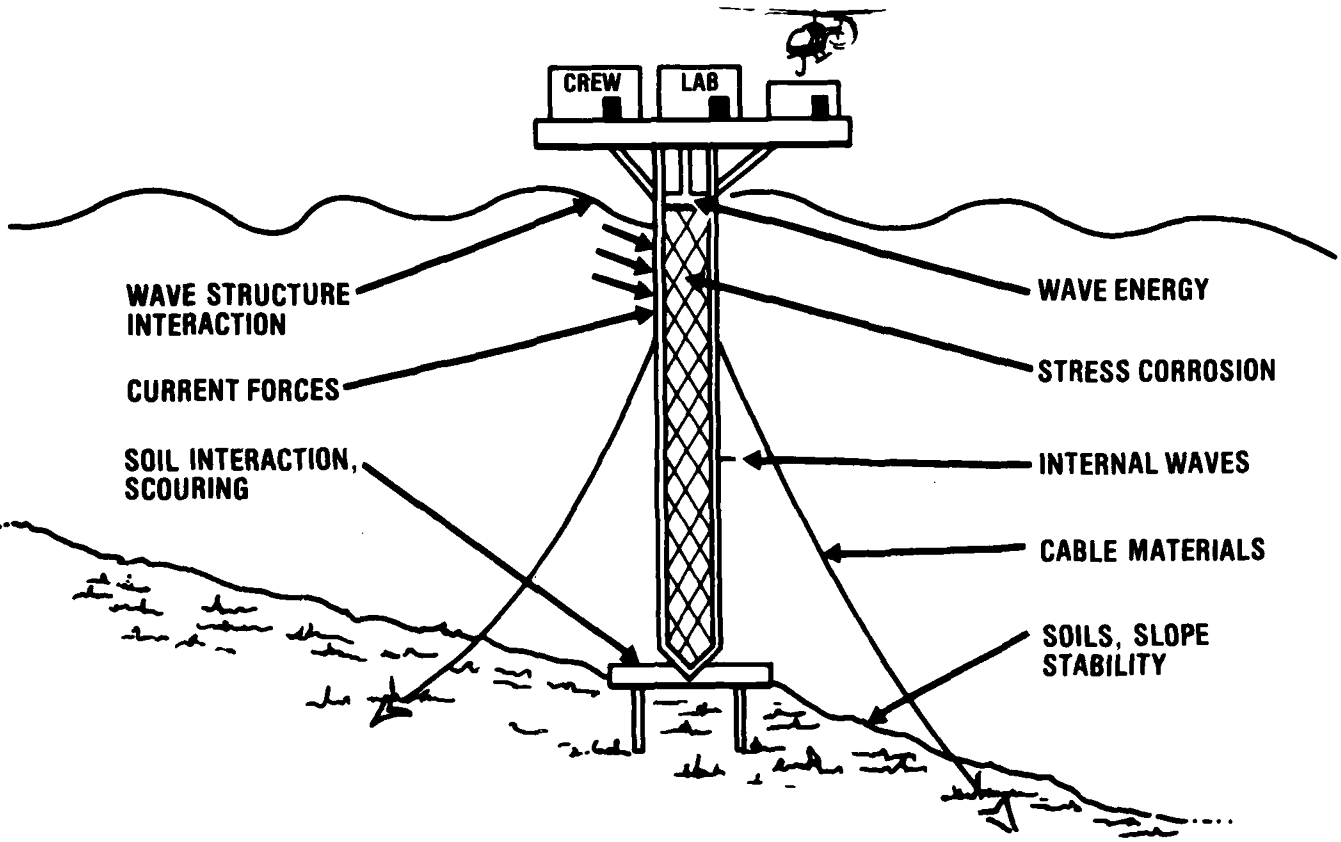

Figure 7. Analysis of a guyed tower.

half times as many robots in use as the United States. The DoD is pursuing research in areas that promise to advance future robotics technology.

Composites. The search for materials having greater strength-to-weight ratios, as well as improved response to shock and vibration, has concentrated on composites. While the microscopic structure of composites is more appropriately dealt with under *Materials,* the macroscopic responses of composite materials and their applications are covered in this area.

A typical program deals with the impact response of composite structures (fig. 8) where the work is centered on the significance of damage below the critical threshold, particularly under repeated compressive stress excursions.

Experimental Methods. Experimental methods include the design of instruments and techniques to characterize the phenomena described in the preceding topics. Strain gauges, holography, acoustic emission, and Fourier transform spectroscopy are examples.

Fluid mechanics. Within fluid mechanics falls the investigation of how systems interact with or use flowing fluids, either liquids or gases. (Aerodynamic systems are discussed under *Aeronautical sciences*, p. 22). Calculations of free and bounded flows are performed that address viscosity, turbulence, temperature, wall materials, and other parameters. These studies have applications ranging from the performance of compressors and turbines to the motion of a ship through the water. Figure 9 is a representation of the flow field around the hull of a ship.

A subcategory of this area is fluidic technology. Fluidics is the technology whereby devices operating on fluid flow, but using no moving parts, can be made to sense, amplify, and perform logic functions. Fluidics, now little more than 20 years old, has progressed from turbulent-flow devices to laminar-flow devices, with attendant gains in signal-to-noise ratios, sensitivities, and dynamic ranges of orders of magnitude (fig. 10). A whole world of applications has now been opened to fluidic technology, a technology which is inherently reliable, rugged, low cost, and for the most part, maintenance free.

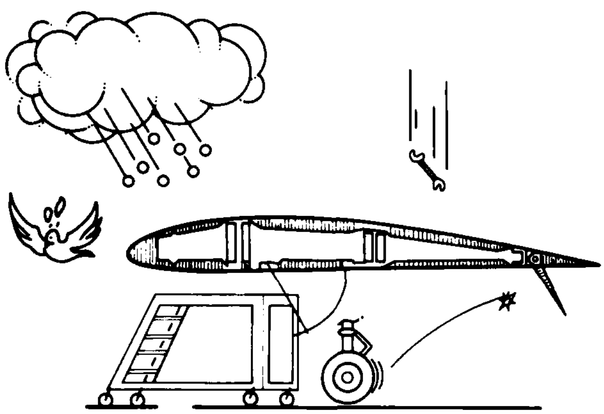

Figure 8. Impact response of composite structures.

Rocket/missile aerodynamics. Rocket/missile aerodynamics includes research leading to improved aerodynamic performance and stability for guided missiles. Increased maneuverability, for instance, requires better understanding of the separated, unsteady flow fields characteristic of flight at high incidence angles. The research aims to advance the methodology for predicting and analyzing aerodynamic and stability characteristics of general, slender shapes over large variations in Mach number and geometric orientation.

Aircraft aerodynamics. In aircraft aerodynamics, advancements are needed in analytical and numerical procedures applicable to the analysis of three-dimensional transonic and supersonic flow past complex shapes, including the possibility of multiple interfering bodies. Particular problem areas include specification of optimum computational grids and development of efficient numerical algorithms necessary to reduce the computer time and storage requirements for these complex computations. Phenomena arising from viscous-inviscid interacting flows can have significant and usually adverse impact on the performance of flight vehicles at some point within their design envelope. Shock-wave/turbulent-boundary-layer interaction is a problem in this class which is both of fundamental interest and of important practical concern. Similarly, the interactions of exhausting jets with surfaces which often occur with V/STOL aircraft can cause significant changes in control and performance characteristics. Figure 10 illustrates the flow field that is encountered

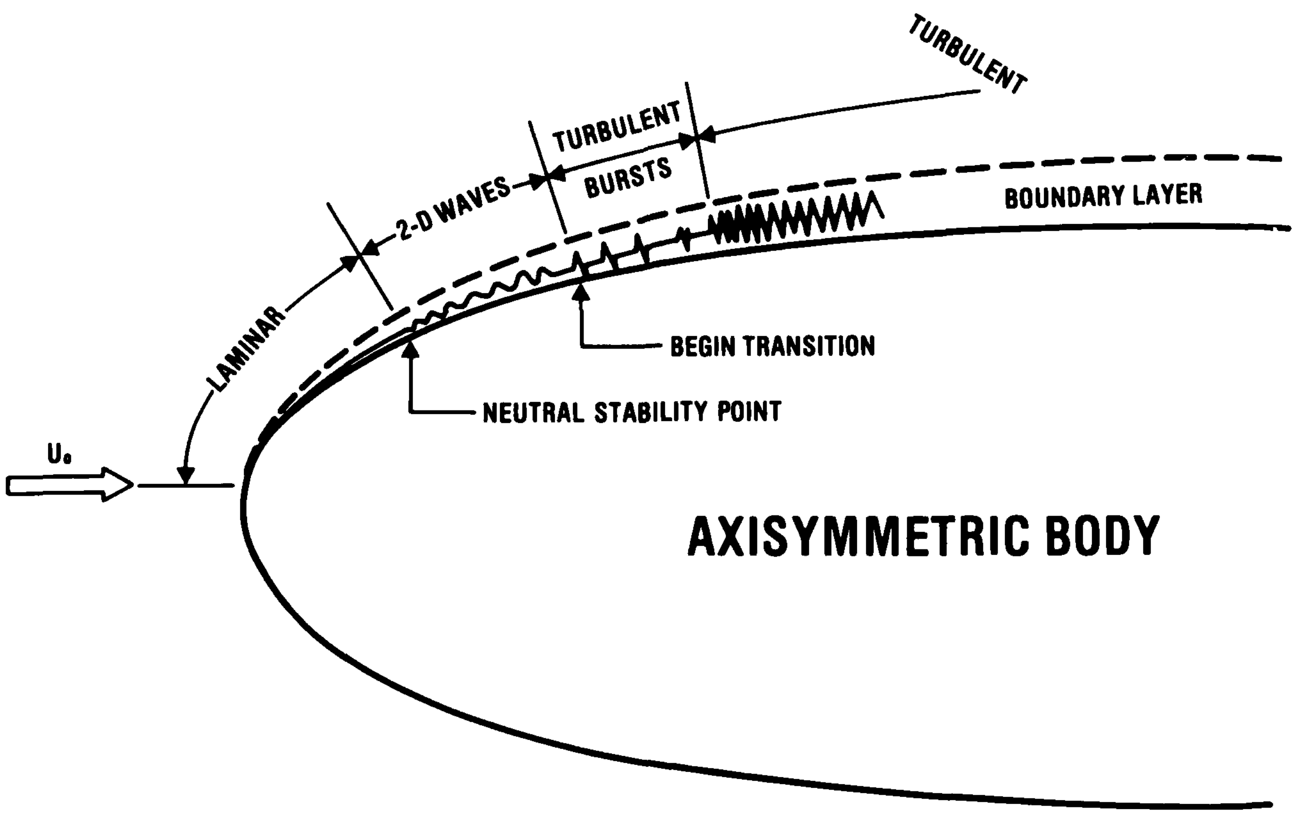

Figure 9. Flow field around hull of ship.

when this type of aircraft is in the vicinity of the ground.

Experimental flow field simulation. A problem under study in flow field simulation is the comparability of wind-tunnel experiments to flight. The effects of wind-tunnel walls tend to distort the normal flow patterns (fig. 11a and b), and the distortion can be particularly severe at transonic speeds. Using the concept of active wall control (fig. 11c), a joint Navy-Air Force research effort has been able to significantly reduce wall-interference effects in demonstration experiments.

Power plant internal flow. In addition to the external flow aspects of the problems discussed above, numerous problems of internal fluid dynamics and of reactive and nonreactive flow are associated with turbine and ramjet engines; these questions must be addressed for both the subsonic and hypersonic flight regimes. Examples of research topics that contribute to the solutions of problems in these regimes are strong viscous interactions, unsteady flow effects, aerothermodynamics and mixing in transitional shear layers. Activity associated with flow in rotating machinery includes the quantification of secondary flow effects, the prediction and control of compressor stall, the determination of inlet-flow distortion effects, the development of true three-dimensional theoretical analysis methods, and studies of forced vibration and aeroelastic phenomena.

Turbulent shear layers. Most flow fields of practical interest in aeronautical applications occur at conditions which result in the production and evolution of turbulence. In order to understand the properties of turbulent boundary layers on solid surfaces and free shear layers associated with jets and wakes, research is required into the fundamental characteristics of turbulence and its associated processes such as mixing. More accurate and dependable prediction of transition from laminar to turbulent flow would permit, for instance, significantly improved prediction, and possibly reduction of vehicle drag through improved design methodology. An Air Force Office of Scientific Research program on the origin and structure of turbulence is based on the recent discovery that deterministic concepts describe some aspects of the structure of turbulence. Experimental efforts in these areas are directed toward quantifying the role of large-scale coherent structures in turbulence models of reasonable generality and greatly increased accuracy.

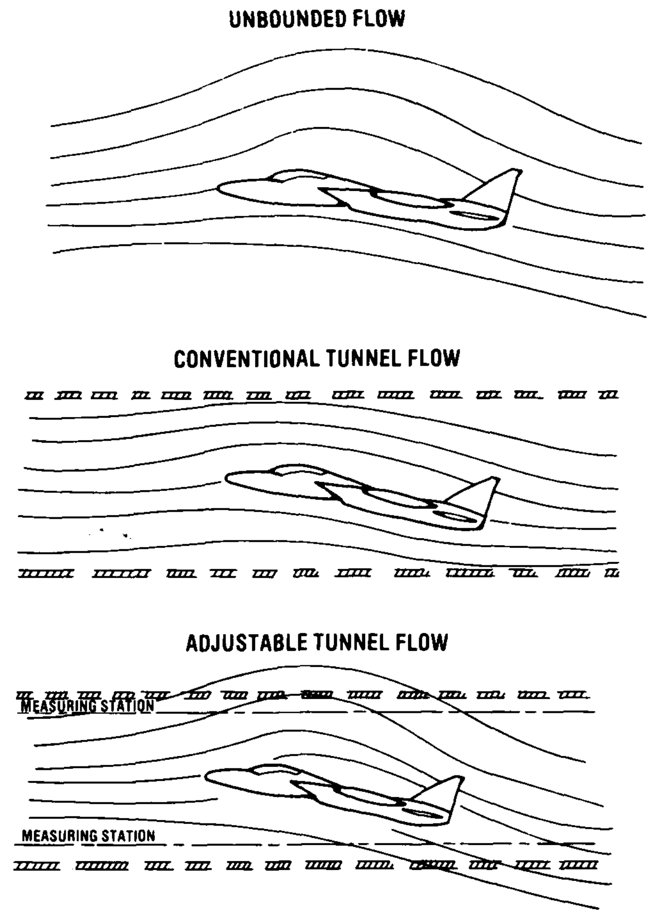

Figure 11. Effect of active wall control on wind-tunnel simulation: (a) unbounded flow, (b) conventional tunnel flow, and (c) adjustable tunnel flow.

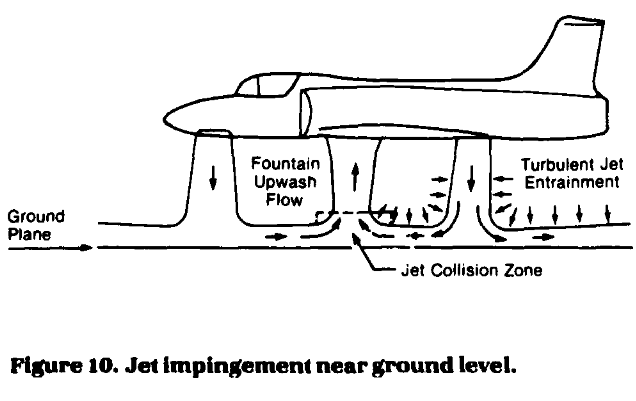

Figure 10. Jet impingement near ground level.

Power generation concerns not only the more efficient generation of electrical power, but also the improvement of vehicle and auxiliary power systems for aircraft, marine, and missile applications. This includes the investigation of more efficient use of fuel and propellants, flow and dynamic processes, and interaction phenomena.

In the area of electrical power, a program is under way to investigate the properties of high-temperature, high-pressure plasmas for pulsed magnetohydrodynamic power.

Energetic materials. Explosives are widely used in DoD weapons systems. Recent advances in fast laser diagnostics, many-body quantum theory, computional statistical mechanics and other areas are exploited by the DoD in basic research related to the discovery of new explosives, improved performance of energetic materials, and reduced danger of undesired explosive detonation.

Rocket combustion dynamics. Rocket combustion dynamics include a wide variety of processes associated with generating propulsive power through energy-conversion processes which are primarily self-contained. In general, attention is focused on means of achieving the maximum power within a given weight or volume constraint, while avoiding the hazards associated with explosives, low safety factors, and lightweight structures.

The expanding use of satellite systems and the advent of space-shuttle transport to low Earth orbit are generating increased applications for nonconventional propulsion systems to operate in space for purposes such as station keeping and orbital transfer. This has prompted Air Force research on concepts such as the pulsed magnetoplasmodynamic thruster, which can use modest amounts of power (e.g., from solar collectors or on-board nuclear reactors) to achieve specific impulses several times higher than can be achieved with chemical propulsion systems.

An improved understanding of rocket exhaust plumes is needed for a variety of systems applications. For example, plume radiation (ultraviolet, visible, infrared, and microwave) and radar cross sections can be used for detection and tracking. Plume technology is multidisciplined, requiring knowledge of thermophysical and optical properties of gases and particles as well as the chemistry and physics of these gases and particles in flowing systems. To achieve the research objectives, important progress is being made on noninterfering diagnostic techniques, such as Raman scattering, laser-induced fluorescence, coherent anti-Stokes Raman scattering, and optical techniques including optical tomography.

The environments in which upper-stage and space motors must operate are extremely rigorous, making high performance difficult to achieve, since extra propellant or inert hardware reduces payload weight. The Air Force has markedly increased performance through improved understanding of higher-energy ingredients, such as nitramines, and more efficient combustion of aluminum fuels.

Airbreathing combustion dynamics. An improved understanding and control of airbreathing combustion dynamic processes is vital to meeting the airbreathing propulsion needs of future Air Force systems. Airbreathing combustion dynamics concerns the generation of more efficient and reliable propulsive power through chemical energy-conversion processes using air as the oxidizer. This area is multidisciplinary and requires knowledge of the fluid mechanics, thermodynamics, heat-transfer, acoustic, and chemical kinetic properties of the fuel-air mixtures and their interrelated effects in reacting flow systems. To address the problems associated with this area, research efforts are currently under way and progress is being made in such topics as understanding and characterizing fundamental mechanisms and processes involved in fuel-air preparation in high-speed turbulent flows; flame holding and acoustic instabilities in ramjet and turbojet environments; ignition, combustion, and flame stabilization enhancement; ignition, combustion, and detonation attenuation and prevention; combustion of high-energy/high-density fuels; and combustion-generated emissions (e.g., soot) from conventional hydrocarbon and alternative fuels (e.g., shale oil and coal derived). Also, in view of the increasing scarcity of domestic fuel supplies and the vulnerability of foreign fuel resources, DoD is emphasizing the development of more efficient internal-combustion engines, including diesels and turbines. New and innovative concepts in carburation, combustion chamber design, fuel injection, and engine materials are being sought.

The Air Force Office of Scientific Research is supporting a university-industry program, the Air Force Program for Research in Aircraft Propulsion Technology, that attracts new graduates to aircraft propulsion graduate research. In this research program, graduate students participate in a course of study at a university and gain work experience at an aircraft gas turbine company. The universities involved in this program are MIT, Purdue, and Texas A&M. The companies are AVCO Lycoming, Detroit Diesel Allison, Garrett, General Electric, and Pratt & Whitney Aircraft.

Materials

The study of material properties is closely related to the type of work done as part of *Mechanics*, in that much of the behavior of a mechanical device depends on the materials from which it is made. The investigations carried out in the materials discipline span the spectrum from basic solid-state physics to mechanical engineering processes.

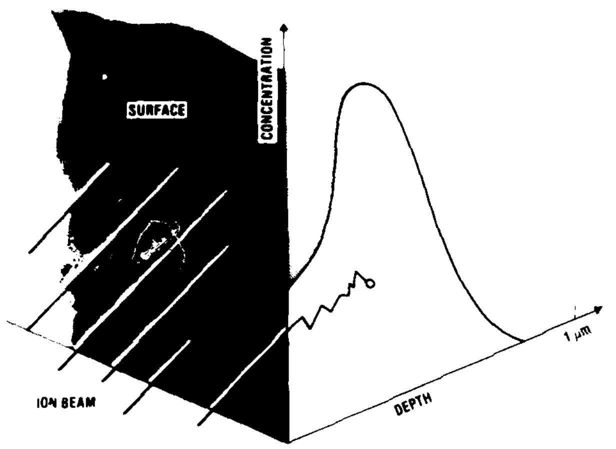

Figure 12. Ion implantation for surface modification.

Degradation and reactivity of materials: programs are concerned with corrosion, oxidation, hot gas erosion, environmental effects, protection of materials from severe environments, properties of surfaces and interfaces, thermodynamic and kinetic properties, and reactivity of materials formed by new technologies.

Mechanical behavior of materials: major interests are in fracture, fatigue, plastic deformation, creep, failure under shock loading, micromechanics of wear and fretting, and shock and laser pulsing.

Synthesis and processing of materials: programs involve fractional melting, molecular design of new materials, sintering, powder metallurgy, crystal growth, and laser welding and machining of metals (such as aluminum welding)

Effects of structure, defects, and composition on physical and chemical properties: research is concerned with relation between electronic structure and magnetic properties of alloys, structure and defects in solid electrolytes, high-pressure equation of state of metals, the role of hydrogen in metal alloys and hydrides, and properties of amorphous materials.

Work in ion implantation is aiming to modify the surface chemistry of materials (fig. 12). Such work has possible applications in corrosion inhibition, reduction of sliding wear and friction, improvement of fatigue lifetime, metastable alloys, modification of refractive indices, semiconductor doping and device fabrication, modification of superconductive properties, and simulation of neutron damage.

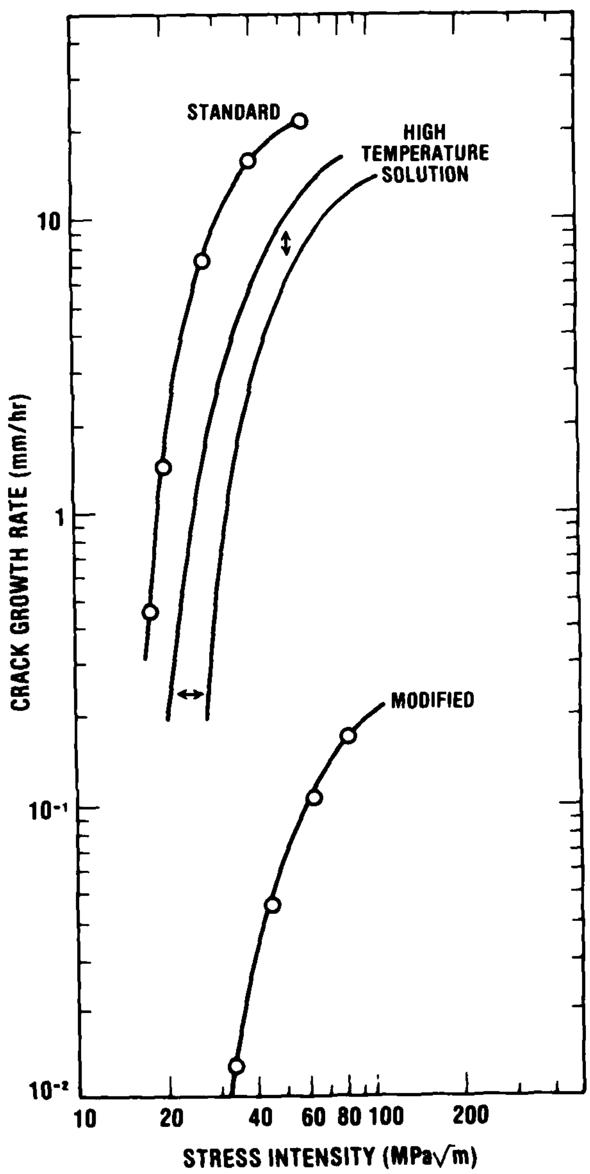

Figure 13. Crack growth in Alloy 718 at 650°C.

New concepts in testing analysis and simulation: of particular interest are characterization of point and boundary defects with positron annihilation, laser photoacoustic techniques, vibrothermographic examination of composite materials, inelastic electron tunneling, spectroscopic techniques for the study of corrosion, and the simulation of phase-equilibrium structures and defect structures.

Several classes of materials are currently of interest to DoD: metals, ceramics, composites, and polymers; most of the work done in the materials discipline falls into these areas. Application areas include ship, aircraft, and missile structures, machinery and propulsion systems, protective coatings, optical components and sensors, and armor and penetrators. There is a demand for new materials to perform new functions (e.g., magnetic amorphous metals, corrosion-resistant coatings for high-velocity vehicles), operate in extreme environments, and fulfill existing functions more efficiently and reliably (e.g., metal-matrix composites for stronger lighter structures, long-life turbine rotors).

Recent accomplishments in metals include (1) the development of nickel-base superalloys for gas-turbine engine applications where creep resistance is an essential property (fig. 13), (2) increased temperature capability for aluminum alloys using powder metallurgy techniques, and (3) improvements in the deformation and fracture behavior of beryllium. Hydrogen storage in metal hydrides is an area of interest not only for DoD but for the nation.

Work in ceramics continues the search for high-temperature capability with low weight and ease of manufacture for turbine engine parts. Composite of polymeric material work centers on the search for materials with high strength-to-weight ratios, low cost, and high durability. These properties are needed for structures such as helicopter rotor blades. Another possible application of composites may arise from the current work in intercalated graphite, which has a conductivity comparable to copper at less than 25 percent of the specific weight. Strong, lightweight electrical conductors are only one of several applications that may arise as this new material is studied further.

Environmental Sciences

- ***Oceanography***
- ***Terrestrial Sciences***
- ***Atmospheric Sciences***

Oceanography

Predictably, oceanography is of primary interest in the Navy. The objective of the work in this area is to provide knowledge of the ocean environment for the improvement of future naval systems and the most effective use of present systems.

Physical oceanography. Physical oceanography includes descriptive, analytic, and modeling studies of the open ocean environment. Emphasis is on the time variability of the ocean, with the long-term goal of developing a predictive capability for the three-dimensional time-varying ocean structure. The scales of importance here are particularly those not studied by the National Science Foundation or the National Oceanographic and Atmospheric Administration—i.e., horizontal dimensions less than 200 km and time intervals less than two weeks. Other program emphasis is on filling gaps in the National Physical Oceanography program that are of importance to the Navy. Programs include studies of the upper ocean, including internal waves, the mixed layer, fine structure and microstructure, horizontal shear currents, atmospheric forcing, and turbulence; development of new oceanographic instruments, particularly expendables, and those for use by ships of opportunity; synoptic oceanography; and remote sensing, including satellites and high-frequency over-the-horizon radars. Particular attention is given to interdisciplinary research such as the bottom benthic boundary layer (with geology and biology), Gulf Stream rings (with biology and chemistry), the marine boundary layer (with meteorology), and tomography to monitor ocean weather (with acoustics).

Chemical oceanography. Three general problem areas are dealt with under chemical oceanography.

- The processes and mechanisms governing the inorganic composition of seawater including chemical composition, physical and chemical properties, and the interactions both in the solution phase and at solution-solid or solution-gas interfaces
- The chemical fluxes through the marine environment, including the vertical motion of particulate matter; the exchange of gases between the atmosphere and the sea; the solute flux at the sediment-seawater interface; and the flux of organic matter with all its manifestations in marine chemistry
- The impact of life processes (photosynthesis and respiration) on the chemistry of the oceans, including their impact on the distribution of major seawater components; processes, rates, and mechanisms of biological activity on trace metals; and inorganic-organic complexing relationships

Specific topics being considered include the behavior of materials in the sea (corrosion and fouling), pollution, underwater visibility, prediction of acoustic reverberation, and ocean-surface phenomena including the exchanges of gases and surface films. All aspects of the program are coordinated in a major new investigation that is both a new area of scientific research and an area of great Navy interest: the short-wavelength (fractions of a kilometer) distribution of trace elements, reduced gases, and dissolved organic matter. Analytical chemical techniques have only recently been developed to measure these components with meaningful signal-to-noise ratios and normally at intervals of hundreds of kilometers. The Naval interest is in chemical wake trailing and requires the development of underway analytical and sampling methods plus an understanding of the sources, sinks, and chemical pathways of these trace components of seawater.

Marine geology and geophysics. Primary emphasis in this program is to develop a detailed physical understanding of the amplitude, coherence, and mode of propagation of acoustic energy in the ocean bottom at frequencies down to about 1 Hz. Because many areas of the ocean are bottom limited (i.e., for near-surface acoustic sources, the long-range acoustic propagation paths encounter the sea floor), significant amounts of acoustic/seismic energy interact with and are propagated through the oceanic sediments, crust, and lithosphere. This interaction affects the operation of Navy surveillance systems as well as bottom-bounce sonars. The effects of bottom interaction become more apparent as frequencies become lower. At very low frequencies, it may even be possible to detect signals propagating through the ocean bottom from targets when no waterborne arrival exists. Projects are focused on determining (1) the compressional velocity, shear velocity, velocity anisotropy, density structure, and attenuation of the ocean sediments, crust, and lithosphere, (2) the variation of these parameters both laterally and with depth, (3) the effect of the variability of these parameters on seismic propagation on the ocean bottom, and (4) the interaction of the ocean bottom with acoustic energy propagating in the ocean volume. These projects include modeling techniques, inversion studies, seismic/acoustic experiments, ambient-noise studies, and down-hole seismograph experiments in the seafloor.

Studies of benthic boundary-layer processes will provide data on the "benthic storms" that occur during that 5 percent of the time when dynamic bottom currents exist. These currents will destroy Naval seafloor systems designed for a tranquil abyssal environment. This program will quantify the magnitude and variability of deep ocean currents, predict the response of cohesive, biologically altered sediment to the imposed stresses, and examine the role of benthic boundary currents in ocean mixing of such factors as heat, salt, chemical traces, and sediment. The results will enable the prediction of seafloor physical properties and their influence on cables, structures, and potential concepts of nuclear waste disposal using the sea bed.

A third program area is the study of oceanic crustal structure, gravity field, magnetic field, and bottom bathymetry. The thrust here is (1) to understand the physical processes that form the oceanic crust at ocean ridges, that modify its characteristics with time (distance from ridge), and that cause its destruction in trench subduction zones; (2) to use this background information based on plate tectonic theory to select critical areas where field experiments can test the predictability of sediment thickness, acoustic velocity structure, and crustal layering; (3) to determine where these crustal properties can be measured in anomalous bottom regimes such as fracture zones and oceanic plateaus; (4) to understand the genesis of various types of seamounts and other bathymetric features and ultimately be able to predict their location and size; (5) to extend the use of marine magnetic measurements to determine the cause and effect of marine magnetic anomalies; and (6) to develop and extend techniques for analyzing variation of gravity and the resulting geoid which are essential for accurate mapping of the earth, inertial navigation, improved missile targeting, undersea navigation, seamount detection, and mapping of ocean currents, fronts, and eddies.

Ocean biology. Ocean biology encompasses all aspects of biological research in the ocean that are of concern to the Navy. This includes research in biological oceanography, i.e., the study of the oceans themselves from the standpoint of the organisms found there. An example might be the study of plankton and their interactions with the physical environment by the use of high frequency acoustics. A second type of research is marine biology: the study of the biology, physiology, and biochemistry of organisms that live in the sea. Examples might include studies of cellulose digestion in shipworms (wood boring molluscs) and in the gribble, the second major destroyer of wooden piles in piers. In both cases, this program conducts basic research to learn to break up that specific part of the biofouler's life cycle and thus allow for long-term protection of the Navy's 150 miles of wooden piers.

Ocean biology is subdivided into the following parts: biodeterioration, fouling, and slime films; bioacoustics, including the study of aggregations of volume-scattering organisms, and the distribution or behavior of large sound-producing animals such as cetaceans (whales and porpoises) and pinnipeds (seals and walruses); the effects of sea-floor sediment/fauna interactions on the physical properties of sea-floor sediments; the area, depth, and seasonal distribution of bioluminescence as well as its temporal and spectral signature; plus small programs on noxious marine organisms (such as sharks and venomous organisms) and the perception of weak electric or magnetic fields by marine species.

Ocean technology. The ocean technology program is divided into three major areas. The first addresses the oceanographic community's need for new instrumentation. Advances in oceanographic science are closely correlated with instrumentation development, and this portion of the program seeks to meet this need by developing and applying new engineering technology to oceanographic research problems. An example is a project to establish the limits of underwater photographic and television systems with respect to image resolution and the area that can be imaged, as a function of seawater properties.

The second ocean technology program area provides direct ocean engineering support for oceanographers. Investigators in this area deal with existing or near-term oceanographic problems and work closely with scientists to obtain the desired data. Examples of ongoing work include a cable analysis project to assess the feasibility of re-entering a deep-sea drilling hole without the use of a drilling ship, investigations of magnetic-bubble memory applications, and improved tape-recorders for high-data-rate ocean-bottom seismometer development.

The third portion of the ocean technology program addresses basic research questions in Navy ocean engineering. Examples of projects in this area include the introduction into deep-ocean design wave-force analysis of breaking-wave effects on cylindrical members, studies of the interaction of waterfront facilities with mean channel flows and their effect on dredging requirements, development of analytical processes to minimize the computer time required for analysis of cable payout and retrieval, and the development of unmanned, air-deployable, deep-ocean (6000 m) subsurface instrumentation moorings for open ocean and Arctic applications.

Ocean optics. Ocean optics is a relatively small program directed toward gaining sufficient understanding of optical processes so that optical propagation parameters can be predicted from geological, meteorological, biological, and oceanographic data. Optical properties are geospecific and time varying, so that random measurements make no sense. Emphasis is on determining how optical properties and measurements can be used to predict oceanographic parameters effectively (for example, remote sensing by satellites).

Ocean acoustics. The ocean acoustics program is directed toward determining the fundamental constraints which the ocean environment places on the use of underwater acoustics by the Navy. In particular, the program accelerates the transfer of ocean and seafloor knowledge from other areas of the oceanography program into Navy system use. Three major areas are associated with these constraints: the ocean bottom, the volume, and the surface. Recently, increased emphasis has been placed on bottom acoustics because the bottom becomes increasingly important at lower frequencies. Theoretical emphasis is on lateral variability and anisotrophy in bottom-propagation models. Volume acoustics is concerned with theoretical analysis and modeling of ocean phenomena on acoustic propagation. In the area of random wave propagation, greatest emphasis has been on the clarification of the influence of internal waves and fine structure on sound transmission. Acoustic tomographic experiments are under way to develop ocean-basin mapping techniques to define and track ocean fronts and eddies. Here, the acoustic inversion problem in producing synoptic, real-time sound velocity profiles is particularly difficult. Surface acoustics is concerned with achieving a detailed physical understanding of how sound interacts with a rough surface that is not easily characterizable in a theoretical sense.

Research vessels. Twenty percent of oceanography funding is devoted to research-vessel operations for at-sea experiments, or to programs for upgrading research-vessel equipment. These are primarily Navy-owned vessels operated by academic oceanographic institutions. The equipment-upgrade program to enhance the effectiveness of these research vessels encompasses two areas: mid-life replacement of hull equipment (such as AC generators, bow thrusters, and oceanographic winches) and installation of new scientific equipment to increase the scientific productivity of the research vessels and to open new fields of ocean research to the academic community. Five examples: Multibeam echo sounders will be installed on at least two of the research vessels. These will provide a geomorphic picture of the sea floor instead of the single-track data currently available. Doppler velocity measurements of upper ocean currents, combined with precise Global Position System navigation data, will provide a new picture of the upper ocean dynamics, particularly near ocean fronts. Long towed seismic arrays will facilitate studies of sediment, crust, and mantle layering and heterogeneity. New acoustic and TV sensors will define the precise distribution of plankton, rather than the previous smeared picture provided by net tows. Towed chemical pumping systems and, eventually, *in situ* sensors will provide new concepts in the distribution of ocean trace elements, reduced gases, and dissolved organic matter.

Terrestrial Sciences

Research in the terrestrial sciences is needed to fill gaps in our understanding of and ability to predict processes governing the structure and dynamics of the earth, snow and ice, coastal and Arctic regions. Requirements for such knowledge stem from the obvious needs of combat operations, surveillance, navigation, environmental prediction, geophysical surveying in strategic areas, and military construction and other public works. However, the possible civilian spin-offs of such programs are many, including earthquake prediction and hazard mitigation, waste disposal, navigation improvement, discovery and assessment of energy and mineral resources, Arctic transportation and resource development, mapping techniques, construction of roads and buildings, control of waterways, and remote sensing from space of terrestrial conditions (such as soil moisture, vegetation cover, terrain roughness, coastal waves, currents, tides and navigation hazards, and geoidal changes).

Properties of earth materials. Properties of earth materials cover soil and rock mechanics and dynamics, including snow and ice. Topics of particular interest are (1) constitutive relationships under static and dynamic loading, including two- and three-phase systems, (2) methods for testing and measuring earth properties *in situ* (at the earth's surface or down bore holes) and for using relationships between these measurements to determine unique solutions to geophysical survey data, and (3) stress-wave propagation in unconsolidated, anisotrophic media (soils and marine sediments). Also of interest are topics in soil chemistry and novel measurement techniques such as remote sensors.

Geophysical remote sensing and mapping. Novel concepts are explored for measuring and interpreting surface and subsurface properties and anomalies on land and in Arctic and coastal regions, geodetic modeling, location of submerged navigational hazards, terrain modeling, sensor modeling, feature signatures and location, as well as image (and other) sensor interpretation and processing for automated mapping processes. Various applications of seismic sensors are important for remote battlefield and shallow-water surveillance and intelligence gathering (including nuclear test detection) as well as for estimating earthquake risk at military installation sites. Applications of new technology in cryogenic instruments for surveillance and improved geophysical surveying are important for detection of weapons systems. New techniques are explored in geophysical signal processing and inverse problems.

Earth-fluid dynamic processes. Work being supported in this area revolves around the need to understand (1) the processes which cause localized severe flooding, (2) wave and tidal action on port and harbor installations and on beaches, headlands, inlets, and other areas of amphibious operations, (3) the behavior of natural and battlefield-induced dust as a function of soil properties, and (4) vehicle-induced susceptibility of erosion of terrain. Also included is the development of an understanding of air-ice-sea-land interactions important for operations in Arctic regions.

Geomagnetic and electromagnetic field variability. Under this heading comes the study of external and induced geomagnetic and electromagnetic fields and their variability, for temporal and spatial prediction in magnetic anomaly detection operations, mine warfare, shallow water surveillance, and passive geophysical navigation. Also performed under this heading are modeling and field studies on the effect of rock electrical conductivity on the induced geomagnetic field and on the spectra of environmental electromagnetic ambient noise.

Arctic research. This program is focused toward an enhanced knowledge of the Arctic environment. Scientific disciplines of particular interest are meteorology, acoustics, geophysics, remote sensing, and oceanographic engineering. In recent years the program has shifted geographic emphasis from the oceanic area north of Alaska to that part of the Arctic Basin north of Greenland. Research is traditionally carried out from manned camps on the pack ice. In the future, research emphasis will be in the marginal ice zones.

Coastal sciences. The coastal zone is a "triple point" junction of land, sea, and atmosphere and this requires research which spans a variety of disciplines. Topics of interest include: improved wave and tide prediction models; physics of coastally-trapped waves; time evolution of bar and berm topography; physics of the coastal marine atmospheric boundary layer; acoustic propagation in shallow water; physical oceanography of confined regions such as straits.

Atmospheric Sciences

The atmosphere has always imposed limitations on military operations and weaponry. As these operations and weaponry become more automated, computerized, and sophisticated, the atmospheric limitations become more severe and make necessary a greater emphasis on atmospheric sciences to solve the problems. The problems concern launch conditions, precise navigation of big missilery, and the ability to "see" through the atmosphere in the sense of transmission, not only in the visible, but also in the ultraviolet, infrared, and microwave wavelengths. Deterioration of the "seeing" conditions is due to changes in the concentration of the variable gases of the atmosphere (water vapor and ozone), various kinds of particulates (dust, haze, precipitation), changes in refractive conditions, and fluctuating atmospheric radiation backgrounds, such as the aurora.

Cloud and aerosol physics. Cloud and aerosol physics is concerned with the characterization of natural and synthetic solid and liquid particles in the atmosphere; the physical, chemical and electrical processes resulting in the formation, growth, and dissipation of natural aerosols; instrumentation techniques; and usable models by which to predict and specify atmospheric conditions.

Atmospheric effects on transmission. The study of atmospheric effects on transmission entails active and passive measurement of the following properties and constituents of the atmosphere from the millimeter through the infrared and visible to the ultraviolet portion of the spectrum: line shapes, line broadening effects, temperature dependence, absorption, scattering and refractive indices, and the effect of turbulence on electromagnetic propagation. Modeling for the effect of these processes on atmospheric transmission phenomena is also required. This kind of research is most necessary for improved performance of modern weaponry that depends on electro-optic systems for guidance and target seeking.

Small-scale atmospheric processes. Studies of small-scale atmospheric processes include the following: predictions of mesoscale flow including the effects of topography, adiabatic heating, and internal boundary friction effects; modeling of temporal and spatial variability over two hours in time and 40 km horizontal by 5 km vertical in space; models for studying the transport, diffusion, and interaction of natural and man-made materials released into the atmosphere; and cloud models.

Middle atmospheric processes. Studies of middle atmospheric processes include the following: diurnal, seasonal, and spatial variations of atmospheric constituents at the atomic and molecular level; atmospheric dynamics including diffusion, wind, waves, heave, and striations; the interaction of radiation with the atmosphere; electrical phenomena in the atmosphere; coupling of upper and lower atmospheric processes through the middle atmosphere.

Atmospheric sensing and probing. Atmospheric sensing and probing requires instrumentation, techniques, and modeling of the optical properties of the atmosphere including natural and man-made aerosols, remote measurement of standard meteorological parameters, and the use of satellites and remotely piloted vehicles for meteorological observations. This instrumentation includes millimeter-wave sensing of the atmosphere for stratification and variability of temperature, density, aerosols, lidar, water vapor, and other molecular constituents.

Earth-limb measurements of solar transmission. Satellite techniques are used to look at the solar transmission at satellite sunset and sunrise to precisely determine very-high-altitude refraction. The information is used to more precisely determine star positions, which are used for mid-course correction of large weaponry navigation.

Development of longer-range and more accurate weather forecasts. Climate dynamics, solar-terrestrial connections, and the coupling of upper and lower atmospheric dynamics are studied to help improve and extend the period of reliable application of Numerical Weather Prediction (NWP) techniques; other studies focus on planetary boundary layer (PBL) effects, atmospheric moisture effects, and energy transport processes and effects. These studies are most important to accurate weather forecasting and are necessary to develop better techniques and to understand the basic physics necessary to improve forecasting models.

Atmospheric radiative processes. The study of atmospheric radiative processes includes the measurement and modeling of upper atmospheric processes that control infrared and optical emissions in auroral and nuclear-disturbed atmospheres; the determination of spectral, spatial, and temporal variability of airglow emissions with and without solar illumination; and the measurement of excited-state emissions resulting from high-velocity plume-atmosphere interaction. These measurements are necessary to assess and evaluate the feasibility and effectiveness of various through-the-atmosphere optical and infrared sensors for detection, surveillance, communications, and identification.

Upper atmospheric/ionosphere composition and structure. Included in upper atmosphere studies are measurement of chemical constituents of the upper atmosphere in the D, E, and F regions; identification of new, probable, suspected, or unsuspected chemical species in the chemical structure of the upper atmosphere; measurement and modeling of ionospheric structure and behavior, especially with respect to dynamics and dynamic influences on compositional structure; measurement and modeling of ionospheric density structure and scintillation phenomena. These studies are most important to modeling the effects of the upper atmosphere/ionosphere on communications, surveillance and warning systems and the development of new capabilities.

Marine boundary layer. Marine boundary layer research involves the study of air/sea interactions, in particular, the micro and mesoscale transfer of momentum, heat, and moisture between the atmosphere and oceans and the modeling of these processes. In addition, aerosol distribution, fog formation, visibility, and various factors affecting the formation and maintenance of the marine boundary layer are of interest.

Life Sciences

- ***Biological and Medical Sciences***
- ***Behavioral and Social Sciences***

Biological and Medical Sciences

Research in biological and medical sciences primarily supports DoD's efforts to protect and conserve its most valuable resource, man. The prevention and treatment of militarily significant diseases and the care of combat wounded are classical concerns of this area; these concerns are compounded by the emergence of new disease threats in strategically important areas of the world and the ability of enemy threat systems to produce a variety and severity of combat injury unseen in former conflicts. Of relatively more recent concern are the physiological demands imposed by developmental weapon systems and modern doctrine. These demands approach and may exceed the limits of human tolerance, thus making man the limiting factor in modern systems design.

Human hazard protection and performance effectiveness. Modern combat doctrine and weapons systems make heavy demands upon military personnel. Work in this area aims to provide the human biological data bases needed to protect and support human beings in combat.

The major goal of interest in this area is the determination of the biological effects and human tolerance of such military environmental stresses as non-ionizing radiation, toxic emissions of weapons systems, physical force environments (vibration, impact, and acceleration), and environmental extremes (heat, cold, high altitude, deep submergence). Knowledge of the distribution and absorption of electromagnetic energy at tissue and cellular levels is necessary to determine safe exposure levels both for regulatory purposes and to ensure optimal human performance in the presence of such radiation. This is particularly critical given the development and proliferation of pulsed and high-frequency (millimeter and near-millimeter) systems, which may in some circumstances produce nonthermal effects in certain biological tissues. Such effects have been reported by Eastern bloc researchers, though not uniformly reproduced in our own laboratories. Investigations into the biological effects of physical and environmental stress are needed to provide design criteria for safer, more effective military systems. Such work extends the concern with the man-machine interface beyond static anthropometry to the physiology of perception and performance, and the dynamics, physical and psychological, of the interaction of the operator and the developmental system.

Doctrinal concepts likewise place great demands upon human physical and neurophysiological capabilities. Studies of physical and mental fitness, nutrition, and unit effectiveness seek to avoid or overcome the effects of fatigue, isolation, rapid translocation, and continuous performance, demands imposed by modern combat.

Another vital interest is the defense of the individual against chemical and biological (CB) weapons. These investigations deal with detection of CB agents, decontamination of exposed personnel and materiel, and treatment of exposed personnel. This last topic requires understanding how the CB agent acts against the body. A typical nerve gas agent is an anticholinesterase which inhibits the production of the nerve impulse transmitter acetylcholine. More research needs to be done to more fully understand the action of this and other transmitters. A related topic of interest is innovative materials for human protective clothing and equipment.

Food and Nutrition Sciences. The DoD has a continuing interest in better ways to preserve, protect, and deliver food to the combat field to include extension of ration shelf life, reduction of weight and bulk, and protection of food from natural contamination and pests. Future interest areas will include determination of possible interactions between foods consumed and physical and mental performance. Such studies will involve collateral investigation of human food behavior/acceptance under combat stress conditions.

Infectious disease. Major topics in this area include the epidemiology, microbiology, immunology, and pathophysiology of infectious diseases of known or possible military significance. The list of diseases of concern is long and worldwide in scope. We are primarily concerned with understanding tropical diseases, potential biological agents, and diseases which hamper mobilization and deployment. Knowledge of the interactions among the human host, the infecting agent, and vectors (if any) are essential to development of control and avoidance techniques. Entomological studies of disease vectors are also important. Pharmacological studies are undertaken to help in producing safe and effective curative and therapeutic drugs.

Diseases of major concern in this area are malaria, dengue, plague, scrub typhus, leishmaniasis, hepatitis, Rift Valley fever, Ebola/Marburg, Lassa fever, diarrheal disease, respiratory disease, schistosomiasis, and arbovirus infections.

New techniques emerging from basic research in biology and medicine will be increasingly exploited to advance knowledge in this area. Recombinant DNA methodology provides a basis for improved strain definition and production of immunological reagents, as do monoclonal antibody techniques (fig. 14). The ability to cultivate fastidious organisms *in vitro* (as with malaria) will substantially advance abilities for field and laboratory assessment of infectious diseases. Knowledge of host pathogen relationships in viral infection will hasten development of antiviral compounds. There is need to exploit these newer scientific tools to address military infectious disease problems. Rational approaches to drug synthesis have revolutionized antimalarial therapeutic pharmacology; these concepts need to be extended to other diseases of military interest.

Of special military concern is improved knowledge of the epidemiology and geographic distribution of infectious disease. On this data base will depend future programmatic and operational decision making.

Combat casualty care. Combat trauma is, of course, of particular military concern. In addition to classical interest in the pathophysiology of injury, and exploration of new bases for surgical and ancillary care, there is increased interest in the epidemiology of wounding and the physiology of wound healing. Implicit is a need for more complete understanding of relevant normal human physiology.

A fuller understanding, for example, of neurophysiology, in addition to providing a firmer basis for defense against chemical warfare agents, is needed for better, more definitive early field care of specific types of injury.

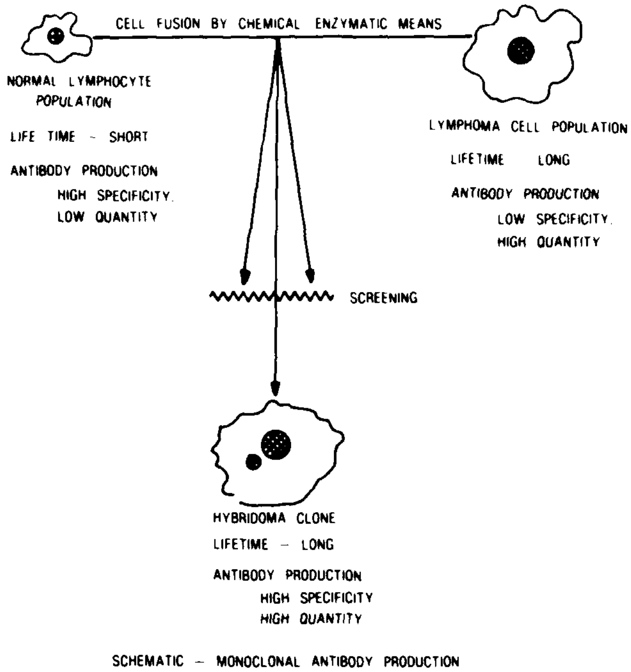

Figure 14. Monoclonal antibody productlcn.

Other topics of interest in this area include improved diagnosis of injury, anesthesia, and the basis of traumatic shock. Much recent interest centers on the possible role of endorphins in ameliorating pain and shock.

Recent work on blood and blood substitutes has centered on freeze-preservation techniques, shelf-life extenders for preserved blood, stroma-free hemoglobin for possible battlefield use, and development of techniques for removing blood group determinants from whole blood, thus providing "universal donor" blood on demand.

Historically, much of the effort in this area has aimed at improvements in hospital-based care. New directions are emerging toward development of knowledge needed for early care of the wounded, for care rendered in remote areas without highly skilled personnel, and for improvements in the efficiency of medical care systems, both field and fixed.

Economic biology. A relatively small effort is devoted to the avoidance or prevention of economic loss due to the action of biological organisms on military material. Integrated pest management approaches the problem of insect infestation of stored food stuffs, for example. Other interests include mycological organisms which cause deterioration in textiles and other materials.

A related effort derives from concern about the effect of military production facilities and systems on ecosystems.

Behavioral and Social Sciences

The arena in which the armed forces must function is becoming increasingly complex. Weapon systems are more sophisticated, the speed of battle has increased, and the demands on the individual are mounting. Even the pressures of changes in our social system during peacetime are being felt by the military. Therefore, DoD supports research in the behavioral sciences that aim at fuller understanding of the most complex device of all, the human being.

Organizational effectiveness. The organizational effectiveness program aims at enhancing the performance of crews, teams, and other groups by helping to determine principles governing human interactions, ranging from informal face-to-face encounters between individuals to formal interactions between large organizations. Research in this area aims to increase understanding of the ways interactions develop and the relationships between human interactions and organizational effectiveness. Research in the program falls into four clusters.

Adaptation in organizations: research on the factors that determine how individuals adapt to work in organizations and the ways in which organizations can be changed to enhance work performance and satisfaction

Intergroup relations: research aimed at improving our understanding of how individuals with diverse ethnic and cultural backgrounds can be merged into effective teams, crews, and units (conditions of close confinements such as on board ship are of particular interest; the effects of integrating women into the military continue to be a major area of emphasis)

Leadership and management: theoretical and empirical research with the ultimate aim of improving programs on leader and manager development

Personnel and training. Research in personnel and training will enable the Services to more efficiently obtain and use qualified personnel. To this end, research efforts are dedicated to methods for assessing people's potential and competence, for rapid, efficient training. Two considerations focus the effort. First, it appears that the best opportunities for increasing the efficiency of assessment and training lie in the individualiation and automation of both processes. Second, the increasingly technological character of many military jobs suggests that cognitive and information-processing skills and aptitudes should receive major emphasis. These considerations have led to the support of research on objective, quanitifable theories of cognition and information-processing performance of the types required on military jobs. Much of the same research is also concerned with the methodologies needed to assess and individual's cognitive aptitudes and competencies, and improving those competencies through training. The work on those theories and methodologies falls into four main groups.

Theory-based personnel assessment. Research in this area should lead to more efficient and valid psychological assessments for selection, classification, training, and advancement.

Information-processing abilities. Exploration of individual differences in information-processing abilities is aimed at a clearer understanding of aptitudes and other abilities important in military jobs.

Instructional theory and advanced training systems. Work on instructional theories is being undertaken with a view to their application in generative, knowledge-based, automated training systems.

Cognitive processing. A fourth area aims to model the cognitive processes and structures underlying skilled performance in real-world tasks with complex information-processing demands.

Engineering psychology. Programs in engineering psychology are concerned with assuring the effective performance of personnel working with the high-technology equipment characteristic of modern military systems. We seek better fundamental understanding of human perceptual, decision making, and psychomotor behavior, in order to develop general guidelines for the design of compatible interfaces between people and their machines. We are particularly interested in research that shows how personnel perforance can be improved through simplified procedures and built-in performance aids. We are also interested in the development of equipment design principles that will lead to reduced training requirements. The programs are organized into three clusters.

Man-machine system interfaces. This area focuses on the human control of systems and vehicles. Current emphasis is on advanced computer-aided control.

Visual and auditory perception. This work aims at broadening the data base and advancing selected aspects of perceptual theory. We are phasing out threshold-level studies and are siginificantly increasing attempts to understand more complex suprathreshold situations involving perception of multidimensional signals. This shift is motivated by new requirements stemming from increased use of computer-generated displays and the anticipated introduction of three-dimensional imagery.

Information processing and decision making. This research seeks to understand how people assess situations and select actions under conditions of uncertainty and risk; it also includes investigation of computer programmer performance. There is increased emphasis on the role of individual differences and the effect of task characteristics in decision performance, and on understanding how people generate new hypotheses and new action choices.

DoD Departments/Agency

- ***Department of the Army***
- ***Department of the Navy***
- ***Department of the Air Force***
- ***Defense Advanced Research Projects Agency***

Department of the Army

The Army's basic research program is divided into two distinct segments, the in-house work performed in the Army's 35 laboratories, and the extramural effort. Figure 15 shows the relation of the various organizations involved in research efforts to the command chain. Much of the Army's research program is conducted in, or contracted from, the laboratories associated with the Army's Materiel Development and Readiness Command (DARCOM). DARCOM is responsible for the development and acquisition of all the Army's combat and combat support systems. Within DARCOM, the Army Research Office (ARO) provides the principal interface with Universities. With such a broad mission, DARCOM performs most of the Army's research program (70 percent for FY 82). The remainder of the program is divided among the Surgeon General's Office and the Medical R&D Command (21 percent), the Corps of Engineers (6 percent), and the Army Research Institute for the Behavioral and Social Sciences (3 percent), which reports to the Deputy Chief of Staff for Personnel.

Extramural program. Along with the contracts let by the in-house laboratories in support of their own programs, much of the extramural research program is in the form of contracts from ARO, mainly to academia, with a small number going to industry and nonprofit organizations. There is also an overseas contract program carried out by the European Research Office which receives funds and program guidance from ARO. ARO's program is structured along lines similar to the DoD disciplines discussed in the first half of the report, with a division director and staff in each of the following areas.

Atmospheric and terrestrial sciences.
Biological sciences
Chemistry
Communication engineering and electronics
Materials
Mechanics and aeronautics
Physics

The ARO program is a mix of short-, mid-, and long-term programs that are responsive to the needs of the Army laboratories. The programs reflect the judgment of the ARO staff of what new and exciting, higher-risk work may have large payoffs in the future. Although the bulk of ARO's program results from the receipt, evaluation, and support of unsolicited proposals, it does allow its interest in specific topics to become known throughout the scientific community through its publications and personal contact. In recent years, ARO has also allowed part of its program to be somewhat shaped by its direct interactions with the Army Tactics and Doctrine Commands and Schools. An example of this is the increased emphasis in several of its divisions on various aspects of chemical and biological warfare defense research, resulting from very intensive joint planning in this area between ARO, the Chemical Systems Laboratory and the U.S. Army Chemical Schools.

When proposals are received, ARO subjects them to a three-level review: a peer review in the scientific community for technical excellence, an Army laboratory review for both excellence and military relevance, and an ARO internal review. Depending on the results of these reviews, the proposals may then be funded. Through its Scientific Liaison program, individuals in the army labs may request to be kept apprised of specific programs and to receive copies of reports and publications which may prove useful to their own projects. Once a year, the entire ARO program is evaluated by the DARCOM Laboratory Directors to determine how it is responding to the needs of their own organizations. Contracts with the 35 in-house laboratories are negotiated directly with the in-house laboratory researchers.

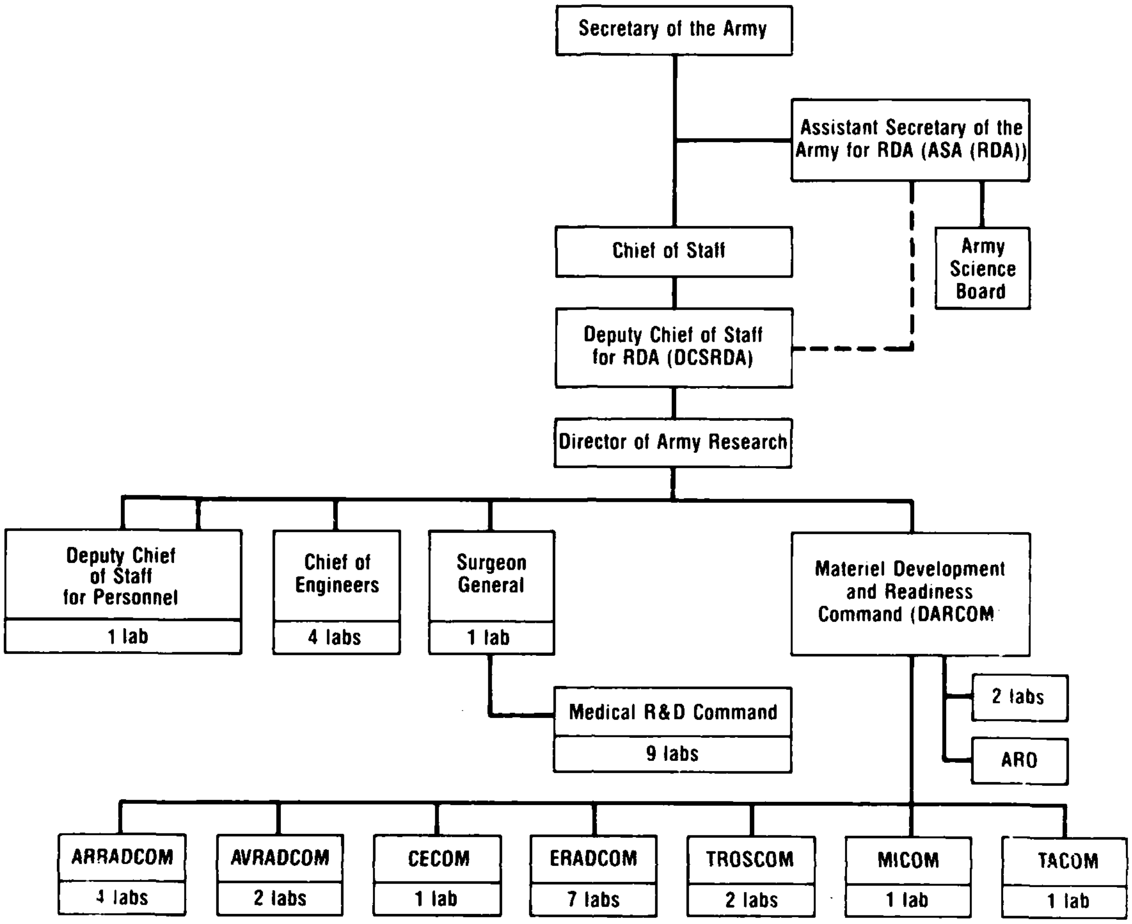

Figure 15. Army research management structure.

In-house program. The in-house laboratories program is organized along the lines of laboratory responsibilities. Each laboratory's research effort is supported by a Single Project Funded (SPF) line item which relates more closely to the overall mission of the lab than to some specific scientific discipline. The content of each SPF is determined by each laboratory's Technical Director and his staff. Research in the laboratories is designed to be the first step in the development chain, and many of the tasks undertaken within the SPF are intended to eventually lead into development programs. The technical content of the SPF's is formally reviewed each year by each Command Headquarters and by the Directorate of Army Research. This evaluation process provides an opportunity for closer coupling of the Army's in-house and extramural programs.

In addition, from time to time the Assistant Secretary of the Army for Research, Development and Acquisition will request the Army Science Board (ASB) to review some particular area of the research program to assure its responsiveness to some especially pressing Army problem.

Technology areas of emphasis. Along with the laboratories' mission-oriented research program and ARO's discipline-oriented program, the Director of Army Research (DAR) has identified technology thrusts. These are areas which respond to specific military needs having a high urgency and which might be solved by a major infusion of technological effort. Research in these areas is encouraged and is given preference in the annual budget cycle. The related tasks are usually performed by several laboratories in-house and on contract within their respective SPF's, and the work is coordinated either formally through some form of planning document or informally through oversight by each Command Headquarters and the Department of the Army Headquarter's Office of the Director of Army Research.

The thrusts do not address all of the Army's research concerns. Efforts in such all-important areas as mobility, survivability, and firepower will certainly continue. The thrusts, however, are designed to maximize the advantage we can gain from some of our genuinely *high-leverage technologies.*

Research efforts support thrusts in a number of areas including very intelligent surveillance and target acquisition (VISTA), distributed command, control, communications and intelligence (C^3I), self-contained munitions, biotechnology, and the soldier-machine interface.

A case history in Army R&D management. When the problem of limited visibility in the tactical environment became apparent several years ago, members of the Army Science Board suggested that systems operating in the near-millimeter wave(NMMW) region might provide a compromise between the high resolution capabilities of infrared radiation and the greater penetrability of microwaves. The NMMW region is defined as that portion of the spectrum bounded by the atmospheric windows at 100 and 1000 GHz (the 100-GHz window includes 94 GHz). A select group of scientists was asked to evaluate the potential payoff of this technology and make recommendations to the Director of Army Research. The Harry Diamond Laboratory (HDL) led this study.

The result was a four-year technology base plan for the Army which outlined in great detail the Army's current position in the technology, where it had to go to achieve its goal of a limited-visibility systems capability, and what it had to do to get there. Over 160 individual work units were laid out, ranked by priority, and assigned to specific laboratories for execution. Funding was obtained and an Army-wide steering group was established to coordinate the program. In addition, the expert committee's technology overview was edited and published to provide technical guidance to the research community. R&D efforts were coordinated and in some cases cooperative programs were established with the Navy, the Air Force, and DARPA. The level of awareness in industry was raised. The result of this effort was a deliberate, unified, and well-planned initiative into a new technology for the Army. The near-millimeter wave program is now part of the VISTA thrust.

Department of the Navy

The Office of Naval Research (ONR), under the direction of the Chief of Naval Research, reports directly to the Assistant Secretary of the Navy for Research, Engineering and Systems. ONR was established by an Act of Congress in 1946 (Public Law 588, 79th Congress), which granted the new organization the statutory responsibility "to plan, foster and encourage scientific research in recognition of its paramount importance as related to the maintenance of future naval power and the preservation of national security." The Navy has a continuing requirement for research to provide the scientific foundation of understanding, techniques, and information required for future systems and operations.

ONR's organizational structure, under the Navy secretariat (fig. 16), ensures that research funds remain properly insulated but not isolated from the pressure of resource requirements in the Navy's near-term development programs. An awareness of development and fleet problems, which frequently indicate needs for research investment, is maintained through close and continuous interaction with the Office of the Chief of Naval Operations (OPNAV), the Naval Materiel Command (NAVMAT), and its laboratories. ONR is also responsible for attending to the research requirements of the Marine Corps.

Extramural program. Two major types of programs are supported by ONR. First, fundamental knowledge that leads to solutions of Navy problems is acquired through support of long-range research. Second, programs of applied research and exploratory development are conducted to develop naval technologies and to study and test novel concepts in naval operational systems. The scientific directorates in support of these research and development programs are:

Mathematical and Physical Sciences
Environmental Sciences
Engineering Sciences
Life Sciences

Contracts are generally awarded in response to unsolicited proposals. The academic, in-house laboratory, and acquisition manager constituencies are frequently consulted for opinions on individual proposals. The criteria employed in evaluating specific proposals are (1) excellence and creativity of the principle investigator, as evidenced by previous publications and reputation within the scientific community, (2) relationship to Navy and Marine Corps needs, (3) correspondence to previously stated program thrusts, and (4) evidence of uniqueness and appreciation for other similar efforts being funded by other government agencies in the field. The selection of major thrusts evolves mostly from relevance and opportunity, while decisions on individual program proposals within an area are based primarily on scientific quality. An informal peer review system exists, but final decisions rest with the scientific managers.

In-house program. The Naval Research Laboratory (NRL), and the Naval Research and Development Activity (NORDA) are the Navy's corporate research laboratories: the Naval Materiel Command R&D Centers and the Naval Medical R&D Command also have research laboratories. These laboratories have unique and critical roles in the overall process of linking diverse fields of science, within and outside the Navy, to naval technology and mission needs. Although in most fields each lab is one of several U.S. performing organizations, these labs are the primary or critical U.S. researchers in a few broad areas.

NRL, besides being a Navy corporate laboratory, is the principal in-house laboratory of ONR. Research funding at NRL is about 20 percent of the laboratory's total funds, and plays a major role in NRL's total operation. The R&D Centers under the Chief of Naval Material, although funded to a much lesser degree than NRL in the 6.1 research area, are, like NRL, full-spectrum laboratories with expertise in all areas of science and engineering from basic research to fleet support. The research at these laboratories is intended to ensure the effectiveness of the Navy in conducting its mission now and in the future. In brief, these centers, as full-spectrum performers, contribute directly to research areas pertinent to Navy interests, take a multidisciplinary approach not readily available elsewhere, act as important links to pertinent research carried out in other places, and help to apply research advances to naval problems.

Coordination. Research is coordinated in various ways, according to government needs and to the nature and level of activities and interests of different research fields. The overall research program is reviewed annually by the Office of the Under Secretary of Defense Research and Engineering and is actively coordi-

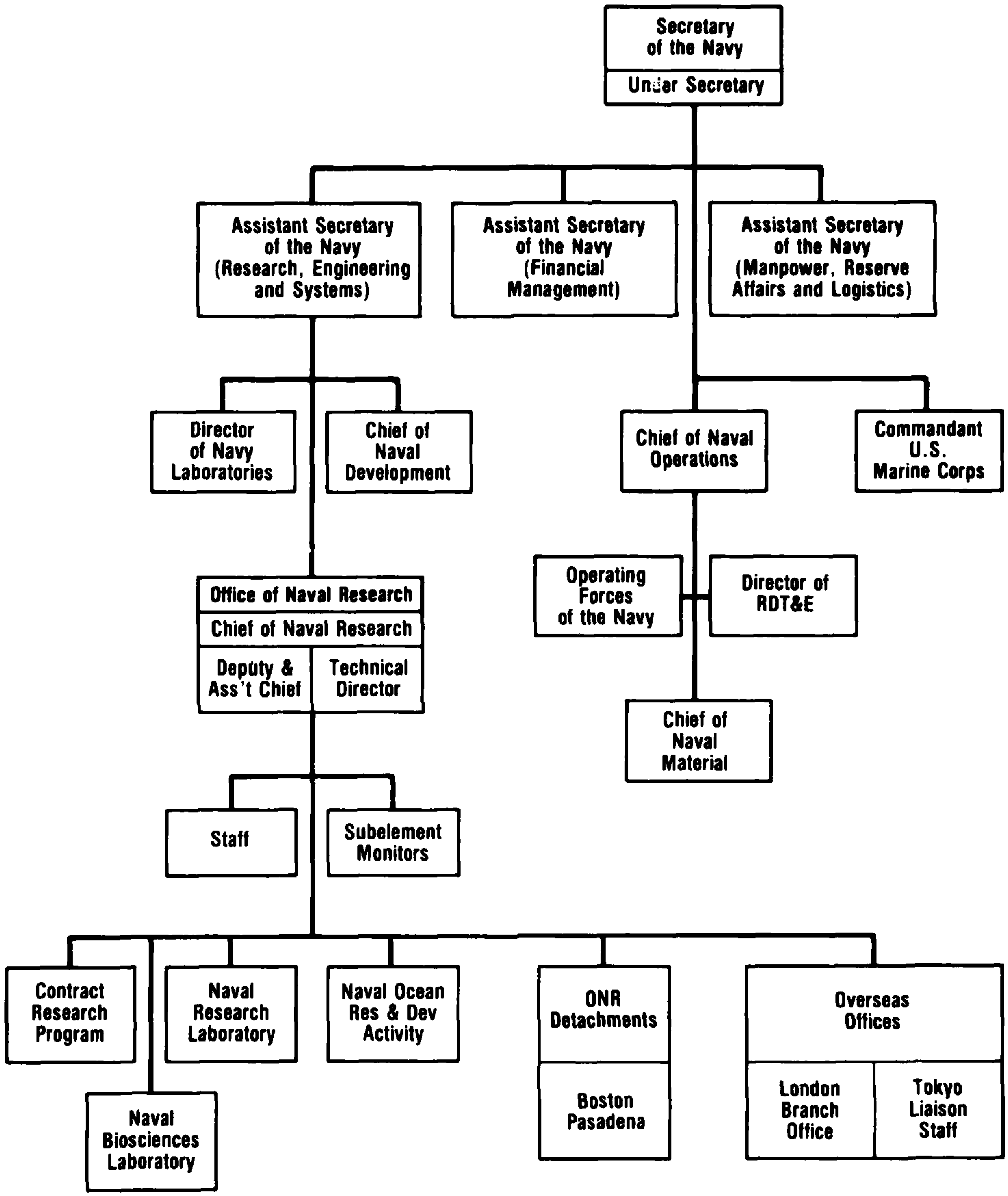

Figure 16. Navy research management structure.

nated with the National Science Foundation and the U.S. scientific community. Medical research is coordinated through DoD committees and with the National Institutes of Health. Oceanographic research is coordinated with the National Oceanographic and Atmospheric Administration, as well as the National Science Foundation. Joint symposia are held with other Military Services and government agencies.

Coordination is also accomplished through the usual means of professional scientific communication by ONR program managers who are active in professional affairs. Numerous relationships are maintained with industrial research and development firms to coordinate the transition of successful research results to industrial development. Industry may also request to use special in-house facilities for tests and evaluations of components and instruments; these requests are honored in accordance with DoD policy on technology transfer.

Technology. Research is interrelated with the Navy's Exploratory Development or applied research program under the direction of the Chief of Naval Development. The program includes concept formation, analytical, and experimental efforts to (1) identify and solve problems arising during development, (2) identify technological opportunities which may stimulate the development of substantially improved or totally new operational capabilities, and (3) demonstrate the usefulness of new discoveries to a degree which warrants their consideration for support under advanced development. Technology areas of emphasis are as follows.

Undersea surveillance
Air vehicles
Materials and Structures
Directed energy
Surface and Submarine vehicles
Logistics and Personnel
Electronics and Communication
Computer technology
Surface and Aerospace weapons
Undersea weapons
Ocean environment and technology

Department of the Air Force

The Air Force Office of Scientific Research (AFOSR) is the Air Force organization charged with planning, managing, implementing, and controlling the USAF Defense Research Science Program. AFOSR is directly subordinate to Headquarters, Air Force Systems Command, and includes the European Office of Aerospace Research and Development in London and the Frank J. Seiler Research Laboratory, at the U.S. Air Force Academy. As shown in figure 17, AFOSR is the single manager of the Air Force research program, unlike in the other Services, where the responsibility rests in several offices. AFOSR is responsible for research conducted in-house at eight Air Force laboratories, the extramural research contract programs of those Air Force laboratories, and extramural research contracts and grants for fundamental research awarded directly by AFOSR.

Extramural program. AFOSR grants and contracts for research constitute approximately 60 percent of the Air Force research budget. They are awarded in areas of science and engineering related to the needs of the Air Force. A high percentage of awards go to university researchers. Air Force programs are directed toward increasing knowledge and understanding in the physical, engineering, environmental, and life sciences related to national security needs and the mission of the Air Force. The broad goal of these programs is the continued superiority of the operational Air Force over any potential adversary, through the provision of fundamental knowledge required for the solution of military problems, the anticipation of technological surprise, the development of technological alternatives, and the continuous innovative support of Air Force development activities.

The Air Force research program encompasses a broad spectrum of research areas. Although not identical to the DoD disciplines previously discussed, they are similar. The 12 discipline projects funded by the Air Force are as follows:

- Physics
- Chemistry
- Mathematics
- Electronics
- Materials
- Mechanics
- Energy conversion
- Terrestrial science
- Atmospheric science
- Astrophysics and Astronomy
- Biological and medical sciences
- Human resources

Research to be supported is selected from unsolicited proposals from scientists investigating problems of their own choosing. Proposals are selected on the basis of the significance of the proposed research to the Air Force, originality, scientific merit, competence of the investigator, and the reasonableness of the proposed budget. AFOSR's support of these proposals has been instrumental in providing the basis for many of the technological advances vital to the Air Force today. This support has produced scientific knowledge, new concepts for technology advances, and the supply of qualified personnel to carry on these advances. Examples are advances in electronic computers, much of microwave technology essential for radar and communications, numerous advances in antenna design, essential ability in hypersonic and transonic aerodynamics, chemical lasers, control theory and linear filtering, and fracture and fatigue mechanics.

Air Force laboratory contracts for research constitute approximately 20 percent of the Air Force research budget. Laboratory research contracts are awarded through either unsolicited proposals or from responses to requests for proposals. These research contracts are generally in areas that directly complement laboratory in-house programs.

Laboratory research program. Air Force laboratories which perform research are reimbursed for research expenses by AFOSR. The Research Plan developed by AFOSR serves as the master guide for all Air Force basic research activity. The Air Force laboratories which perform research are the following:

- Air Force Armament Laboratory
- Air Force Geophysics Laboratory
- Rome Air Development Center
- Air Force Rocket Propulsion Laboratory
- Air Force Wright Aeronautical Laboratories
- Flight Dynamics Laboratory
- Materials Laboratory
- Avionics Laboratory
- Aeropropulsion Laboratory
- Air Force Human Resources Laboratory
- Aerospace Medical Division
- Air Force Weapons Laboratory

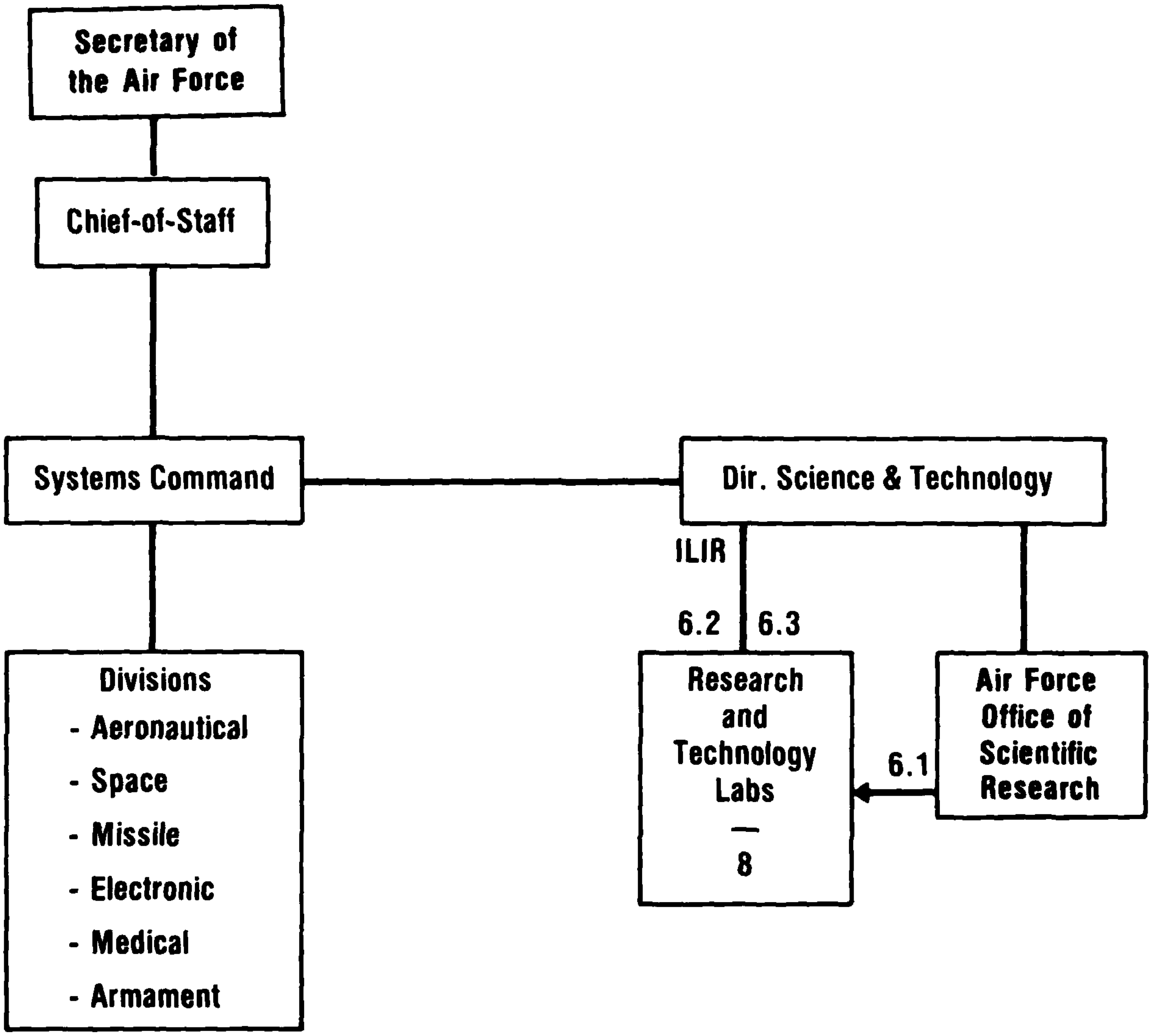

Figure 17. Air Force research management structure.

In addition to the Research Plan, the Air Force Systems Command (AFSC) prepares a Research Planning Guide which identifies research needed by the Air Force. This document informs military and civilian research and development communities of research objectives which offer the greatest potential for affecting future military operations. Research objectives are grouped into seven technical areas: life sciences, materials, geophysics, aerospace vehicles, propulsion and power, weaponry, and electronics. Each technical area is divided into subareas which are categories of research objective within the technical area. The presentation for each subarea contains a short description of its scope, and a listing of points of contact in appropriate laboratories.

AFOSR Initiatives in Basic Research. In the past year, the Air Force Office of Scientific Research established a program of interdisciplinary initiatives in areas of basic research that are of special importance to the Air Force mission and that require a concentrated effort over a period of several years. The Air Force program of initiatives encompasses basic research programs in defense against chemical agents, energy efficient aircraft, low speed take-off and landing, systems automation, manufacturing science, space propulsion and power, spacecraft structures and materials, and processing of spacecraft imagery.

Defense Advanced Research Projects Agency

The Defense Advanced Research Projects Agency (DARPA) is a separate agency within the Department of Defense and serves DoD as a "door opener" to new technological ideas. DARPA is entrusted with the corporate, or central, research function of DoD. Its function resembles that of a corporate research division in private industry, which is responsive to the highest levels of corporate authority. Its programs focus on proof-of-concept demonstrations of revolutionary approaches for improved strategic, conventional, rapid deployment, and sea-power forces, and on the scientific investigation into advanced basic technologies of the future. Thus, DARPA is able to explore the possible military benefits of new and unconventional concepts and technologies for all Services, without regard to the specific roles or missions which their applications might have.

DARPA's corporate investment strategy is guided by DoD's responsibility to maintain technological leadership in defense capabilities. Although R&D projects in advanced technologies are often high-risk investments, DARPA is encouraged to assume these risks where it is convinced that, when the technology matures, a major advancement in military capability will be within reach. The agency was created by Public Law 85–325 in February 1958, partly from the pressures caused by the launching of Sputnik and partly in response to the urgent need for high-level attention to selected research projects stemming from promising advanced concepts and required long-range development and tests. DARPA's programs encompass a wide range of scientific disciplines, which address the full spectrum of this nation's national security needs. DARPA's present organization is indicated in figure 18.

Operation. DARPA operates in circumstances defined by defense policy and budgets, strategic arms negotiations, and a continuing need to maintain the credibility of the nation's strategic deterrent capability and the viability of its tactical forces. To fulfill its responsibilities, DARPA selects for support only those R&D initiatives that promise to advance U.S. national security interests while lowering costs through technological advances, or to prepare the foundations for further technological progress.

DARPA's fiscal approach is to ensure funding at a level that does not compromise the attainment of the technical goals of the project. Because the project can move forward at a pace limited only by technical knowledge and human resources, this approach yields an early determination of the utility of the R&D and its probable future success. DARPA proceeds with its initial investment in this manner: it accepts the risks, withdraws support from unproductive projects, and selectively extends the most promising projects into modest-scale demonstrations for evaluation. During the planning and conduct of these demonstrations, DARPA seeks increased participation by the Military Services in formulating the objectives and scenarios consistent with the criteria for evaluating and selecting military technology. DARPA executes its programs through Service agents and, where appropriate, also demonstrates technical feasibility and military utility in joint experiments and demonstrations with the Services. This joint participation facilitates the subsequent transition of selected technology programs to the Services for advanced development.

Defense Sciences Office

The Defense Sciences Office (DSO) is committed to supporting advanced R&D initiatives which promise benefits from many disciplines. The objectives of its R&D efforts are to support national security in the area of nuclear monitoring, to support the military services in developing advanced materials leading to new structures or electronic and mechanical components and devices, and to advance the cybernetic sciences and system technologies for improved military operations, maintenance and training. To achieve these objectives, DSO is divided into three corresponding divisions—Geophysical Sciences, Material Sciences, and System Sciences—each of which is discussed in turn below.

Geophysical Sciences Division. The geophysical sciences research program supports R&D to provide technological options for improving test-ban treaty monitoring. To these ends, the Geophysical Sciences Division (GSD) supports R&D efforts which address major problems associated with the detection and characterization of foreign nuclear explosions. Major

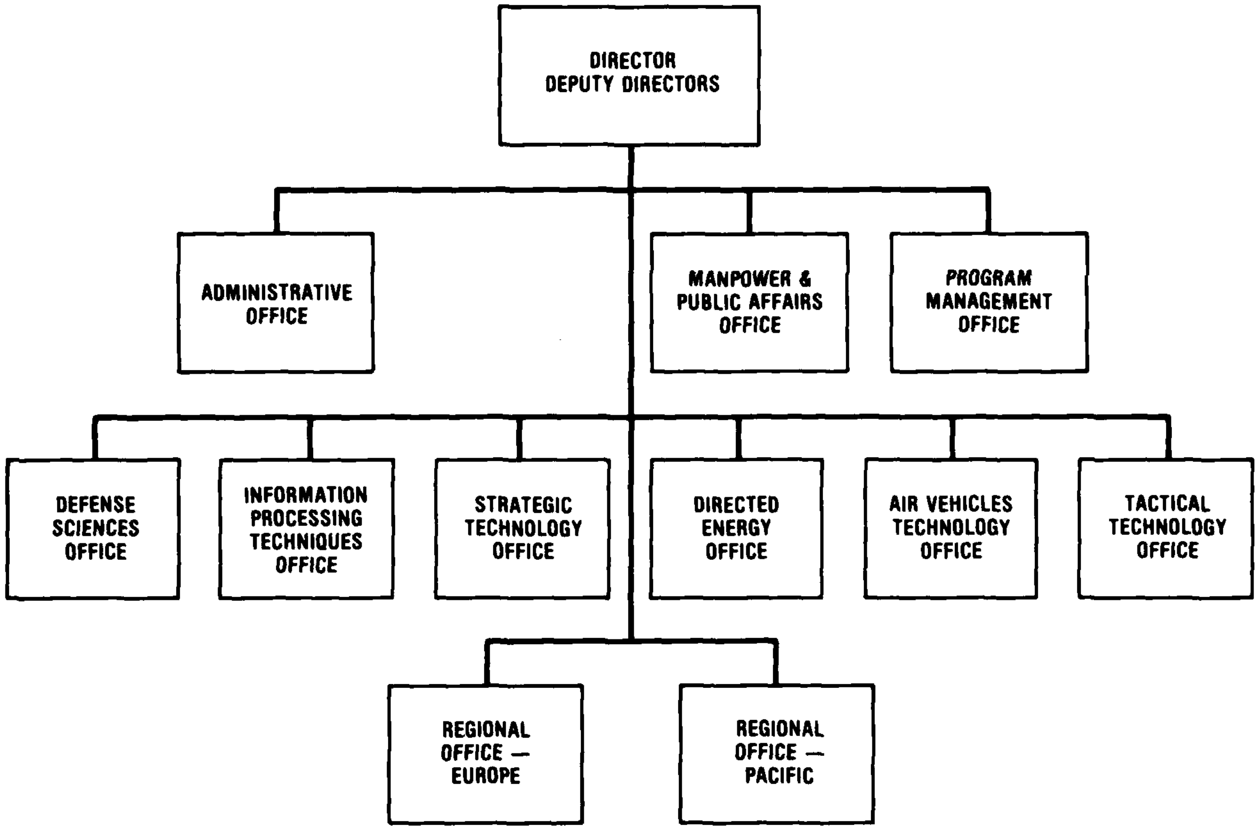

Figure 18. DARPA research management structure.

areas requiring research include the detection of low-yield underground bursts and their unambiguous differentiation from earthquakes. Other major problem areas are accurate estimations of the yield of underground explosions and improved methodologies for determining the characteristics of nuclear bursts in remote locations on earth or in space. GSD supports R&D efforts in geophysics and related disciplines, and the development of advanced instrumentation for detecting and measuring nuclear-explosion-related phenomena. GSD is also supporting the development of a variety of advanced sensors and data-processing hardwares. Currently under development are simplified detection systems for worldwide deployment; advanced data collection, processing, and analysis systems for global networks; and ocean-bottom borehole seismometer systems for improved worldwide coverage.

Materials Sciences Division. The Materials Sciences Division (MSD) is supporting R&D initiatives with the objective of developing materials or structures that offer better performance, greater ease of use, or lower cost while achieving greater strength, greater durability, lighter weight, or greater fuel efficiencies. MSD is also supporting an extensive research program in electronic and electro-optical materials and devices, with current emphases on radiation detection materials, monolithic microwave circuits, and the fabrication of devices with submicron features.

Specific areas of MSD's research presently include advanced bearings, optical ceramics, strategic systems materials, rapid solidification technology, radiation and particle detectors, advanced armor and anti-armor technologies, penetration mechanics, optical communications, high through-put signal processing, advanced electronic devices, and laser windows, coatings, and mirrors. MSD is also supporting advanced materials processing technologies in many areas: future turbine technology, integrated circuit processing, structural ceramics, focused-beam (directed-energy) processing, gallium-arsenide monolithic integrated circuits, quantitative nondestructive testing and evaluation, and metal-matrix composite materials for space and weapon systems applications. In addition, MSD has a new program in the dynamic synthesis and processing of high-value materials for military applications.

MSD also pursues R&D initiatives with special emphasis on research into the possibility of retiring engine components for cause rather than by schedule, which can prolong operational lifetimes, increase safety, and reduce acquisition and maintenance costs.

System Sciences Division. The opportunities afforded by an understanding of human behavior and by the application of that understanding to military technologies are the concern of the System Sciences Division (SSD). The objectives of its diverse R&D efforts are to enhance systems and system management, to improve man/machine interactions, and to capture the benefits of advances in the understanding of human psychology and physiology, and in biotechnology.

SSD supports R&D efforts in advanced biochemical technology, the design of command-and-control systems, including spacial data-base management, mapping, image clarification, teleconferencing, and group decision-aiding; initiatives to overcome the problems of software development; efforts to develop training aids which permit distributed, individualized training, such as small, low-cost task simulators, maintenance aids, and interactive movies; and initiatives to match human capabilities to the design and functioning of unconventional vehicles, including walking machines and person-powered or low-powered vehicles.

Information Processing Techniques Office

The Information Processing Techniques Office (IPTO) is dedicated to developing advanced information processing and computer communications technologies for critical military and national security applications. In its area, IPTO's research program is the largest in the Federal government and includes both basic research and exploratory development. IPTO's central purpose is to advance the technology and options for its application to command, control, and communications (C^3), intelligence (I), and military information processing.

IPTO's first area of interest in basic research focuses on artificial intelligence, system software and architecture, the design and architecture of integrated circuits, and advanced network concepts. The questions posed by artificial intelligence—how can machines replicate or expand the capabilities of human intelligence and how can this knowledge be best represented and utilized in a computer—are at the center of the problem of developing expert programs for application in remote, autonomous systems, such as emplaced sensor transmitters or "smart" weapons. Research on integrated circuit design is addressing the revolutionary possibilities of more efficient, nontraditional circuit architectures which permit parallel rather than sequential processing. Additional research is addressing the fundamental question of what designs and design techniques on computer chips are appropriate for the million-plus-gate integrated circuits of the future. A critical related question deals with the capability of producing working chips in a timely fashion. Since integrated circuit fabrication usually takes many months, IPTO is supporting efforts to develop a network-based methodology for rapid turnaround and implementation from design to packaged chip.

The size of the IPTO research effort reflects both the scope and increasing sophistication of information processing and computer technologies. If the conventional battlefield of the next two decades emphasizes the dispersal and mobility of military resources, it will also impose ever greater requirements on the management of these resources. More information and more sharing of information than ever before will be needed at all echelons. The same is true on a far larger scale in the processing of intelligence data from numerous and varied sources. Finally, advanced "smart" weapons of the next twenty years may need to be launched from stand-off platforms and, to avoid interception or capture, will need to be self-guiding. Such "smart" weapons will require an on-board, autonomous capability to collect and process information to guide them to their targets while avoiding attack.

The technological requirements and applications needs of such promising systems are diverse. System architecture for ensuring system security is a central concern. Research to facilitate the use of information processing in strategic and tactical situations is exploring the possibilities of decomposing speech and data into discrete packets for transmission and reassembly over shared packet-switched networks. Because such networks will need to be comprehensive and will handle large amounts of data, IPTO is supporting research on effective communication algorithms and management protocols for large-scale networks.

The ramifications of these and many other possible applications of these advanced technologies are far from being fully comprehended. Continued R&D efforts are being pursued to realize and exploit the revolutionary opportunities to enhance U.S. defense and national security capabilities in information processing and computer communications.

Strategic Technology Office

The Strategic Technology Office (STO) is committed to developing the technology base for near-space strategic military and national security systems and to substantiating proof-of-concept of advanced technologies by test demonstrations. Existing technologies have already made space a potential battlefield; future technologies will exploit its possibilities for military activities. In an area in which revolutionary developments can have large, worldwide consequences, advanced strategic technologies are necessary to enhance U.S. capabilities, to avoid technological surprise, and to reduce manpower and costs.

Tactical Technology Office

The Tactical Technology Office (TTO) undertakes innovative R&D programs to demonstrate the feasibility of advanced weapon and weapon system technologies for use on land and sea by tactical commanders of U.S. general-purpose forces. The purposes of these R&D programs are directed towards ensuring technological superiority, operational effectiveness and flexibility, and reduced manpower, maintenance, and acquisition costs. The number and variety of these undertakings reflect the diverse possibilities for making significant improvements in conventional or tactical nuclear warfare.

TTO supports R&D initiatives in its three primary areas of interest: weapon technology, target acquisition and engagement, and ocean monitoring and control. In each area, the dominant concern is to make advanced technologies available to the Military Services for applications to combat situations.

Directed Energy Office

The Directed Energy Office (DEO) pursues advanced research in lasers and particle-beam technology, and explores the feasibility of directed electromagnetic radiation technologies for space defense and strategic communications. DEO's objectives in these activities are to ensure technological superiority and to develop opportunities in an area in which advances of global significance are possible. For, if near space becomes a battlefield, it will likely involve more than surveillance and communications technologies or conventional or nuclear explosive munitions. The possibilities that presently exist in the use of energy beams suggest their adaptation to military uses in space. DEO pursues these possibilities in three program areas: space-defense high-energy lasers, particle beams, and laser communications.

Air Vehicles Technology Office

The Air Vehicles Training Office (AVTO) is committed to supporting R&D initiatives to substantiate the feasibiity of advanced technologies for manned and unmanned aircraft systems. The purposes of these R&D efforts are to explore and evaluate the many possibilities for major technological improvements in platforms, equipment, and techniques; they are also to retain technological superiority and to utilize technological improvements to lower acquisition and maintenance costs, to reduce manpower requirements for operations and maintenance, and to increase energy efficiency. The goal is to provide a broad array of options for responses to the changing circumstances and requirements of air warfare.

AVTO programs address technologies in numerous areas, including advanced manned aircraft (fixed wing and rotary), advanced unmanned platforms (remotely piloted vehicles and cruise missiles), advanced air-platform propulsion technologies, advanced materials and structures, advanced flight-control systems, and advanced aerodynamics. These programs support R&D efforts which promise to help general-purpose forces both in deterring conventional and nuclear war and in sustaining U.S. interests if deterrence should fail.

Appendix A

Tabulated Data

The following tables contain data relating to the DoD research program. The data both describe the program itself and show its relation to the rest of the RDT&E program and to the national research effort.

Figure A–1 shows the sources and performers of basic research nationwide and how the picture has changed in 1962, 1972, and 1982. The federal government obviously plays a major role as a supporter of this kind of work.

Figure A–2 shows that DoD Research makes up almost 4 percent of the total RDT&E budget. The funding history of the research portion of the DoD RDT&E budget is displayed in Figure A–3.

Table A–1 shows obligational authority, that is, the amount that Congress permits DoD to obligate. Figure A–4 shows the distribution of basic research funds by agency for 1984.

Within DoD, research support is broken out between the Services and agencies as shown in table A–1.

Table A–2 shows the distribution of individual 6.1 research projects according to the size of funding allocated to them.

Table A–3 displays how the DoD research budget is distributed among research performers; table A–4 refers specifically to the support of university research programs. Table A–5 is a recapitulation of the DoD research programs, this time divided into the 12 discipline areas.

The remaining charts show how the three Services and DARPA divide their programs. Table A–6 refers to the Army, showing the ARO research program, which falls more along the lines of DoD disciplines. Tables A–7 and A–8 show the Navy and the Air Force breakout. The DARPA organization is more fully described in the body of the report (p. 45).

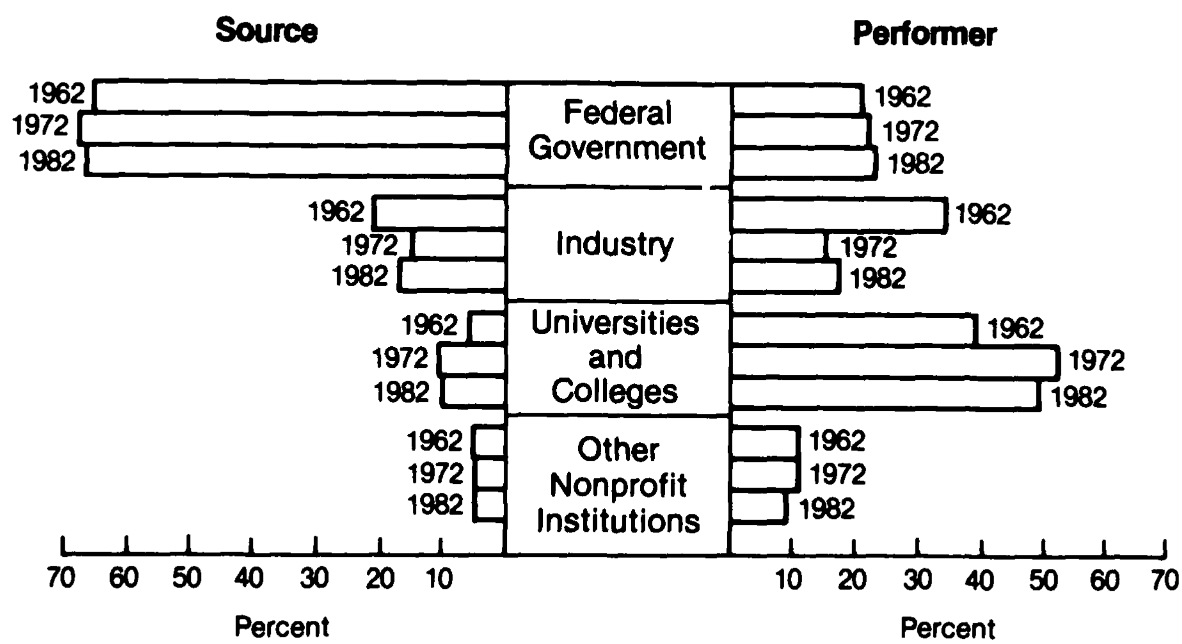

Figure A–1. Sources and performer of basic research, 1962, 1972, and 1982.

Type of RDT&E activity	Funding ($M) FY82	Funding ($M) FY83	Real growth (%)
Research	695	779	7
Exploratory Development	2,213	2,434	9
Advanced Development	3,476	3,881	8
Engineering Development	7,683	8,611	10
Management and Support	2,009	2,200	9
Operational Systems Development	3,968	4,987	18
Total	20,044	22,805	13

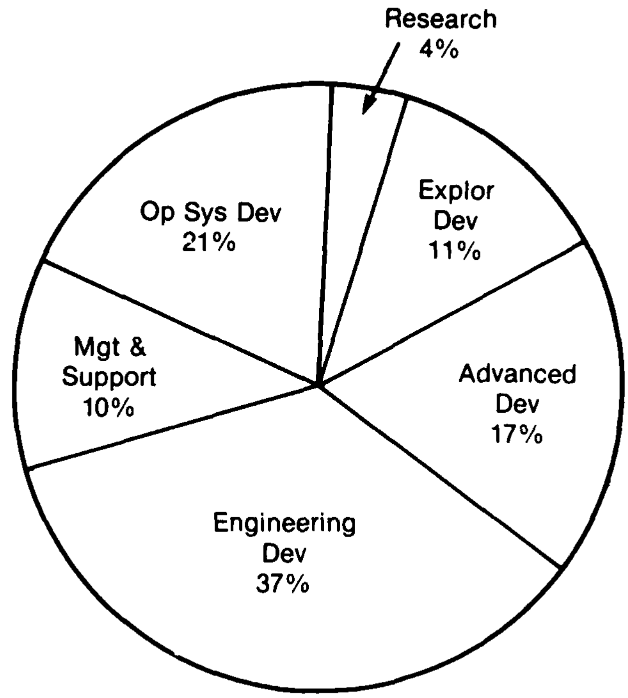

Figure A-2. RDT&E by activity type (millions of dollars).

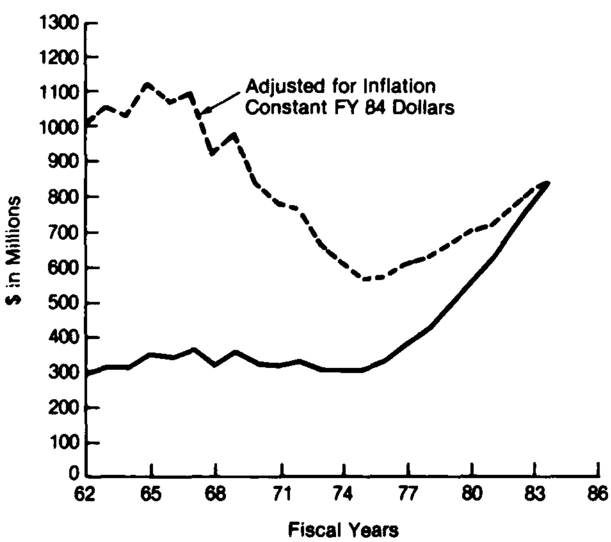

Figure A-3. Funding history of DoD research budget

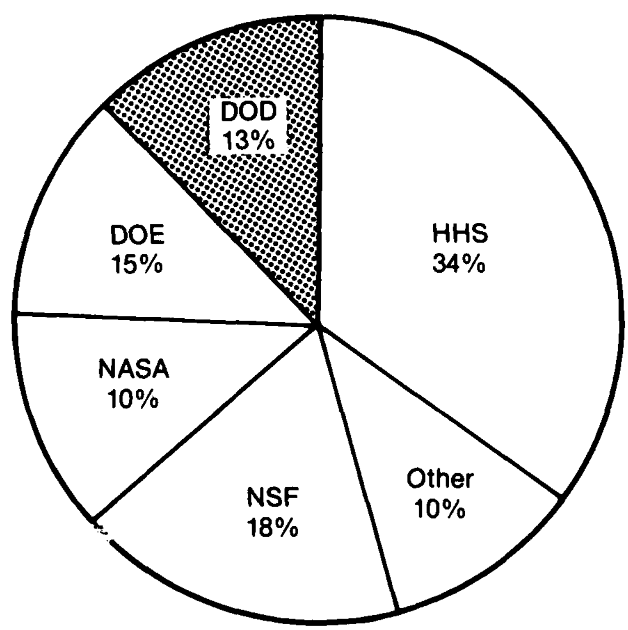

Figure A-4. Perspective on DoD research-distribution of basic research funds by agency (FY-84 budget)

Table A-1. Military Services Research (6.1) Funding (Obligational Authority).

Program element[a]	Funding ($M)	
	FY82	FY83
Army		
61101A (ILIR)	21.6	21.9
61102A (DRS)	156.4	180.5
subtotal	178.0	202.4
Navy		
61152N (ILIR)	21.4	23
61153N (DRS)	255.0	283
subtotal	276.4	306
Air Force		
61101F (ILIR)	11.3	13
61102F (DRS)	136.5	155
subtotal	147.8	168
DARPA		
61101E (DRS)	94.4	101
USUHS		
61101W (ILIR)	1.7	1.4
Total	696.6	772.2

[a]ILIR—In-House Laboratory Independent Research
DRS—Defense Research Sciences
DARPA—Defense Advanced Research Projects Agency
USUHS—Uniformed Services University of the Health Sciences

Table A-3. Research Performers (FY 84 Estimates)

Performers	Basic Research (6.1)	All R&D
Universities	50%	4%
Government Labs	30%	21%
Industry and Federal Contract Research Centers	20%	75%
Total Funds	$850M	$29B

Table A-2. Funding Size Distribution of Individual 6.1 Research Projects.

Service	Proj[illegible] by size in thousands of dollars							
	0—25	25-50	50—75	75—100	100-125	125—150	Over 150	Total
Army	668	477	405	218	85	41	201	2095
Navy	1062	378	258	203	70	77	113	2161
Air Force	586	120	115	137	97	75	414	1544
DARPA	0	0	0	0	0	0	0	0
and USUHS	52	5	0	0	0	0	0	57
Total	2368	980	778	558	252	193	728	5857

[3]DARPA—Defense Advanced Research Projects Agency
USUHS—Uniformed Services University of the Health Sciences

Table A-4. Allocation of Research Funding to Universities.

Organization	Funding ($M)		
	FY81	FY82	FY83
Army	52.1	71.7	90
Navy	118.1	143.8	155
Air Force	69.5	79.0	88
DARPA[a]	25.5	32.3	54
Total	265.2	326.8	387

[a]*DARPA—Defense Advanced Research Projects Agency*

Table A-5. DoD Program Funding (FY 82 to FY 83)

Disciplines	Funding ($M)		
	FY82	FY83	increase %
Physics, Radiation Sciences, Astronomy, Astrophysics	76.0	79.5	4.6
Mechanics, Aeronautics and Energy Conversion	73.1	79.5	8.7
Materials	57.1	59.8	4.7
Biological and Medical Sciences	62.9	64.8	3.0
Electronics	63.6	65.8	4.2
Oceanography	51.1	51.2	.19
Chemistry	53.1	59.3	11.6
Mathematics and Computer Sciences	48.2	56.9	18.0
Atmospheric Sciences	20.8	21.9	5.2
Terrestrial Sciences	22.1	24.8	12.2
Behavioral and Social Sciences	19.5	21.6	10.7
Subtotal	547.5	585.2	6.8
DARPA	92.5	101.0	9.1
USUHS	2	2	—
Total	642	688.2	7.1

[a]*DARPA—Defense Advanced Research Projects Agency*
USUHS—Uniformed Services University of the Health Sciences

Table A-6: Department of Defense Funding for Basic Research by Service and Discipline, FY 1982 and FY 1983 (Budget authority in millions).

	Army	
	FY 1982	FY 1983
Physics, radiation sciences, astronomy, and astrophysics	$ 18.5	$ 19.0
Mechanics, Aeronautics and energy conversion	15.1	15.8
Materials	14.8	17.0
Electronics	20.3	22.9
Oceanography	—	—
Biology and medical sciences	36.9	38.3
Chemistry	22.2	23.8
Mathematics and computer sciences	13.8	14.7
Terrestrial sciences	5.3	5.9
Atmospheric sciences	5.5	5.8
Behavioral sciences	4.2	5.3
TOTAL	$156.6	$178.5

Table A-7: Department of Defense Funding for Basic Research by Service and Discipline, FY 1982 and FY 1983 (Budget authority in millions.)

	Navy	
	FY 1982	FY 1983
Physics, radiation sciences, astronomy, and astrophysics	$ 37.5	$ 40.3
Mechanics, energy conversion and aeronautical sciences	28.2	31.0
Materials	24.2	23.7
Electronics	27.1	27.9
Oceanography	51.1	51.2
Biology and medical sciences	17.9	18.0
Chemistry	17.1	18.8
Mathematics and computer sciences	21.7	27.5
Terrestrial sciences	14.4	16.4
Atmospheric sciences	6.4	6.4
Behavioral sciences	9.1	10.5
TOTAL	$254.7	$271.7

Table A-8: Department of Defense Funding for Basic Research by Service and Discipline, FY 1982 and FY 1983 (Budget authority in millions).

	Air Force	
	FY 1982	FY 1983
Physics, radiation sciences, astronomy, and astrophysics	$ 20.0	$ 20.2
Mechanics and energy conversion	29.8	32.7
Materials	18.1	19.1
Electronics	16.2	15.0
Oceanography	—	—
Biology and medical sciences	8.1	8.5
Chemistry	13.8	16.7
Mathematics and computer sciences	12.7	14.7
Terrestrial sciences	2.4	2.5
Atmospheric sciences	8.9	9.7
Behavioral sciences	6.2	5.8
Aeronautical sciences		
TOTAL	$136.2	$145.0

Appendix B

Points of Contact in Department of Defense Research Program

Department of Defense

Director for Research and Laboratory Management
Office of the Under Secretary of Defense
for Research and Engineering
The Pentagon, Room 3E 114
Washington, D.C. 20301
202-697-3228

Army

Deputy for Science and Technology
Office of the Assistant Secretary of the Army
(Research, Development and Acquisition)
The Pentagon, Room 2E673
Washington, D.C. 20310
202-695-7674

Director of Army Research
Office of the Deputy Chief of Staff (Research,
Development and Acquisition)
ATTN: DAMA-ARZ-D
The Pentagon, Room 3E363
Washington, D.C. 20310
202-697-3558

Technical Director
U.S. Army Research Office
Research Triangle Park, NC 27709
919-549-0641

Research and Development Office
Office of the Chief of Engineers
ATTN: DAEN-RDZ-A
20th Street and Massachusetts Avenue, N.W.,
Room 6208
Washington, D.C. 20314
202-272-0254

Assistant Surgeon General for Research
and Development
Office of the Surgeon General
ATTN: DASG-RDZ
The Pentagon, Room 3E474
Washington, D.C. 20310
202-697-1120

Technical Director
U.S. Army Research Institute for the Behavioral
and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333
202-274-8636

Navy

Deputy for Research Applied and Space
Technology
Office of the Assistant Secretary of the Navy
(Research, Engineering and Systems)
The Pentagon, Room 4D745
Washington, D.C. 20350
202-694-5090

Technical Director
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217
202-696-4262

Air Force

Deputy for Research and Development
Office of the Assistant Secretary of the
Air Force (Research, Development and
Logistics)
The Pentagon, Room 4D977
Washington, D.C. 20330
202-695-2317

Director
U.S. Air Force Office of Scientific Research
Bolling AFB
Washington, D.C. 20332
202-767-5017

DARPA

Deputy Director for Research
Defense Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209
202-694-3035

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