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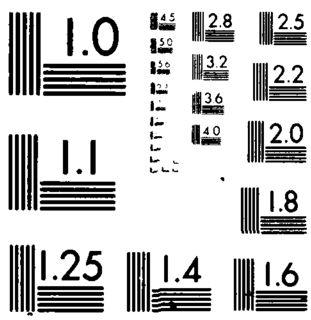


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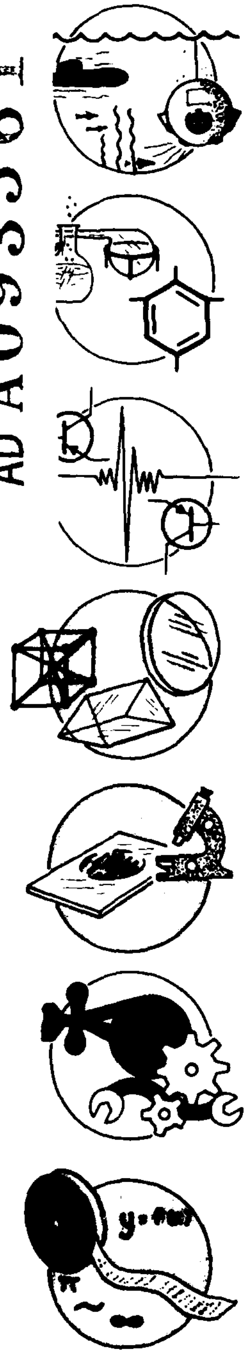

Department of Defense

# BASIC RESEARCH PROGRAM

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This document was prepared by the Office of the Director for Research, Office of the Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology) for the purpose of providing information on the DoD Research (6.1) program. Comments regarding this document or suggestions for improvements in further editions should be forwarded to

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Editorial review, photocomposition, design, and layout by the Technical Reports and Visual Information Branches, Harry Diamond Laboratories, ERADCOM.

# Foreword

This report has been prepared by the Research Office, Office of the Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology). It is the first report ever written for the express purpose of describing the Department of Defense basic research program. The report is part of an overall 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.

The goal of this report is to present an overview of the DoD basic research program including the entire range of disciplines of interest to DoD; however, space constraints permit citing only a few specific examples. Consequently, many exciting parts of the program could not be described in detail; this should not be taken to indicate lack of interest or lower priority.

This publication is our initial effort, and we are already looking toward a second edition. To that end, we invite your comments and suggestions on how this document could better serve to help us communicate with you.

We would like to thank the Offices of the Assistant Secretaries in the Military Departments and the Office of the Director of the Defense Advanced Research Projects Agency for their assistance in putting this report together. Particularly, I would like to single out I. R. Hershner, Robert J. Lundegard, Richard W. Haffner, and Carl Romney. Lastly, and most importantly, I want to thank Edward A. Brown, of the U.S. Army's Harry Diamond Laboratories, who had the overall editorial responsibility for this report.

Of course, any errors or omissions remain the sole responsibility of the Research Office.



George Gamota
Director for Research

# Contents

"We must ensure that we are building our defense research base to provide for our national security in the future. . . Our science and technology base related to national security must be the best in the world."

With these words, the President, in his Science and Technology Message to the Congress (27 March 1979), expressed his support for an active and vital research program in the Department of Defense (DoD). This thought was echoed in a historic memorandum from Secretary of Defense Harold Brown shortly thereafter:

"Prudent planning for the future demands a deliberate and continued commitment to basic research."

Secretary Brown then went on to request each of the Services and defense agencies to review their research programs; he directed the Under Secretary of Defense for Research and Engineering to oversee their progress. The goal is a DoD research program that is, on the 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

In this report, the description of the research program is approached from two points of view: what the program contains technically and how it is managed by DoD. This approach should allow the reader to gain a full understanding of the DoD research program.

### *What is 6.1?*

The annual DoD budget is presented in the form of 10 "programs." Program 6, entitled "Research, Development, Test and Evaluation" (RDT&E), includes several budget categories which mark the development of a technology program from its beginning as a fundamental investigation, through development, and into the engineering of a military system. The first budget category in Program 6 is "Research"—hence the designation 6.1.

Projects undertaken in 6.1 differ in basic philosophy from work in the other categories (6.2—exploratory development, 6.3—advanced development, etc) in that no military product is expected to result directly from such efforts. This is not to say that the needs of the nation's defense establishment are not considered. Rather, the emphasis is on high-quality basic research which results in better understanding of the fundamental laws of nature, such understanding being necessary for the future development of applications. One of the best and most often touted 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 payoff. Today the laser is found in all aspects of military training and operations, and its use is expanding rapidly.

### *How DoD Views its 6.1 Program*

Historically, with the establishment of the Office of Naval Research (ONR) by Congress in 1946, DoD became the first government organization to formally support basic research. Its commitment to research continued with the establishment of the Army Research Office (ARO) in 1951 and the Air Force Office of Scientific Research (AFOSR) in 1952. However, support for 6.1 work has waxed and waned through the years. For example, in the late sixties, emphasis shifted toward near-term projects as funding was held more or less level. But by the mid-seventies, it was realized 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 its most valuable asset—its relationship with the scientific community and the resulting ability to tap the innovative minds of new scientists and engineers. In 1976, the Secretary of Defense, through the work of the

Defense Science Board, recognized that this pattern of supporting research was unlikely to provide the necessary options for defense needs and sustained technological superiority. A program of real funding growth and increased emphasis on higher-risk, higher-payoff, longer-term research was initiated.

In the same spirit, the President's Science Advisor convened a working group (the so-called "Galt Committee") in 1978 to review the policies and practices of the basic research program at DoD. The panel made several recommendations as well as affirming the importance of a DoD research program that is extensive, vigorous, imaginative, and of high quality. The report endorsed the DoD decision to continue substantial increases in the level of basic research funding, and noted that the maximum quality and effectiveness of such a DoD program was dependent on an appropriate mix of performers including universities, in-house laboratories, industry, and nonprofit organizations.

Three specific actions were taken in response to the panel's recommendations. First, to improve communications between DoD and the research community, bimonthly Research Topical Reviews were scheduled, one for each of the 12 DoD research disciplines. The reviews are held at the National Academy of Sciences and have had an average attendance of over 500, about 50 percent from academia and 25 percent each from industry and government. These meetings provide overviews of each of the topical areas, with some specific programs highlighted, followed by an open forum for discussion of technical and managerial issues of interest to the research community.

Second, the panel recommended that DoD provide a focal point for basic research. This was done in January 1978 with the establishment of the position of Director for Research in the Office of the Deputy Under Secretary of Defense for Research and Engineering. This position has been given broad responsibility for overseeing all DoD research, both internal and external, and is also assigned the role of advocate for the research program. It is in this office that the investment strategy for the research program is evolved, coordinated, and guided. This strategy is the basis for deciding which new, promising programs should be emphasized, which older programs have run their course and should be deemphasized, how DoD's research resources should be allocated, and how the programs' return on investment can be maximized.

Third, to make the contracting process more responsive to the special needs of the research community, a new and greatly simplified contract format has been adopted, the Short Form Research Contract (SFRC). The new format and associated procedures should make contracting for basic research much simpler and more flexible, and should speed up the process between proposal submission and receipt of funds. Phase I of the effort is complete, and Phase II, which will remove unneccessary and inappropriate clauses, is under way.

Most of DoD's extramural research programs are supported through individual contracts and grants. However, a recent innovation in this method of support has been the establishment of multidisciplinary or "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; designated senior scientists, serving essentially as program managers, provide clear direction and coordination. Examples of such programs are the tri-Service Joint Services Electronics Program (JSEP) and 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 reviews. In 1976 only 25 programs (JSEP and oceanography) were of this magnitude. Today there are many more. This is indicated in table A-2 (p 68, appendix A), which shows the distribution of work units by funding, where the "Over $150K" category is substantial, reflecting the increased number of such larger projects. Over 130 such programs exist today.

A special kind of cluster program has recently been initiated by ONR. 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 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 see that it is exploited. Examples of some areas currently considered research opportunities include signature suppression, less vulnerable communications, improved visibility in degraded environments, elimination of corrosion, advanced beam technology, advanced data processing, and ultra-small electronics.

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. Most recently, for example, H. C. Brown of Purdue University received the Nobel Prize in chemistry for his work in synthetic chemistry. He specifically singled out ARO for its important support and its enlightened management policy.

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

*Structure of the 6.1 Program*

The DoD RDT&E program makes up approximately 50 percent of the entire federal R&D budget. Of this, approximately 4 percent is devoted to research. This amounts to about $558M in FY80 and $652M in FY81. In FY80 38 percent of this program was conducted in academia, 33 percent was performed within DoD, and the remainder was carried out in industry, including nonprofit organizations.

The RDT&E program is very much 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 or applied research (6.2) in which the proven concept is used in or applied to some device having potential military application. This is sometimes called the "breadboard" stage. Following this is Advanced Development (6.3), during which a prototype, or "brassboard," of a specific system or subsystem is built and tested as a consequence of the preceding 6.1 and 6.2 work. Finally, Engineering Development (6.4) would reconfigure the successful prototype in preparation for production, should circumstances require it.

The obvious foundation for this 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) has been reactivated. DCOR is a coordination and policy-making group at the level of the Deputy to the Assistant Secretary, which has members from the three Services and the Defense Advanced Research Projects Agency (DARPA) and is chaired by the DoD Director for Research. 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, not only within DoD, but throughout the government. Such groups tend to eliminate duplication of effort, provide for a greater interchange of information, enable the sharing of facilities, and make for more effective use of each agency's funds.

The DoD 6.1 program comprises 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 relate to 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 ($47.2M in FY80) 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 for Research, 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.

And what of 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 closer association to specific military requirements, do bear a somewhat greater responsibility to keep some focus on 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 for Research) and thus to preserve the more fundamental nature of 6.1 programs (compared to the more applied 6.2 programs).

The most important criterion for the acceptance and funding of proposals is quality. Next in importance is potential relationship to the DoD mission. The weight given each of the criteria in the decisionmaking 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, higher-risk, higher-payoff concepts into realities.

*DoD Research in the National Context*

From the time of World War II, the DoD research program has strongly affected our nation in many 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 laser has been supported directly by DoD agencies from the original work in the late fifties through every phase of its development, evolution, and application. The counting 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.

The DoD 6.1 program, at over half a billion dollars a year ($558M in FY80), is primarily responsive to the military needs of the nation; however, through both formal and informal contacts, the research program has influence beyond its defense-related responsibilities. The Technology Transfer ($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 work). Since its beginning, the Consortium has grown to 180 organizations throughout the federal government and is now managed by the National Science Foundation as an interagency organization. Through the years, DoD has been an active participant in the $T^2$ process and has formally reaffirmed its commitment to the program every two years by a memorandum from the Under Secretary of Defense for Research and Engineering (formerly the Director of Defense Research and Engineering).

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, superalloys, corrosion research, superconductors, electronic 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 FY80) is performed by contractors and grantees in the private sector.

*This Report*

This report has been prepared by the Research Office, Office of the Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology). It is intended to inform the research community (in-house and extramural researchers and R&D managers) of the content, objectives, expectations, and rationale of the DoD basic research (6.1) program.

To the outside community, DoD may appear to be an intimidatingly large organization, which a researcher would find difficult to penetrate to find out "who is interested in my idea." To help the researcher find possible sponsors more easily, we 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 Research Office 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.

The part of the report describing the discipline areas addresses each in terms of the major technical thrusts, some of the specific tasks being worked on, areas where increased emphasis is required, and several of the more outstanding recent accomplishments. The discussion covers Army, Navy, and Air Force programs only. The DARPA program is somewhat different in its scope and goals and, as such, is presented in the second part, in which the DoD program is described by agency. Included here is a discussion of the management structure and philosophy of each of the Services and DARPA and a description of the difference in perspective that each agency brings to its research program.

Rather than providing great detail, the report discusses the program by highlighting 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. It should be noted that all funding figures are based on the President's FY81 Budget Request as submitted in February 1980. It can be expected that current figures will reflect certain adjustments to the funding levels shown in appendix A. Appendix B provides a list of points of contact to assist those wishing to gain access to the DoD research community.

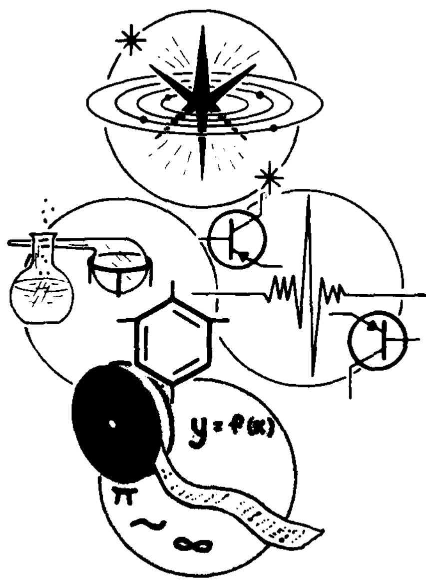
A final word on relevance: we find that all too often good ideas are never brought to DoD's attention because the researcher does not see an immediate "military application." This is unfortunate, since the extramural researcher is not usually the person who should make this determination. We in DoD are 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. The foremost criterion in selecting a proposal is the quality of its scientific content.

**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[c] | Mechanics; Energy Conversion | Mechanics; Energy Conversion |
| Materials | Metallurgy & Materials; Chemistry[c] | 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 on p 57.*
[b] *The Army program division 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 research in the various disciplines are given in the footnotes. For a fuller explanation of the organization of the Army's 6.1 program, see p 45 and appendix A.*
[c] *Programs in this area are also found within 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's laboratories.*
[h] *Programs in this area are also found within the Army Research Institute.*

# *Scientific Disciplines*




# Physical Sciences

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

Fundamental research in the physical sciences is the largest and most diverse area in the DoD research program and, indeed, carries the largest share of funding. 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, spectroscopic investigations and techniques, fluorescence, radiationless transitions, and optical pumping. Of particular interest is the investigation of the properties of Rydberg state atoms, i.e., atoms having an electron in a very high quantum level (fig. 1). 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.

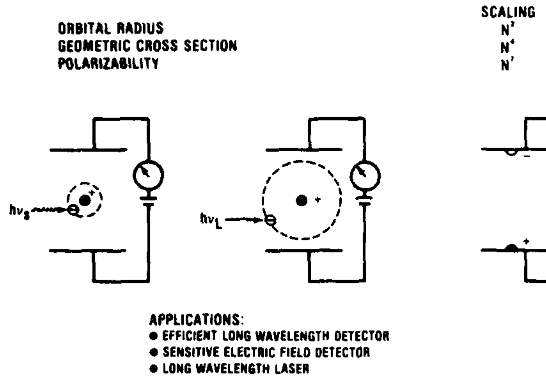



**Figure 1. Rydberg atoms.**

***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. 2). 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 region of the spectrum. It has already generated 1 MW of pulsed power at a 400-μm wavelength, and research in this area is expected to continue.

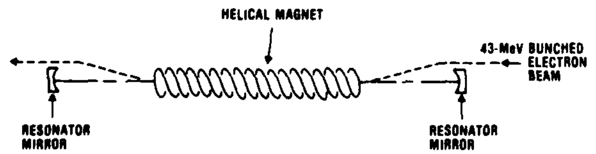



**Figure 2. Schematic diagram of first free-electron laser.**

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.

Research accomplishments in acousto-optic signal processing have been provoking increased interest for several years. A large number of effects have been discovered and a variety of devices built, such as convolvers and correlators (fig. 3). The thrust of this program is to enable very large quantities of data (such as that gathered by radar systems) to be processed in real time and at reasonable cost.

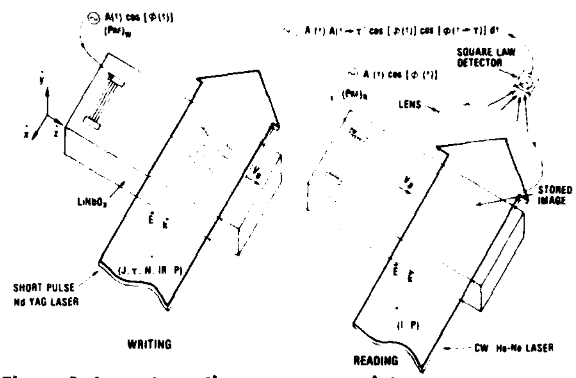



**Figure 3. Acousto-optic memory correlator.**

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.

***Electrical phenomena in gases and plasmas.*** The study of electrical phenomena in gases and plasmas is basically 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 previous area (high-energy lasers).

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 magnets

- 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

***Condensed matter.*** The military interest in condensed-matter physics is extremely broad, including such diverse possibilities 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. One example of work partially supported by DoD in this area is the research on superlattices of Leo Esaki, the Nobel laureate from IBM (fig. 4).

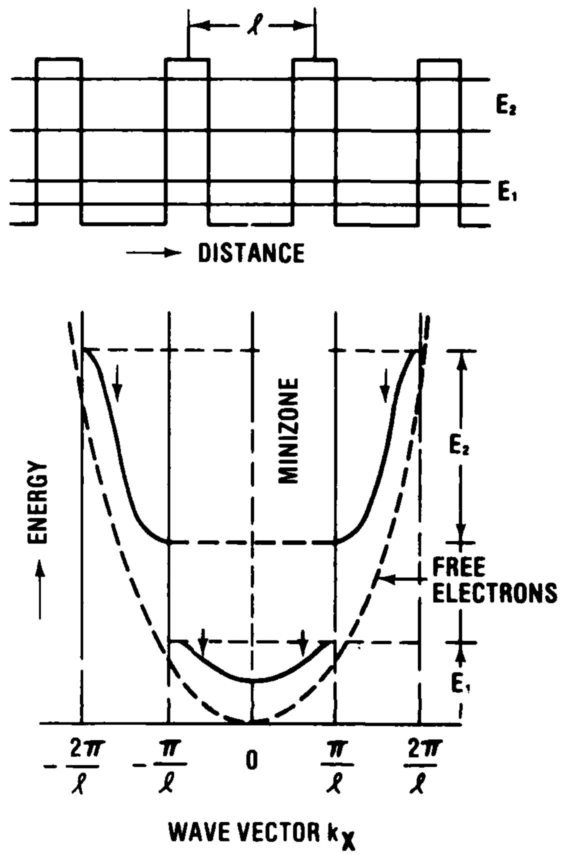



**Figure 4. Superlattice structure gives rise to minizones in wave-vector space, dividing the E-k relation into a series of minibands.**

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. Research on high-temperature superconductive metals has been sponsored by AFOSR.

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

The microwave-tube industry faces a major problem in the gradual loss of talented personnel through the retirement of the pioneering generation and the lack of "new blood" entering this area. This is a critical situation for DoD, which depends on tube devices for many of its systems. A unique program was initiated to counter this trend of decreasing talent. AFOSR, in cooperation with the Stanford University School of Engineering and seven electronics firms, has inaugurated the Air Force Thermionic Engineering and Research (AFTER) program, which supports selected students in a two-year program past the Bachelor's level. The student undertakes course work and independent work in an area pertinent to microwave-tube technology. Tuition and an annual salary are paid by a sponsoring company where the student is employed during the summer. The student graduates with the degree of Engineer, a degree more demanding than the usual Master of Science and specially tailored to enable the student to enter the microwave-tube industry upon graduation. This program is an example of how DoD sometimes must solve its problems in lack of expertise by "growing" its own experts.

***Radiation sciences.*** Because of the great 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. 5). 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.

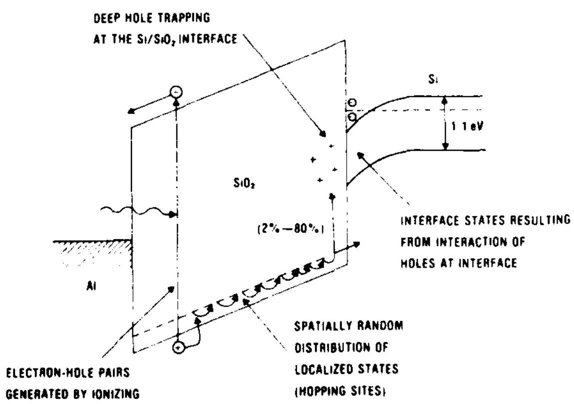



**Figure 5. Schematic of radiation effects problem in metal-oxide-semiconductor structures.**

***Acoustics.*** Much of the DoD support for electro-acoustics 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, communication, 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 communication systems. With the introduction 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.

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. Figure 6 is a 20-day sample of the collected data showing more than 120 x-ray sources, about half of them newly discovered.

Another accomplishment in astronomy is the mapping of the background (nonzodiacal) starlight in both red and blue wavelengths over the entire sky under an

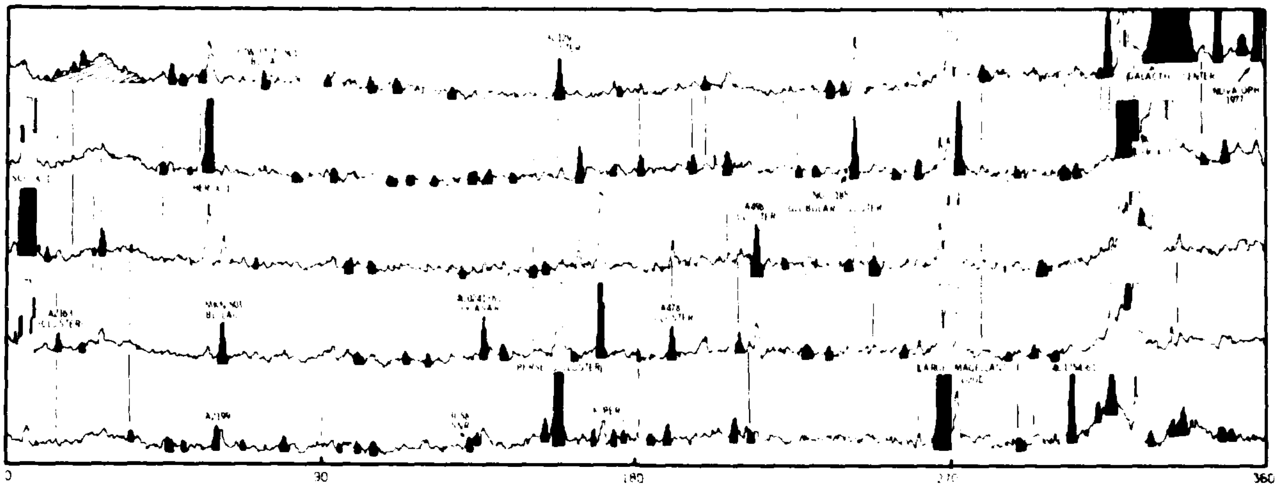


Figure 6. X-ray skymap of the galaxy.

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. 7). Other areas of interest include (but are not limited to) 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.

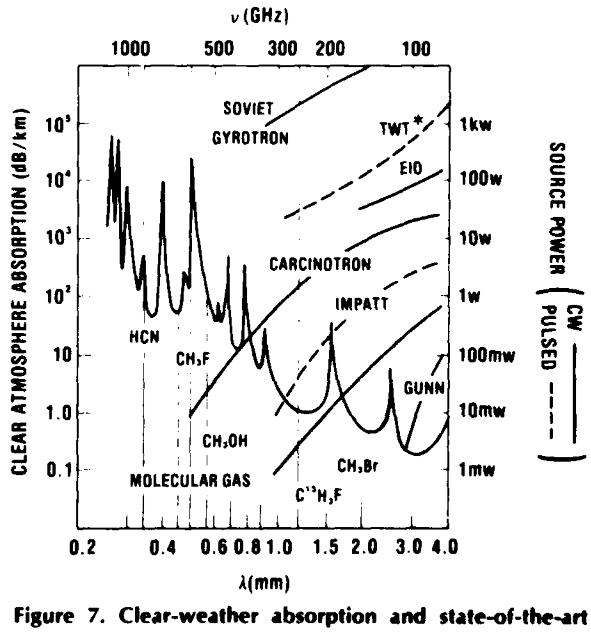



Figure 7. Clear-weather absorption and state-of-the-art source powers in near-millimeter wave region.

# 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 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. A typical program supported in this area is the growth of a GaAs-Si bipolar heterojunction by molecular beam epitaxy. This work has been successfully completed and new efforts will soon begin on a GaP-Si heterojunction.

***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 barely been comprehended at this time. The VHSIC program, now in the developmental stage (6.2), deals with the fabrication of circuit elements on a chip having a resolution in the region of 0.7 to 1.2 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.

Closely related to the VHSIC program is a new effort on Ultra-Small Electronics Research (USER) now being formulated as a tri-Service 6.1 program. The advent of high-resolution electron, x-ray, molecular, and ion-beam lithographic techniques is pushing toward an era of ultra-small devices in which individual feature sizes might well be fabricated on the molecular scale, the goal being 0.02-μm resolution. An idea of the sizes involved here can be gained from figures 8 and 9. Figure 8 shows an LSI circuit which is current technology. Superimposed on the circuit is an amoeba giving a size scale of about 100 μm. Figure 9 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 heterostructure of about 0.015 μm.

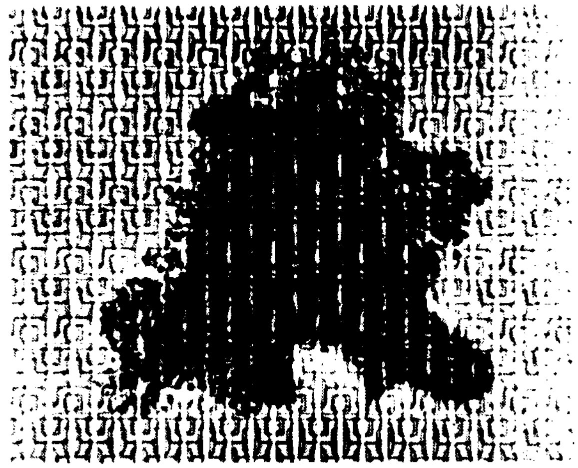


**Figure 8. Amoeba superimposed on LSI circuit.**

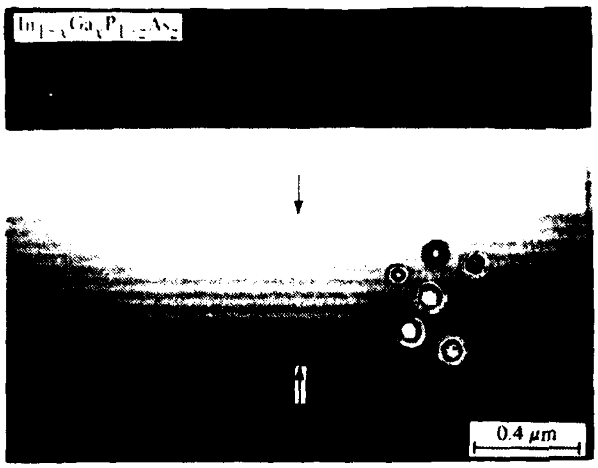



**Figure 9. State of the art in ultra-small electronics technology: leukemia viruses superimposed on heterojunction laser.**

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.

USER has been called one of the last remaining barriers of solid-state electronics where the new fundamental unit is an aggregrate or array of molecules or atoms. The USER program is due to begin 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.

A recent accomplishment in this area is the development of a low-cost antijam antenna. This hybrid analog/digital sidelobe canceller ensures that low antenna sidelobes are maintained, and thus reduces the effects of enemy jamming signals. In general, designing antennas to fit the unusual geometries of military hardware is a continuing problem.

Another major accomplishment in this area is the publication of Volume I of the Near-Millimeter Wave Technology Base Study,* which contains the most up-to-date information available on atmospheric propagation and target and background characterization at these wavelengths.

***Circuits, networks, and related systems.*** The major thrust of this area is improved techniques for the design,

**Available from the Defense Technical Information Center, accession number AD-A079620.*

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, rf, 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.

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.

***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. Two recent accomplishments are significant:

First, it has been shown that uranyl-doped monomers can be readily polymerized with a cw argon-ion laser. Polymerization primarily takes place along the beam profile with little polymerization outside. This technique could be used for high-resolution photoresists and media for three-dimensional holographic information storage.

In a second investigation it was found that lasers can influence the way gas molecules react on surfaces. Figure 10 shows that formic acid decomposes on a heated Pt catalyst surface by two different routes, one producing CO and $H_2O$, the other $CO_2$ and $H_2$. The graph illustrates that when a $CO_2$ laser is tuned to a region of formic acid absorption, the decomposition paths are altered by as much as 50 percent. These results could significantly affect industrial catalytic processes; this technique is a possible means of isotope separation.

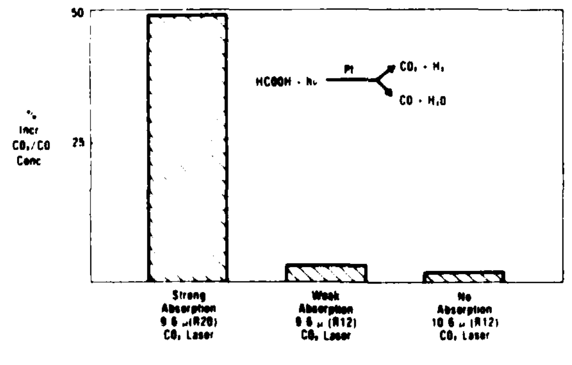



**Figure 10. Laser selective catalytic reactions.**

***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 automobile 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, $(CH)_x$, 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 boron-hydride chemistry resulted in his receiving the Nobel Prize three years later.)

- Investigations into the chemistry underlying the effectiveness of propellants and explosives

- Rapid, safe, and thorough means for destroying chemical agents

- Improved obscurant materials such as smokes, aerosols, and foams

- 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

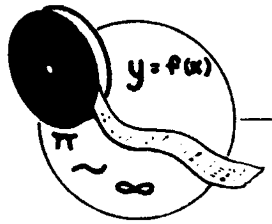
- Enclosed-atmosphere monitoring and purification (e.g., for submarines)

- 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, decisionmaking, 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, $C^3$ (command, control, and communications), and distributed processing in networks.

***Statistics and probability.*** Statistics and probability are related to the broad issues of signal-processing, reliability and maintainability, 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 $C^3$ 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, and 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, and improved methods for parallel processing, artificial intelligence, and robotics.

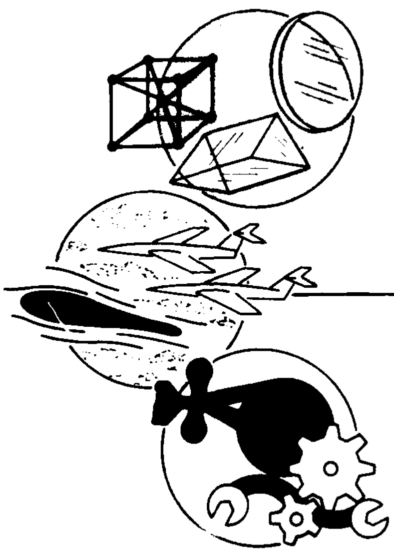
Rising software costs, high error content, and the emergence of new technologies (such as mini- and micro-computers and distributed processing) are problems which the computer software community is facing. Through the formalization of software development, the search for new approaches to software problems,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

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 27)

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. Even the VHSIC program (discussed under *Electronics*, p 17) has as a goal only very modest increases in speed over what is currently possible, compared to what is required. A major breakthrough in this area was the use of a synergism between algorithms and hardware to divide the computational load for many important mathematical operations among very large numbers of very simple computing nodes 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 and Energy Conversion
- Materials
- Aeronautical Sciences

# Mechanics and Energy Conversion

Within the discipline of mechanics and energy conversion are grouped both solid 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.

## *Solid mechanics.*

*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.

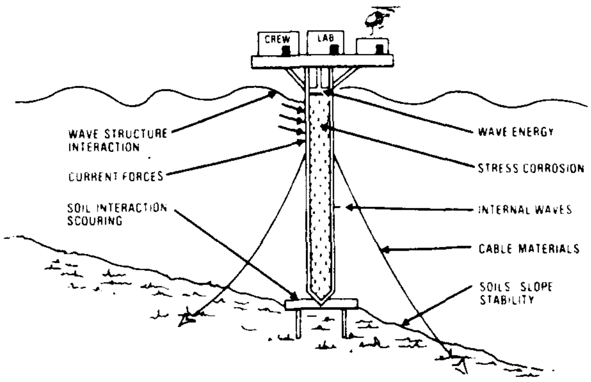



**Figure 11. Analysis of a guyed tower.**

*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.

Figure 11 shows 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 program efforts 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.

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

*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. 12) where the work is centered on the significance of damage below the critical threshold, particularly under repeated compressive stress excursions.

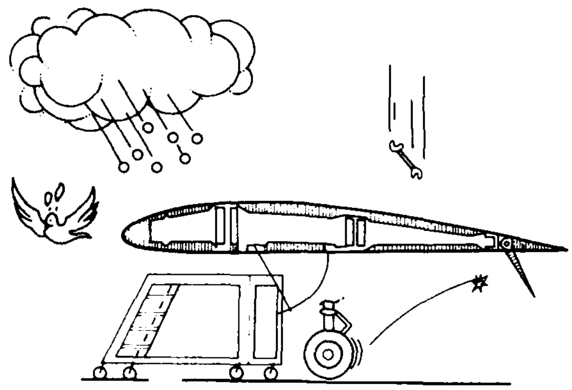


**Figure 12. Impact response of composite structures.**

*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 fluidic 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 31.) 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 13 is a representation of the flow field around the hull of a ship.

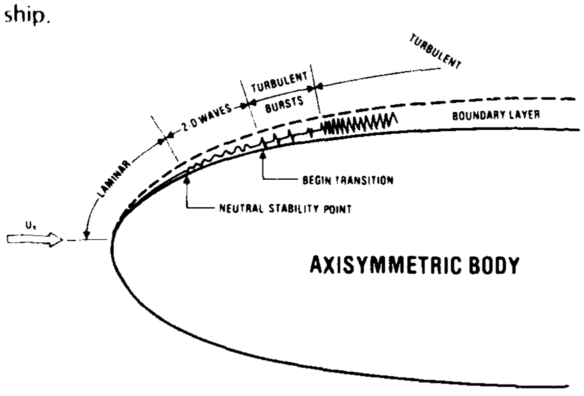



**Figure 13. Flow field around hull of ship.**

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. 14). 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.

***Power generation.*** 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.

***Rocket combustion dynamics.*** Rocket combustion dynamics includes 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, infra-

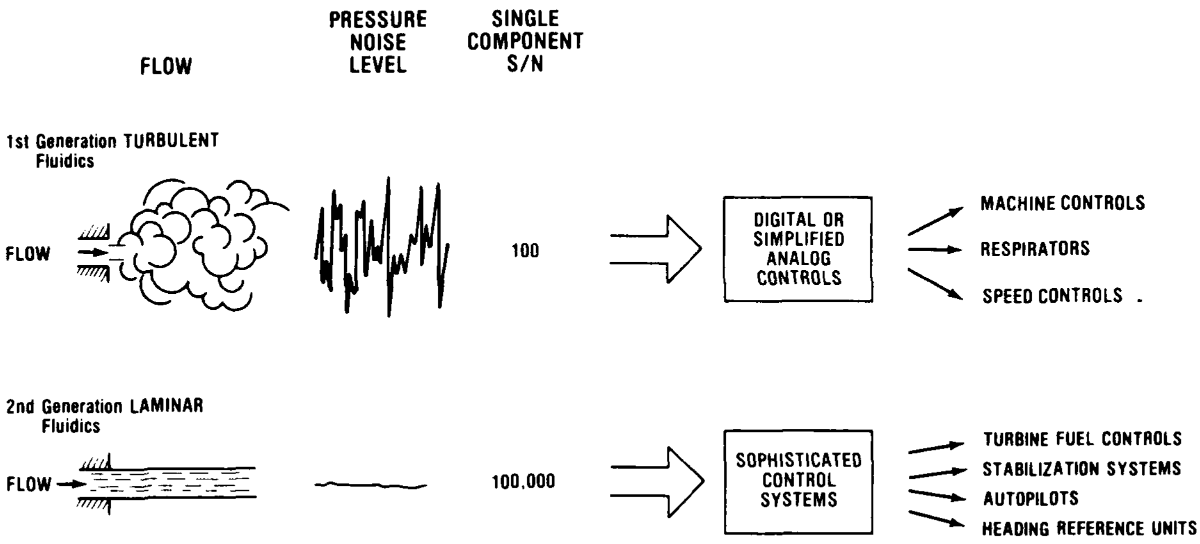



**Figure 14. Advances in fluidic technology.**

red, 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, and coherent anti-Stokes Raman scattering.

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 carburetion, combustion chamber design, fuel injection, and engine materials are being sought.

***Robotics.*** Although this area could be considered a subtopic under *Solid mechanics,* it is discussed separately because of its current importance and because it exemplifies the type of fledgling technology that DoD needs and is ready and anxious to support. The use of robotics in industry is driven primarily by the need for flexible, low-cost, high-productivity automation. American industry has some 2,000 robots at work today, compared to

13,000 in Japan. By 1995 the Society of Manufacturing Engineers predicts that 50 percent of automobile assembly will be done by automated machines and robots.

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.

Currently all three DoD Services are starting with the problem of production, the simplest starting point. The Air Force ICAM (Integrated Computer-Aided Manufacture) project is addressing aircraft manufacture. Figure 15 illustrates a robot-automated assembly station for the F-15 fighter. The Army is also using industrial robots for robotized benching operations and loading of numerically controlled machines for cannon and breach manufacture, and for automated munitions handling.

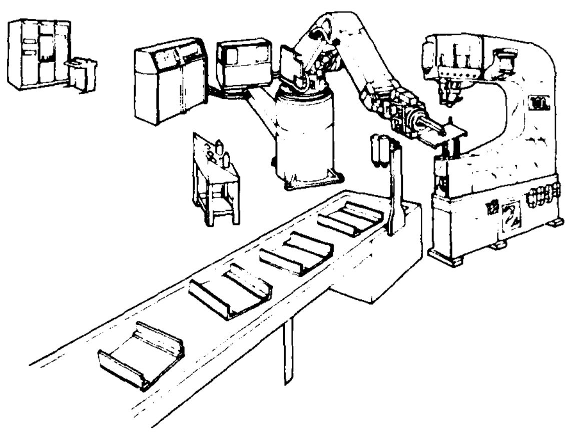


**Figure 15. Production assembly cell.**

In the near future, the use of robots in DoD systems manufacturing will increase in parallel with industry. Maintenance and repair at intermediate- and depot-level activities will begin to use robots as the technology matures to the point where robots can deal with the complications and variations associated with such work. An example of this is the Navy Robotic Deriveter, which is scheduled for a two-year development program beginning in FY81. Deriveting in the Navy is necessary because salt water causes corrosion damage to airframes which must then be dismantled for repair. This time-consuming, tedious, repetitive task will be done by a robot which will use an ultrasonic sensor and common-sense artificial intelligence to "learn" the rivet pattern, rapidly inspect the airframe structure around each rivet, and remove the rivets. This flexible system will be able to handle several sizes of rivets in a variety of patterns on many different aircraft types. Figure 16 illustrates the Robotic Deriveter.

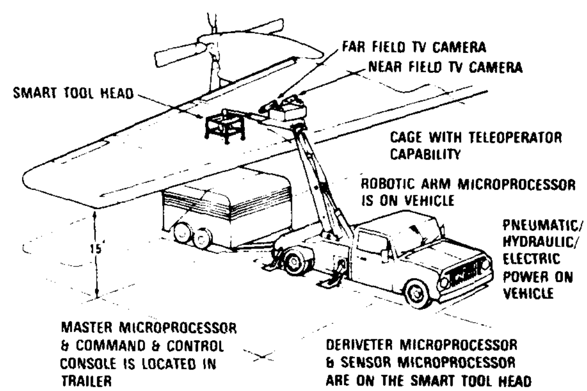



**Figure 16. Robotic Deriveter system.**

In the longer term, robots will be developed for DoD field uses to assist combat and support forces. These field applications will place still greater requirements on robots to be flexible and intelligent, and to have sensory capabilities. An example of such an application is the ONR suggestion that much of the maintenance on board ship could be done more efficiently if each ship used a work cell operated by intelligent robots to manufacture parts needed, rather than carrying vast numbers of seldom-used spares.

Clearly research is needed that will improve the sensory capabilities of robots (including pattern recognition), the thinking capability of robots (that is, artificial intelligence), and the motor and physical dexterity capabilities of robots (an example of such research is the tendon research being done at MIT).

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.

***Degradation and reactivity of materials:*** 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:*** fracture, fatigue, plastic deformation, creep, failure under shock loading, micromechanics of wear and fretting, and shock and laser pulsing

***Synthesis and processing of materials:*** 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:*** relation between electronic structure and magnetic properties of alloys, structure and defects in solid electrolytes, high-pressure equations 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. 17). 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.

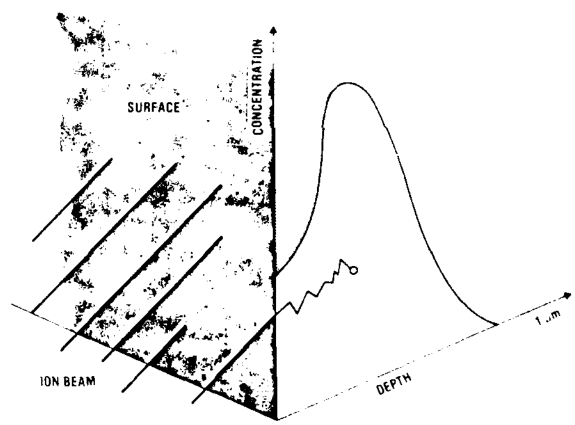



**Figure 17. Ion implantation for surface modification.**

***New concepts in testing, analysis, and simulation:*** 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 one of 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. 18), (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 and polymeric material work centers on the search for materials with high strength-to-weight ratios, low cost, and high durability. Such 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.

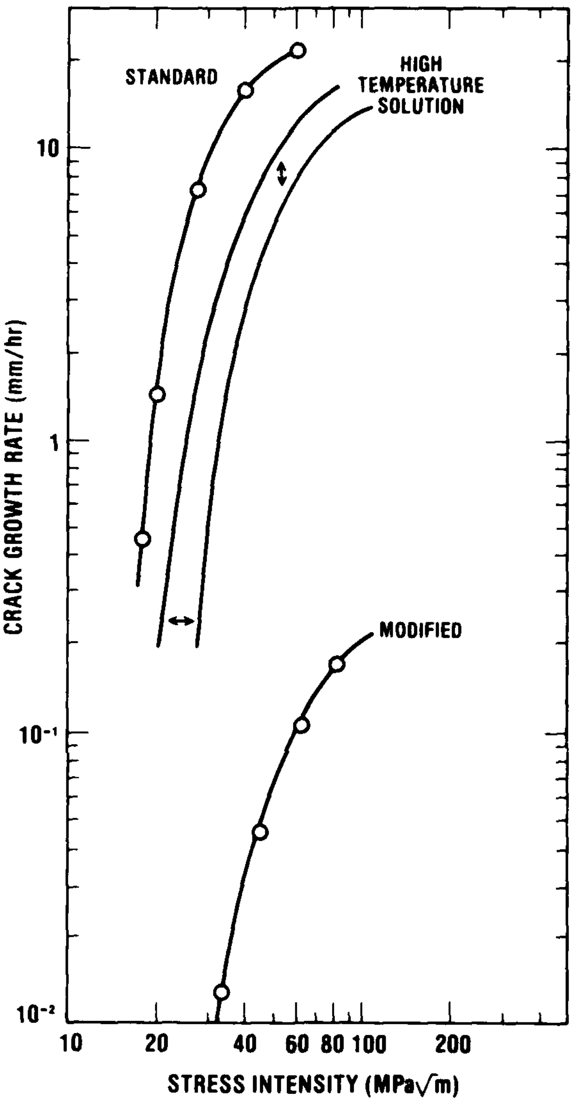


**Figure 18. Crack growth in Alloy 718 at 650°C.**

The wide use of both fixed- and rotary-wing aircraft and missiles in DoD naturally leads to an interest in basic research to improve understanding and performance. As might be expected, the Air Force has such an all-encompassing concern in this area that it does not even recognize aeronautical sciences as a distinct research area: Air Force research in all relevent disciplines, such as mechanics, materials, combustion, fluid flow, and electronic controls, is directed toward solving problems in the operation of missiles and aircraft. However, since DoD as a whole recognizes aeronautical sciences as a distinct area, certain specific problems are highlighted here.

***Rotor dynamics.*** 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, 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.

***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 nonsimple 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. An example of an axially symmetric jet in the vicinity of the ground is shown in figure 19.

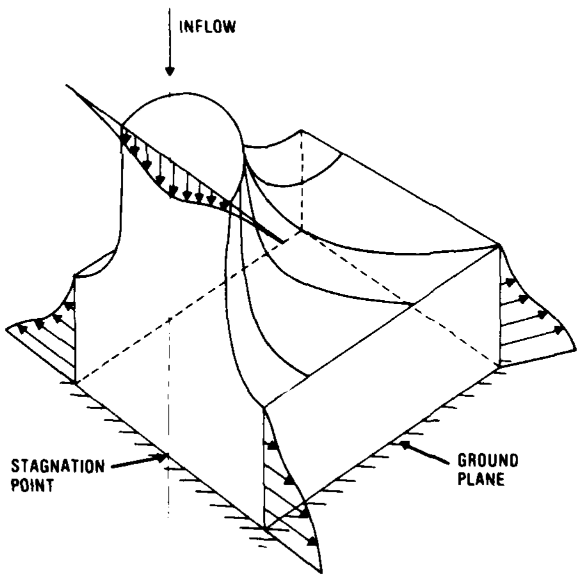



**Figure 19. Jet impingement near ground level.**

***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. 20a and b), and the distortion can be particularly severe at transonic speeds. Using the concept of active wall control (fig. 20c), a joint Navy-Air Force research effort has been able to significantly reduce wall-interference effects in demonstration experiments.

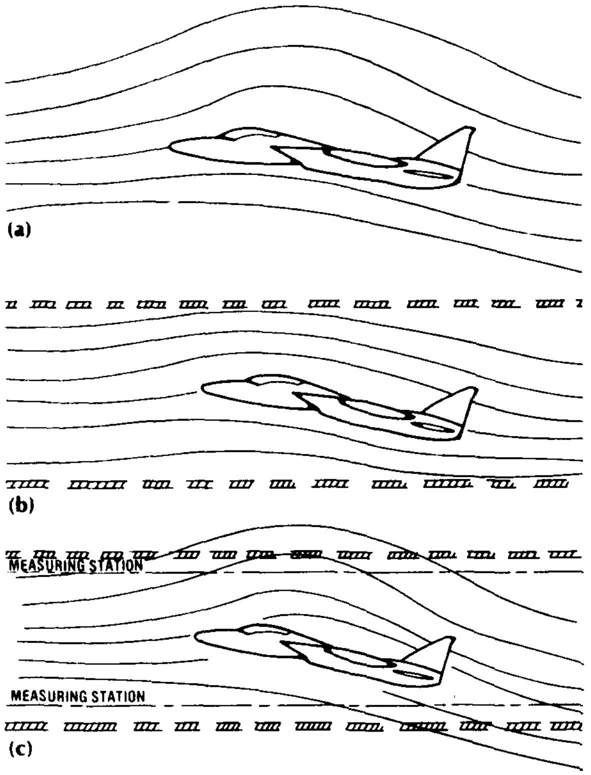
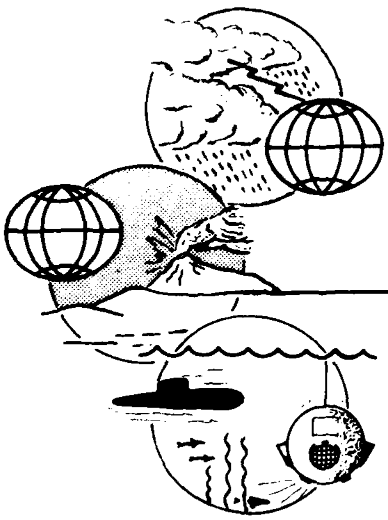



**Figure 20. Effect of active wall control on wind-tunnel simulation: (a) unbounded flow, (b) conventional tunnel flow, and (c) adjustable tunnel flow.**

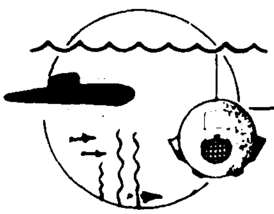
***Power plant internal flow.*** In addition to the external flow aspects of the problems discussed above, numerous problems of internal fluid dynamics and of reactive and nonreactive flow are associated with turbine and ramjet engines; these questions must be addressed for both the subsonic and hypersonic flight regimes. 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. 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. Experiments are directed toward quantifying the role of large-scale coherent structures in turbulence models of reasonable generality and greatly increased accuracy.



# *Environmental Sciences*

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





Predictably, oceanography is of primary interest to 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 North Pacific experiment and the Joint Air-Sea Interaction (JASIN) experiment (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 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 anisotrophy, 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 tracers, 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 the evolution or aging of a Gulf Stream cold core ring by analysis of the gradual dissipation of the cold water fauna in their new, warm, Sargasso Sea environment. A second type of research here is in marine biology: the study of the biology, physiology, and biochemistry of organisms that live in the sea. Examples here might be studies of the calcium-carbonate metabolism of a wood-boring mollusc or the cellulose digestive process 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 of the projects that are attempted is an optical system that is being designed to replace nets for upper-ocean fish density studies. This unit will be towed at speeds up to 12 knots, faster than most nets, and eliminate the integration or smearing effects that characterize net tows. The scientist will be able to know what fish are present and how they occur along a given track. A second example is a project recently initiated to establish the limits of underwater photographic and television systems with respect to image resolution and the area that can be covered, 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 projects include a cable analytics project to assess the feasibility of re-entering a deep-sea drilling hole without the use of a drilling ship, computer analysis to separate mooring motion and instrumentation artifacts from near-surface oceanographic data obtained in the JASIN experiment (NW of Scotland in September 1978), 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 sea-floor 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. Experimental work includes studies of the earth's ocean crustal structure, its variation with age, its lateral homogeneity, and how water-generated sound propagates in the ocean bottom. 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 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. For example, multibeam echo sounders will be installed on at least two of the research vessels in joint programs with the University of California and NSF. 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

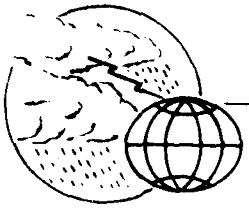
Research in the terrestrial sciences is needed to fill gaps in our understanding of and ability to predict processes governing the structure and dynamics of the earth, snow and ice, and coastal regions. Requirements for such knowledge stem from the obvious needs of combat operations, surveillance, navigation, 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, 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 meeasuring earth properties *in situ* (at the earth's surface or down bore holes) and for using relationships between these measurements and comparable laboratory measurements to determine unique solutions to geophysical survey data, and (3) stress-wave propagation in unconsolidated, anisotropic 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 to 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.



## 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, precipation), 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 man-made 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.

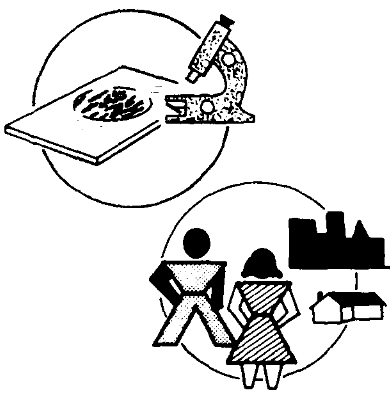
***Atmospheric sensing and probing.*** Atmospheric sensing and probing requires instrumentation, techniques, and modeling of the optical properties of the atmosphere including natural and man-made aerosols, remote measurement of standard meteorological parameters, and the use of satellites and remotely piloted vehicles for meteorological observations. This instrumentation includes millimeter-wave sensing of the upper atmosphere for stratification and variability of water vapor and other molecular constituents. An important development in satellite technique is that of looking through the limb of the earth at the sun to obtain profiles of atmospheric constituents and properties from the high atmosphere to the surface. With this technique it would be easy to detect desert sand storms and also the thin cirrus cloud layers that escape detection by conventional satellite and radar techniques.

***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.

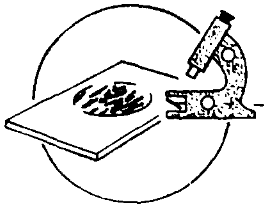
***Atmospheric radiative processes.*** The study of atmospheric radiative processes includes the measurement and modeling of upper atmospheric processes that control infrared and optical emissions in auroral and nuclear-disturbed atmospheres; the determination of spectral, spatial, and temporal variability 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 composition/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 on communications systems and the development of new communications capabilities.



# 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.

Among other topics of interst are innovative materials for human protective clothing and equipment; new ways of preparing, preserving, and delivering nutritious, wholesome, and acceptable food to the combat field; and possible enhancement of human sensory perception. This latter depends on a fuller understanding of perceptive mechanisms.

***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. 21). 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.

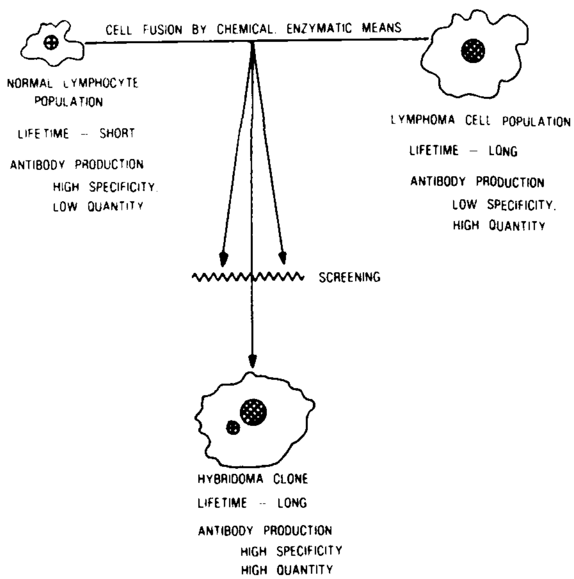



**Figure 21. Monoclonal antibody production.**

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 decisionmaking.

***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.

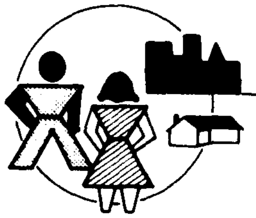
Other topics of interest in this area include improved diagnosis of injury, anesthesia, and the basis of traumatic shock. Much recent interest centers on the possible role of endorphins in ameliorating pain and shock.

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 aims 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 confinement 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)

*Personnel turnover and retention:* research and development on the causes and effects of personnel turnover

*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 individualization 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, quantifiable 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 an individual's cognitive aptitudes and competencies, and improving those competencies through training. The work on those theories and methodologies falls into four main clusters.

*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, decisionmaking, 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 performance 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 and related display technologies.

*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 significantly increasing attempts to understand more complex supra-threshold 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 decisionmaking.* 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

The Army's basic research program is divided into two distinct segments, the in-house work performed in the Army's 34 laboratories, and the extramural effort administered by the Army Research Office (ARO). Figure 22 shows the relation of the various organizations involved in research efforts to the command chain. The bulk 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. With such a broad mission it naturally performs most of the Army's research program (75 percent for FY81). The remainder of the program is divided among the Army's so-called "little three:" the Surgeon General's Office and the Medical R&D Command (18 percent), the Corps of Engineers (5 percent), and the Army Research Institute for the Behavioral and Social Sciences (2 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
Mathematics
Mechanics and aeronautics
Physics

The ARO program is a mix of short-, mid-, and long-term programs; the first two are more responsive to the needs of the Army laboratories, while the long-term programs reflect the judgement 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 contacts. ARO has also allowed part of its program in recent years to be somewhat shaped by its direct interactions with the in-house labs. An example of this is the increased emphasis in several of its divisions on various aspects of near-millimeter wave technology, resulting from very intensive joint planning in this area between ARO and several of the in-house laboratories.

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.

***In-house program.*** The in-house laboratories program is not organized along the lines of scientific disciplines. Rather, 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. It 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 DARCOM SPF's is formally reviewed each year by ARO,

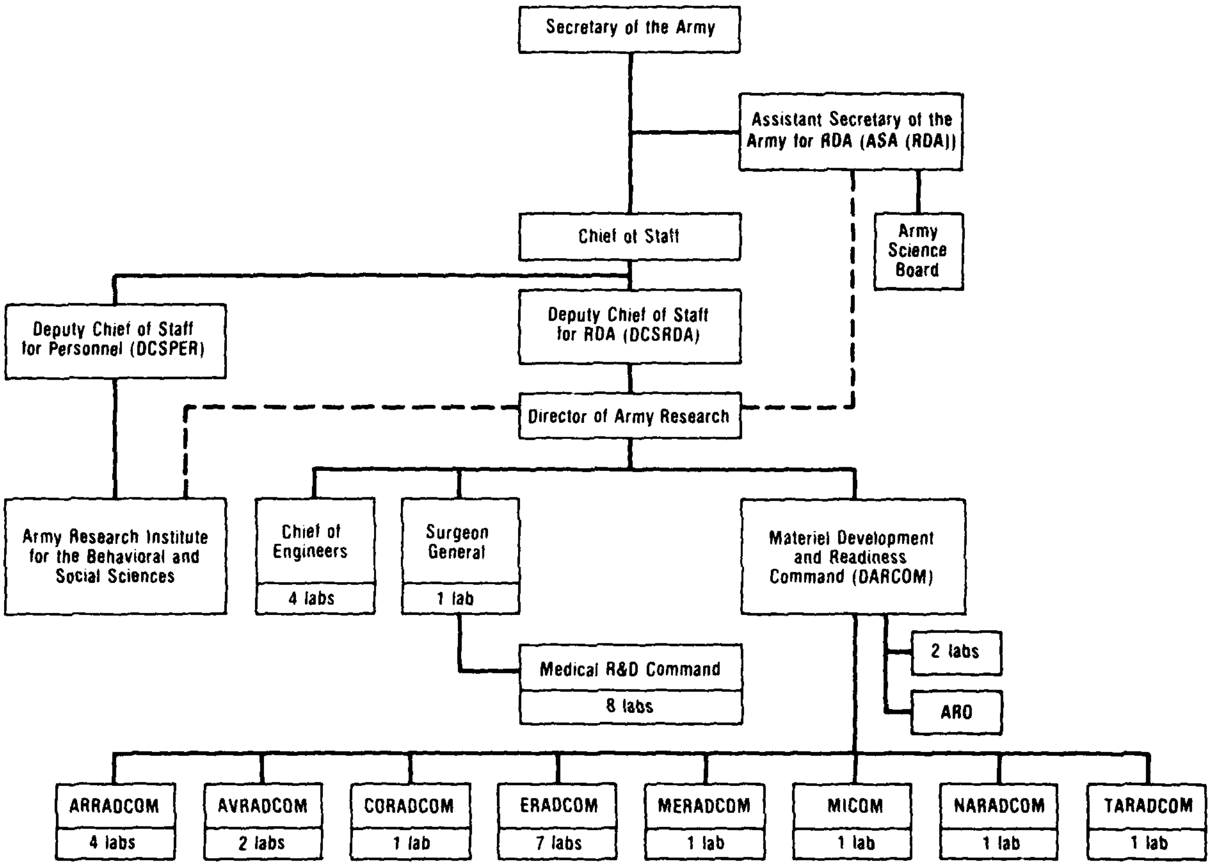



**Figure 22. Army research management structure.**

which acts in this role for DARCOM and Department of the Army Headquarters. The results of the review are reported at the same director's meeting at which the labs evaluate the ARO program. This reciprocal 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. As a regular part of their responsibilities, the ASB assists the Assistant Secretary in reviewing the Army's ILIR program every year.

***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 nine technology areas of emphasis. These are topical areas which respond to specific military needs or problems 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 DARCOM Headquarters and/or the Office of the DAR. The nine areas of emphasis follow.

*Armor/anti-armor technology:* improved armor materials and improved methods of defeating armor, such as kinetic energy penetrators

*Gun propulsion technology:* interior ballistics, new projectile propellants, caseless ammunition, gun tube wear, and erosion

*Millimeter/near-millimeter wave technology:* exploitation of the MMW ($K_a$ band to 70 GHz) and NMMW (100 to 1000 GHz) spectral regions to enable operations in limited-visibility environments

*Smokes and aerosols:* techniques for producing and dispersing materials to mask combat operations from enemy surveillance and to enhance our own operability in a smoke environment

*Microelectronics:* continued improvement in the technology to produce electronic circuitry yielding new capabilities for radar systems, "smart" missiles and projectiles, surveillance, electronic warfare, and communications applications

*Targets versus background signatures:* techniques to discriminate targets from their backgrounds for use in a variety of imaging, tracking, seeking, or guiding systems at various wavelengths; atmospheric effects on target signatures, atmospheric modeling, and radiometric and spectroscopic measurements

*Mobility energy:* engines and fuels for higher efficiency, power, and reliability, and lower cost; reduced dependence on nondomestic fossile fuels

*C³I:* Command, control, communications, and intelligence technology; modeling of C³ systems to provide totally compatible systems integration

*Fire control technology:* increased precision and speed in acquiring and tracking targets, including on-board data processing and stabilization systems, fire-on-the-move and multiple target capabilities

***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 higher resolution of the infrared 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). The Harry Diamond Laboratories (HDL) was asked to evaluate this potential capability and make recommendations to DARCOM and the Director of Army Research. HDL assembled a 50-member committee of experts from government, industry, and academia. The panel met for five months to evaluate the state of the art and outline critical technology gaps. Members of the HDL staff then did a thorough analysis of the current and proposed programmatic aspects of the technology.

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, ARO added emphasis to its academic programs, and international contacts were made. The result of this effort was one of the most deliberate, unified, and well-planned forays into a new technology that the Army has ever made.

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. 23), 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 study and test novel concepts in naval operational systems. The scientific divisions in support of these research and development programs encompass many disciplines, as follows:

- Arctic and earth sciences
- Biological sciences
- Material sciences
- Mathematical and information sciences
- Ocean science and technology
- Physical sciences
- Psychological 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 Ocean 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 25 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

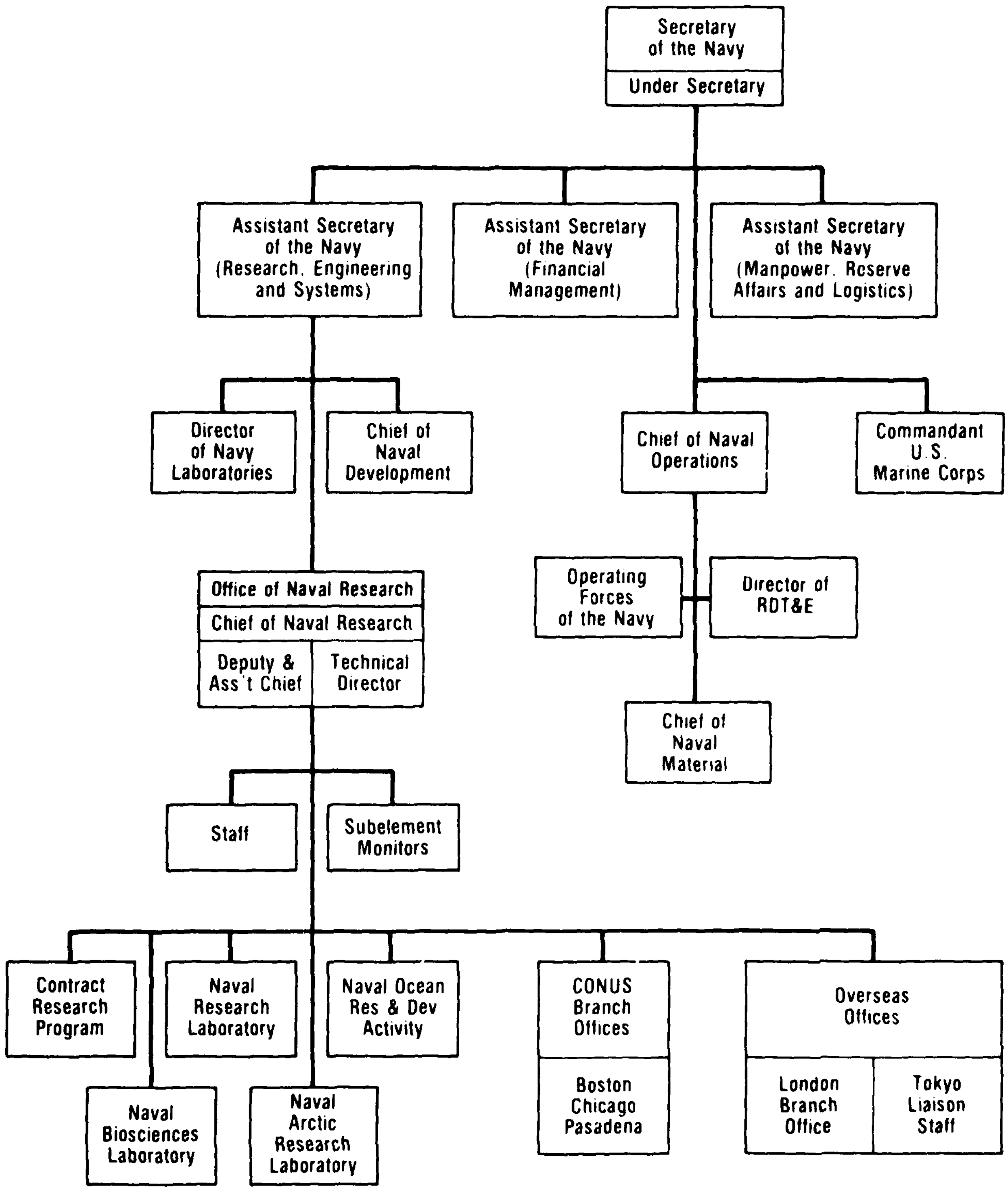



**Figure 23. Navy research management structure.**

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 coordinated 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

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 24, 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 50 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

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 mid-term and long-term 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 objectives within the technical area. The presentation for each subarea contains a short description of its scope, the mid-term requirements, the long-term requirements, and a listing of points of contact in appropriate laboratories. If possible, mid-term requirements are correlated with research needs stated in Technology Planning Objectives defined by each laboratory and by technology needs submitted to the laboratories by AFSC

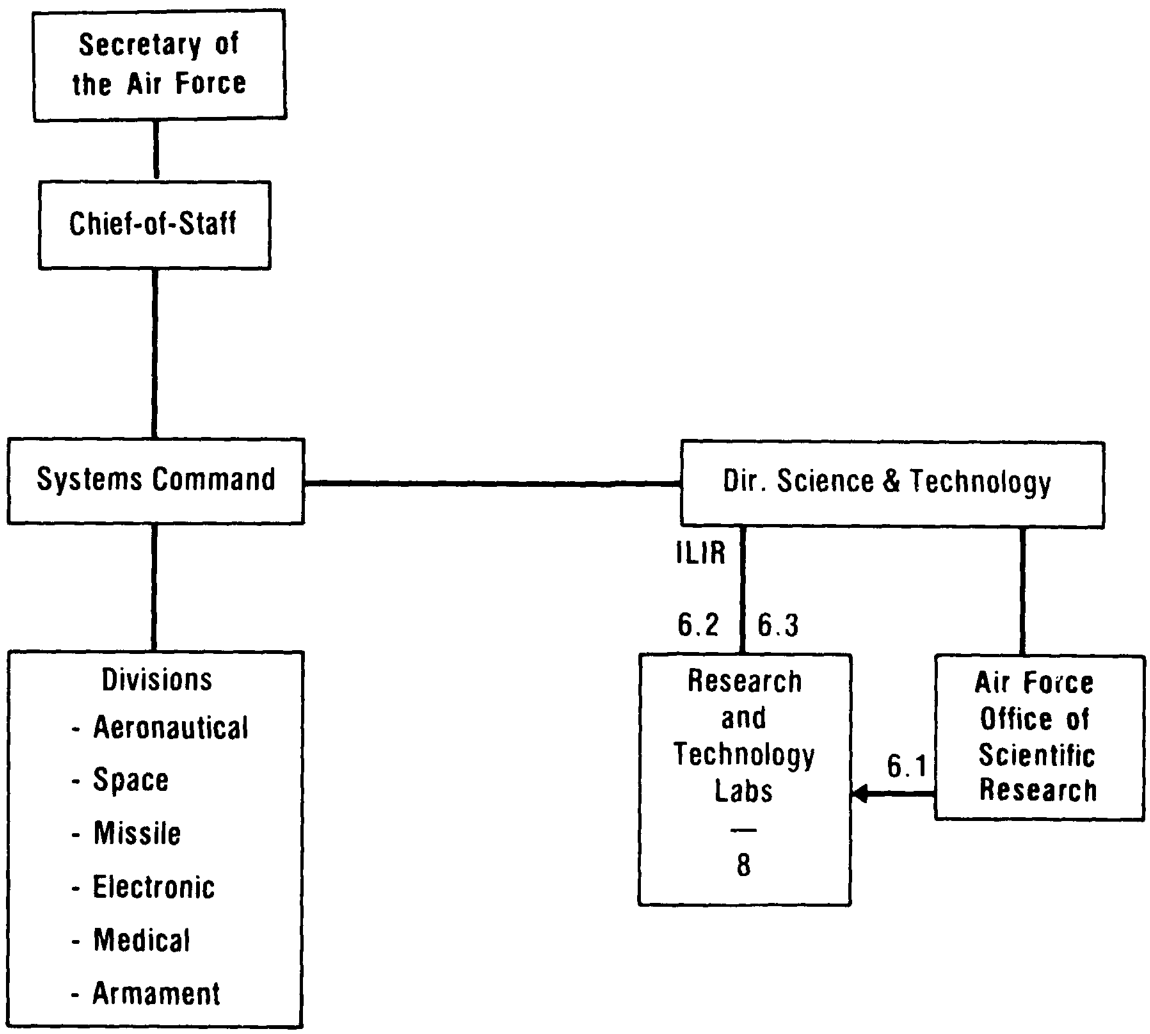



**Figure 24. Air Force research management structure.**

organizations. Long-term requirements are based on Air Force scientists' knowledge and evaluation of the scientific areas of greatest activity and potential.

**Multi-investigator programs.** University programs, particularly those in scientific areas targeted for increased funding, are encouraged to develop into multi-investigator (cluster) programs, in which the efforts of a number of people can be coordinated, and adequate instrumentation and technical support can be provided. This was the style of many successful research programs in the late fifties and early sixties; this form was responsible for considerable scientific progress and for the development of many prominent national leaders of the present day. Such programs were largely discontinued, however, in the early seventies, when drastic reductions in research effort resulted in a proliferation of research programs of much smaller size. This proliferation is judged to have been generally counterproductive, and affirmative efforts are under way to restore the multi-investigator program as an important research form. As funds become available, sizable multi-investigator efforts can be initiated. The objectives of this type of research program will be to explore new ideas, provide long-term stability, encourage junior faculty and post-doctoral fellow participation, and at the same time increase research effectiveness through group efforts. Major programs in critical areas such as energy-efficient transonic flight, directed-energy weapons, self-adjustive dynamic systems, and command and control architecture will be investigated through FY82.

## 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. Like his counterparts in industry, the Secretary of Defense needs a flexible organization, reporting at the highest levels, working at the cutting edge of technology. DARPA's purpose is to discover innovative multi-Service applications of new technologies to potential future defense missions, to provide alternative approaches to ongoing Service developments, and to provide centralized management of programs of significant interest to the Under Secretary of Defense for Research and Engineering. DARPA's role in basic research, and in the successive phases of development and feasibility tests and demonstrations, is to develop selected new ideas from conception to hardware prototypes suitable for transfer to Service development agencies. 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 conducts research and technology development when the risk and payoff are both very high and where the success may challenge traditional roles and missions with new options. Since DARPA has no operational missions, it can maintain a broad perspective in pursuit of the revolutionary research concepts that promise future technology breakthroughs. DARPA's present organization is indicated in figure 25.

***Method of operation.*** DARPA is supported from appropriations for "Research, Development, Test and Evaluation, Defense Agencies," and its program and budget are presented to Congress annually. Because it has a small staff and lacks in-house RDT&E or procurement facilities, DARPA does not conduct in-house research, but relies on the Military Departments and other government agencies for technical and administrative support. DARPA programs are conducted through contracts with industrial, university, and nonprofit organizations in the private sector and with selected Service R&D laboratories. DARPA's programs are executed through Service R&D organizations to augment technical review and coordination and to facilitate the eventual technology transfer to the appropriate Service.

As an example of this method of operation, suppose DARPA decides to support an unsolicited proposal for research in advanced air vehicle technology. The Air Force Systems Command Flight Dynamics Laboratory (AF/FDL) is known to have the Air Force mission responsibility and the desired technical expertise in this R&D area, and DARPA arranges for AF/FDL to assist. Generally, informal contact is established between DARPA technical personnel and those of like interest at AF/FDL. When agreement has been reached that AF/FDL will become the agent and technical monitor for the work performed, DARPA issues a document called an "ARPA Order" (AO). The AO, which starts the procurement process, also (1) transfers the necessary funds, (2) states the scope of work, (3) stipulates the period of performance, reporting requirements, security considerations, and other details, and (4) delegates the full responsibility for contracting under the policies and procedures pertaining to AF/FDL.

***DARPA program planning.*** In planning the DARPA basic research program, an investment strategy is used to maximize the chances for payoff and assure that the technology program is directed toward future military requirements.

Current DARPA research is directed toward requirements in several major application areas: antisubmarine warfare, space defense, space surveillance, air vehicles and weapons, cruise missile technology, $C^3$, nuclear verification technology, and land combat.

DARPA basic research projects include efforts in many of the basic DoD disciplines. The primary disciplines are as follows.

Physics
Materials
Electronics
Oceanography
Mathematics and computer sciences
Terrestrial sciences
Atmospheric sciences
Aeronautical sciences

DARPA research is usually interdisciplinary and focused generally on potential contributions to the national defense and specifically on the expansion of the U.S. technological base needed to meet future strategic and conventional weapon system requirements. Areas of major emphasis are included under the agency's 10 major research and technology development thrusts, described below.

1. *Advanced cruise missile technology.* The DARPA Advanced Cruise Missile Program (ACMP) is directed toward those technologies which will significantly improve the performance of next-generation cruise missiles. This need will increase as our military adversaries develop more effective defenses against cruise missiles.

ACMP has four major elements. First, the Advanced Delivery Systems Program is investigating unconventional design and launch modes, as well as various synergistic subsystem technologies, in order to improve the range-payload product and penetration capability. Second, the Autonomous Terminal Homing Program is developing the precise guidance techniques which will allow broad classes of fixed, high-value strategic and theater targets to be effectively destroyed with nonnuclear munitions. Third, the Advanced Cruise Missile Engine Program is developing high-payoff engine concepts which promise to reduce fuel consumption significantly compared to current cruise missile engines, thus permitting the development of smaller vehicles or vehicles with more range-payload combinations for advance mission options. The addition of advanced ceramic materials to critical high-temperature engine components is also being investigated with the objective of increasing the thrust and thus the performance of near-term engine options.

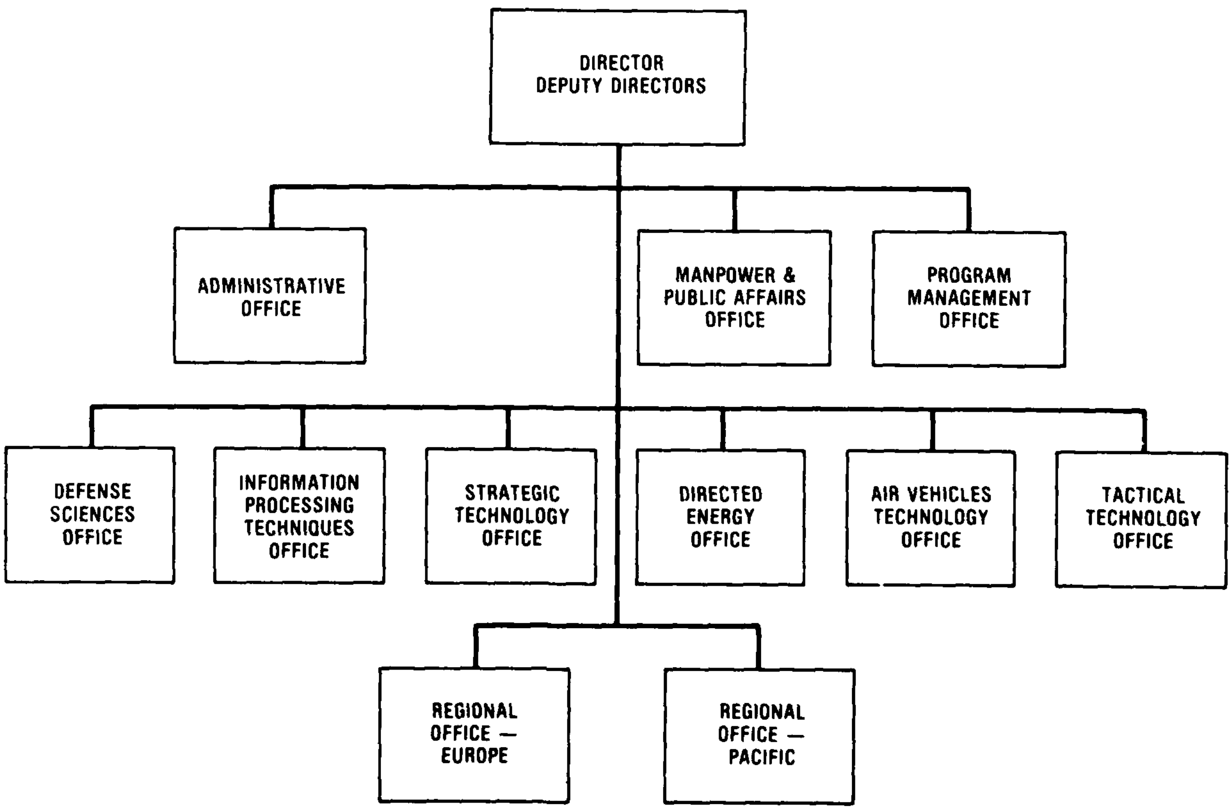



**Figure 25. DARPA research management structure.**

Finally, the program in Advanced Cruise Missile Detection Technology was intiated to characterize and assess potential technologies for defense against cruise missiles. The results of the program should provide DoD cruise missile technology development programs with insight into methods of defeating such defense technologies; also being developed is detection experimentation capability to realistically evaluate the survivability of such advanced missiles.

2. *Space defense.* Space-based military systems play a vital role in the strategic posture of both the U.S. and the Soviet Union. The purpose of the space defense program is to examine space-related military applications and to develop critical technologies necessary for these applications.

Near-term projects concentrate on high-efficiency infrared chemical lasers, large lightweight telescopes, and a precision pointing system for long-range military applications. DARPA has initiated three major programs to demonstrate the key elements of the required technology. These three major thrusts are (1) high-power chemical lasers, (2) acquisition, tracking, and precision pointing techniques, and (3) the beam expander. DARPA is also developing technologies that have potentially high payoff for the longer term. An example is the development of laser radar technology that achieves high resolution by adaptively correcting for atmospherically induced beam aberrations.

3. *Space surveillance.* The DARPA program for space surveillance is expanding the technology base for advanced system concepts to support a broad spectrum of surveillance missions from space-based sensor systems. Examples of these missions include ballistic missile launch warning and tracking, aircraft detection and observation, surveillance of space objects, and, growing in importance, tactical theater surveillance. In addition to classical surveillance and warning missions, a potential capability is evolving for space sensors to perform greater roles in force management, force execution, and damage assessment to support subsequent decisions or evaluate options. A variety of advanced system concepts are being explored to efficiently perform surveillance functions, concepts that range from large sensors at very high orbital altitudes to proliferated smaller sensors at lower altitudes, as well as appropriate mixes for specialized functions.

Advanced sensor concepts use staring infrared detector mosaic focal planes as opposed to the scanning sensor techniques currently employed. The staring sensor inherently provides many orders of magnitude more sensitivity and full-time spatial coverage. Detectors with broad coverage of the infrared spectrum and spectral filters provide a common technology base for a number of strategic surveillance missions, preserve a launch warning capability in the presence of modified signatures, and suppress the effects of interference.

4. *Antisubmarine warfare.* The DARPA acoustic antisubmarine warfare (ASW) program seeks to evaluate, by analysis and experiment, the potential of new technologies and system concepts which are related to the surveillance of current and projected strategic and tactical submarine forces. The program encompasses order-of-magnitude improvements in the performance of passive acoustic systems, advanced signal processing, and integration strategies to link multiple sensors together. The program emphasizes the development and evaluation of major at-sea experiments for proof-of-concept demonstrations. Successful attainment of the DARPA acoustic ASW goals will provide the basic technologies necessary to cope with future generations of quiet submarines operating at longer ranges.

DARPA's nonacoustic ASW program is examining the feasibility and effectiveness of detecting some of the myriad nonacoustic submarine signatures that are not now being exploited by U.S. ASW forces. The program is intended to investigate the new technology issues from the viewpoint of both future U.S. ASW use and vulnerability assessment.

5. *Land combat.* Many development efforts in land combat address specific research objectives and/or operational deficiencies. Representative examples follow.

- Advanced Indirect Fire Support (AIFS) Program.—To improve our capability in the main battle area, DARPA has started two major initiatives in its land combat technology area. A DARPA/Army/industry group has defined initiatives for the next generation of artillery, which should be able to interdict armor beyond the line of sight and to use smart sensors without laser designators. DARPA, jointly with the Army, has initiated a critical technology demonstration for this program, employing advanced terminal homing infrared and millimeter-wave seekers and a tube-launched ramjet projectile for extended range. This program will move rapidly and culminate in seeker field trials and projectile firings in 1981.

- Tank Breaker Program.—DARPA and the U.S. Army have begun to develop the technology needed for a lightweight, shoulder-fired, fire-and-forget missile to be used in the main battle area. This program is based on successful DARPA field trials of the integrated infrared focal-plane-array seeker, conducted this past summer. These trials were the first successful demonstration of focal-array technology in a tactical environment. We will couple this program with work on the advanced shaped-charge warhead in order to demonstrate the total capability of viewers, seekers, missiles, and lethal mechanisms. This advanced development will culminate in live firings in late 1981 or early 1982.

6. *Air vehicle technology.* Development efforts in air vehicle technology are typified by the following programs.

- Forward-swept wing.—The possibility of using the forward-swept wing (FSW) concept for high-performance aircraft depends on the exploitation of the unique properties of advanced composite materials to avoid problems caused by the phenomenon of aeroelastic divergence. The DARPA program is directed at experimentally quantifying the design-performance advantages of FSW designs and at producing a confidence level that will allow for their use in any future tactical aircraft design. Judging from the results to date, it may be possible to design an FSW tactical aircraft that is lighter and consequently cheaper than equivalent aft-swept aircraft: the reduction of aircraft drag in the FSW design translates directly into smaller engines and lower fuel requirements. Wind-tunnel tests are currently being performed to verify the theoretical performance predictions. The next phase of the program will identify technology issues and resolve these issues by the preliminary design of a flight-demonstration vehicle.

- X-wing aircraft.—The X-wing concept combines the vertical-lift efficiency of a helicopter with the high-speed performance of a fixed-wing aircraft by stopping the rotor (in an X configuration) in forward flight. Analysis and test results indicate that an operational X-wing vehicle would have approximately three times the range and speed of a conventional helicopter with equivalent payload-lifting capability. Key to the concept is a method for increasing blade lift by a circulation-control scheme based on blowing air through slots in the rotor blade edges. These special rotor blades must be exceedingly stiff, as in the FSW, and are now made possible by developments in advanced composite materials. The goal of the effort is to show the feasibility of the concept with a demonstration of a 3200-lb vehicle. A full-scale rotor hub and blade assembly has been built and tested. Tunnel tests took place in February 1979, in the 40 by 80 ft wind tunnel at NASA Ames. The next phase of the program calls for the fabrication and flight testing of the demonstrator vehicle.

7. *Command, control, and communications ($C^3$).* As an adjunct to the weapons technology described above, our $C^3$ program emphasizes technologies and architectural concepts for efficient communications (both inter- and intra-theater) and battle management. The DARPA $C^3$ thrust seeks to increase the effective combat power of our forces through the application of computer-communications and information-processing technology in tactical operations. Through a series of technology programs and application testbeds with the Services, we hope to demonstrate that our $C^3$ system has superior survivability, mobility, security, and overall reliability.

Packet-switching technology is the basic computer communications capability and has been applied to satellites, ground tactical radio, and terrestrial nets (including the Automatic Digital Network—AUTODIN II). An internetwork technology has been developed to permit computers on different packet networks to interoperate; computer-communication protocols are now being standardized within DoD for this purpose. Also being developed is a technology for end-to-end secure communication over multiple networks using mixed voice/data/facsimile.

Research is being conducted on secure tactical message and information systems, advanced command and control decision and forecasting systems, and their applications to crisis management in heavy traffic.

Several experimental testbeds are being used to evaluate innovative technology before procurement money is committed. These include the DARPA/Army Packet Radio Testbed at Fort Bragg, the Advanced Command and Control Architectural Testbed (ACCAT) run jointly with the Navy, and the $C^3$ reconstitution experiment with the Air Force (which is primarily a strategic forces experiment with application to tactical forces). The Battlefield Exploitation and Target Acquisition (BETA) program is a DARPA/Army/Air Force effort to develop and test a tactical intelligence "fusion" system.

8. *Nuclear test verification technology.* Over the years the DARPA program in nuclear test verification technology has conducted research aimed at improving our ability to monitor foreign nuclear tests. As a direct result of this program, a firm technological foundation has been established on which to base current U.S. negotiating

strategy and technical positions relating to treaties limiting nuclear tests. The program for FY80 is providing technical guidance on two general programs with different time-scales. The first program seeks the type of information required in the near term to support and enhance total U.S. capabilities for monitoring existing test ban treaties, such as the Threshold Test Ban Treaty (TTBT), the limited Test Ban Treaty, and the Non-Proliferation Treaty, and to support the ongoing negotiations of a Comprehensive Test Ban Treaty (CTBT).

The second program involves longer-term efforts that are currently focusing on solving monitoring problems which would arise should the U.S. sign a CTBT. The overall program includes development of advanced highly sensitive sensors and instrumentation systems that can be deployed in remote areas (including on the sea floor), as well as data reception, management, and analysis techniques to assure the smooth processing of data from remote stations into finished summaries of monitoring activities for the use of officials responsible for verification. Other programs address methods to improve the accuracy of yield estimates of foreign underground explosions, development of countermeasures to thwart potential evasive testing practices, and a long-range program to examine new nonseismic techniques for remotely monitoring nuclear test ban treaties.

9. *Technology initiatives.* DARPA continues to be a spawning ground for innovative concepts and ideas which can have a major effect on reducing new weapons system costs and yielding quantum jumps in defense capabilities. Initiatives to advance the technology of very-large-scale integrated (VLSI) circuits are increasing, because new device design capabilities and fast-turnaround fabrication services have been established on the ARPANET, and novel directed-energy processing and lithographic techniques have been developed for fabricating submicrometer-size electronic circuit elements. DARPA computer science research is developing natural interfaces to distributed data bases, adaptive-interference signal perception and response technology for electronic warfare and related applications, and distributed sensor networks. DARPA is developing advanced turbine blades to extend the reliability and specific thrust of advanced tactical aircraft engines; these blades combine novel design concepts (the radial water blade) with the improvements in blade material properties offered by rapid-solidification-rate powder processing. Quantitative nondestructive evaluation techniques are under development to allow in-service fatigue-crack detection and monitoring of critical aircraft structures, to substantially extend the service life of high-cost turbine engine disks, and to provide a portable ultrasonic imager for the field inspection of aircraft and other high-value defense systems.

*10. Unconventional technology.* In FY79, Congress requested that DARPA assume responsibility for two major programs, the Assault Breaker and the Charged-Particle Beam programs, which are of high potential impact.

- Assault Breaker.—A primary threat to NATO in Europe is the concentration of armored forces. A major new thrust to counter such massed armor was initiated in late FY78. The Assault Breaker (AB) Program is developing a demonstration of a nonnuclear targeting and weapon system that can engage many breakthrough forces in a short period of time. The concept makes use of a processor-intensive target-acquisition radar to find and track company-sized targets. A standoff-launched weapons carrier is then guided into the air above the target array, after which terminally guided submunitions can automatically engage and destroy armored targets. The program is currently competitively developing the radar and weapons system elements under DARPA direction with system concept demonstration planned for mid-FY81. Assuming the demonstration is successful, a steering group consisting of Army, Air Force, and DARPA members is also formulating a plan for Service development, as appropriate, following the FY81 concept demonstration.

- Charged-Particle Beam. In 1979 DARPA assumed the primary responsibility for addressing the physics and technology issues required to assess charged-particle beams as a weapons candidate. The main technical issue for charged-particle beam concepts is whether the beam will propagate stably in the atmosphere. The various theoretical and experimental aspects of answering this critical question form the primary thrust of the DARPA program.

***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 this picture has changed from 1967 to 1978. The federal government obviously plays a major role as a supporter of this kind of work.

Figure A-2 shows how this federal support is broken out among agencies. The approximately $600M shown for DoD makes up almost 4 percent of the total DoD RDT&E budget, as can be seen in figure A-3. The funding history of the research portion of the DoD RDT&E budget is displayed in figure A-4, with the effects of inflation shown in figure A-5, and the historic relation of DoD research support to all federal research support shown in figure A-6.

Note that figures A-4 and A-5 and table A-1 show obligational authority, that is, the amount that Congress permits DoD to obligate. Figure A-6 shows actual obligations, which are usually somewhat less in any particular year, since the expenditure of authorized funds is not always completed by the close of the fiscal year.

Within DoD, research support is broken out between the Services and agencies as shown in table A-1. Figure A-7 and table A-2 demonstrate the distribution of research funds by size of work unit. Note that, although it appears that smaller projects are favored since a greater number of them are supported, there are also a substantial number of projects in the category "over $150K." Many of these are the multidisciplinary or "cluster" programs described in the Introduction.

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. Figure A-5 is a recapitulation of the DoD research program, this time divided into the 12 discipline areas.

The remaining charts show how the three Services and DARPA divide their programs. Tables A-6 and A-7 refer to the Army, the first showing the research program managed by the in-house labs, which is broken out along lab mission lines, and the second showing the ARO program, which falls more along the lines of DoD disciplines. Tables A-8 and A-9 show the Navy and the Air Force breakout. The DARPA organization (see table A-10) is more fully described in the body of the report (p 57).

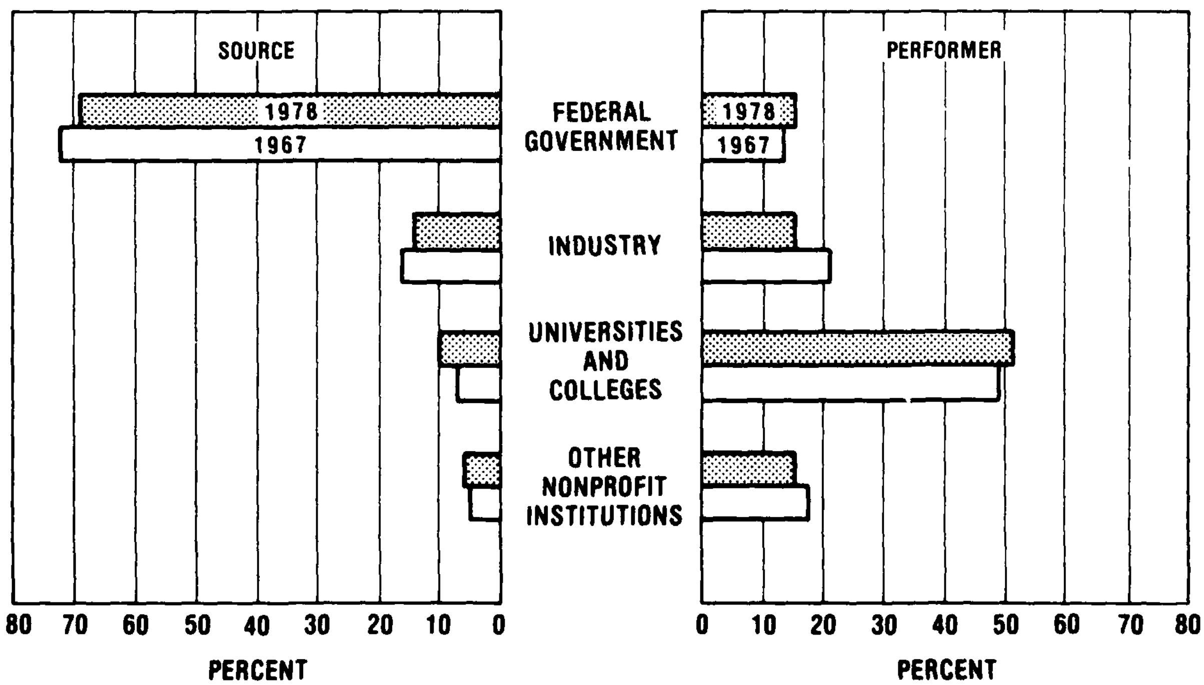



**Figure A-1. Sources and performers of basic research, 1967 and 1978.**

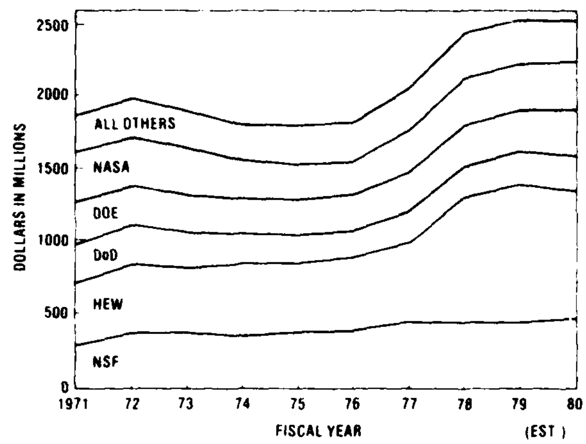



**Figure A-2. Federal obligations for basic research by selected agency, in constant (1972) dollars, FY71 to FY80.**

| Type of RDT&E activity | Funding ($M) FY80 | Funding ($M) FY81 | Real growth (%) |
|---|---|---|---|
| Research | 557.8 | 651.7 | 8[a] |
| Exploratory Development | 1,702.3 | 2,072.5 | 13[b] |
| Advanced Development | 2,783.4 | 3,094.8 | 3 |
| Engineering Development | 4,734.0 | 5,872.6 | 15 |
| Management and Support | 1,477.0 | 1,734.2 | 9 |
| Operational Systems Development | 2,262.0 | 3,059.6 | 25 |
| Total | 13,516.8 | 16,485.5 | 13 |

[a] *Real growth is 10% if reorientation of $12M from 6.1 to 6.2 in DARPA Nuclear Monitoring Program is accounted for.*
[b] *Real growth is 8% if reorientation of $72M from 6.3 to 6.2 in high energy lasers is accounted for.*

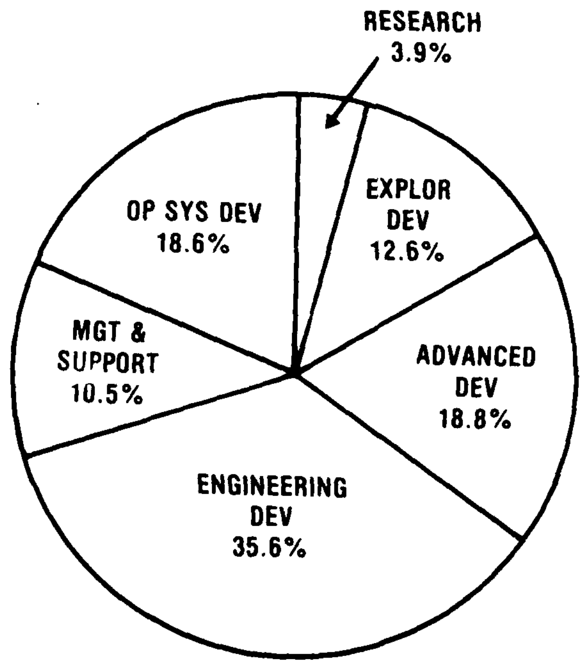



**Figure A-3. RDT&E by activity type (millions of dollars).**

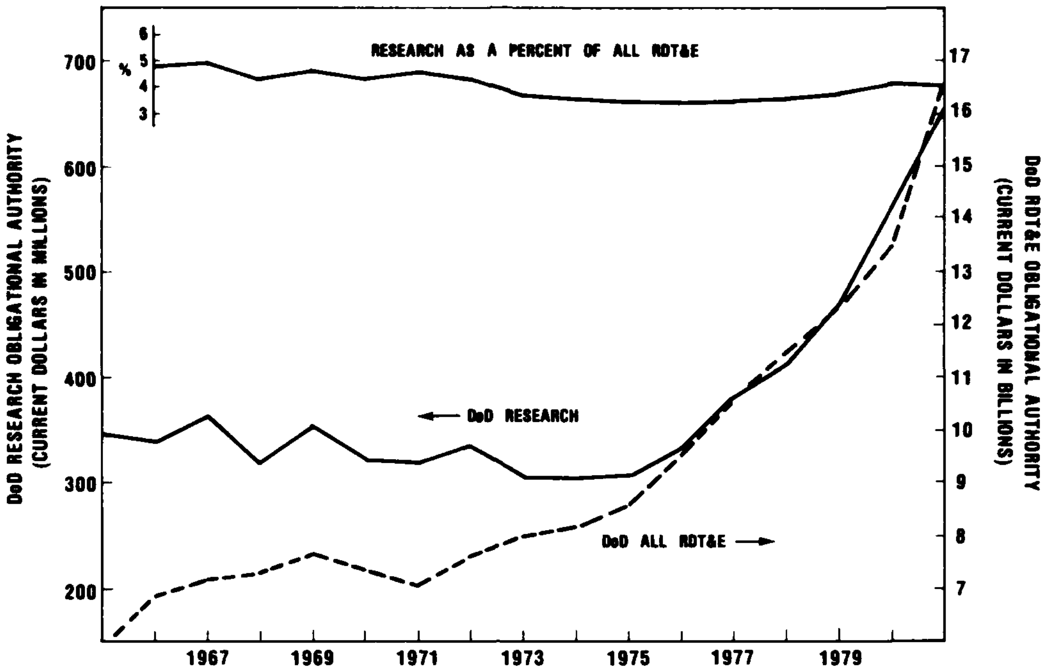



Figure A-4. Funding history of DoD research budget.

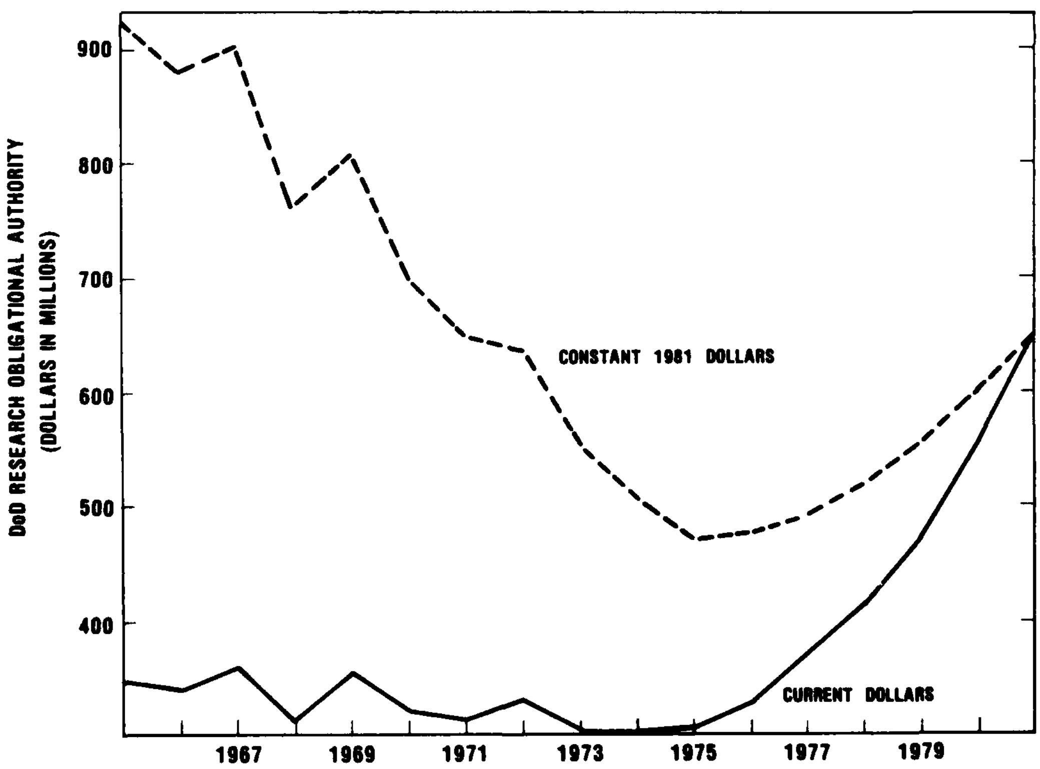



Figure A-5. Effects of inflation on research budget.

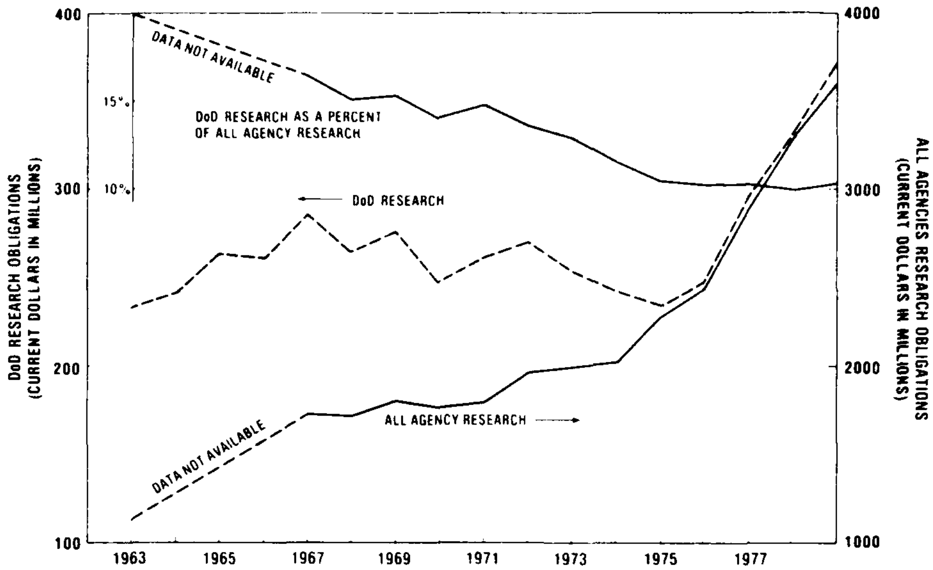



**Figure A-6. Relation of DoD research budget to federal research budget.**

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

| Program element[a] | Funding ($M) | | |
|---|---|---|---|
| | FY79 | FY80 | FY81 |
| Army | | | |
| 61101A (ILIR) | 16.0 | 17.5 | 19.6 |
| 61102A (DRS) | 98.1 | 113.7 | 137.3 |
| subtotal | 114.1 | 131.2 | 156.9 |
| Navy | | | |
| 61152N (ILIR) | 18.1 | 19.1 | 20.7 |
| 61153N (DRS) | 174.1 | 197.8 | 237.4 |
| subtotal | 192.2 | 216.9 | 258.1 |
| Air Force | | | |
| 61101F (ILIR) | 8.2 | 9.0 | 10.2 |
| 61102F (DRS) | 96.8 | 110.0 | 134.1 |
| subtotal | 105.0 | 119.0 | 144.3 |
| DARPA | | | |
| 61101E (DRS) | 62.0 | 89.7 | 90.8 |
| USUHS | | | |
| 61101W (ILIR) | 1.0 | 1.6 | 1.9 |
| Total | 474.3 | 558.4 | 652.0 |

[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*

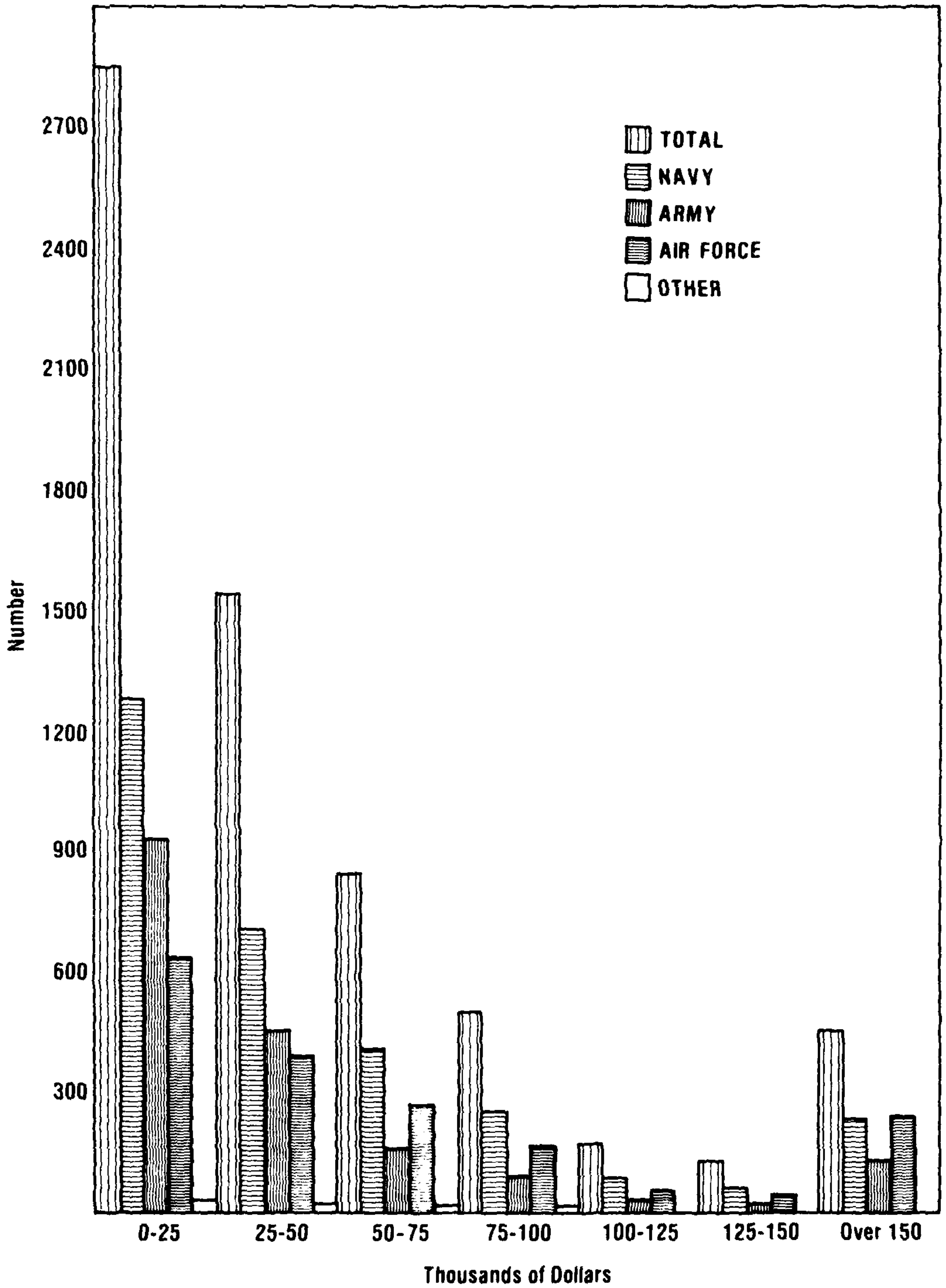



**Figure A-7. Distribution of research funds by size of work unit.**

**Table A-2. Funding Size Distribution of 6.1 Work Units**

| Service | Work units by size in thousands of dollars | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0–25 | 25–50 | 50–75 | 75–100 | 100–125 | 125–150 | Over 150 | Total |
| Army | 920 | 456 | 167 | 92 | 34 | 25 | 130 | 1824 |
| Navy | 1275 | 696 | 407 | 236 | 75 | 59 | 226 | 2974 |
| Air Force | 631 | 381 | 261 | 165 | 54 | 37 | 263 | 1792 |
| DARPA and USUHS[a] | 24 | 7 | 3 | 2 | 1 | — | — | 37 |
| Total | 2850 | 1540 | 838 | 495 | 164 | 121 | 619 | 6627 |

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

**Table A-3. Research (6.1) Performers**

| Programs[a] | Funding ($M) | | |
|---|---|---|---|
| | FY79 | FY80 | FY81 |
| Services | | | |
| In-house | 175.8 | 191.0 | 216.6 |
| Universities | 178.8 | 210.2 | 263.5 |
| Other contracts | 56.7 | 65.9 | 79.2 |
| Total | 411.3 | 467.1 | 559.3 |
| DARPA | 62.0 | 89.7 | 90.8 |
| USUHS | 1.0 | 1.6 | 1.9 |
| 6.1 total | 474.3 | 558.4 | 652.0 |

[a]*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) | | |
|---|---|---|---|
| | FY79 | FY80 | FY81 |
| Army | 36.5 | 43.6 | 55.3 |
| Navy | 86.4 | 101.5 | 129.4 |
| Air Force | 55.9 | 65.1 | 78.8 |
| DARPA[a] | 17.5 | 19.6 | 18.8 |
| Total | 196.3 | 229.8 | 282.3 |

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

**Table A-5. DoD Program Funding (FY80 to FY81)**

| Disciplines[a] | Funding ($M) | | Real increase (%) |
|---|---|---|---|
| | FY80 | FY81 | |
| Physics, Radiation Sciences, Astronomy, Astrophysics | 77.2 | 91.3 | 9.5 |
| Mechanics and Energy Conversion | 58.3 | 69.7 | 10.7 |
| Materials | 49.7 | 59.3 | 10.5 |
| Biological and Medical Sciences | 49.0 | 58.5 | 10.5 |
| Electronics | 48.7 | 57.0 | 8.4 |
| Oceanography | 43.2 | 53.3 | 14.2 |
| Chemistry | 40.2 | 47.5 | 9.4 |
| Mathematics and Computer Sciences | 34.9 | 43.3 | 14.9 |
| Atmospheric Sciences | 20.0 | 24.0 | 11.1 |
| Terrestrial Sciences | 19.6 | 23.8 | 12.4 |
| Behavioral and Social Sciences | 17.4 | 21.0 | 11.7 |
| Aeronautical Sciences | 8.9 | 10.5 | 9.2 |
| Subtotal | 467.1 | 559.2 | 10.8 |
| DARPA | 89.7 | 90.8 | — |
| USUHS | 1.6 | 1.9 | — |
| Total | 558.4 | 652.0 | 8.1 |

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

**Table A-6. Army Project (SPF) Assignments and Funding**

| Command/lab | SPF title and number[a] | Funding ($M) FY80 | FY81 |
|---|---|---|---|
| *Program Element 61102A—Defense Research Sciences (DRS)* | | | |
| Tank Automotive R&D Command (TARADCOM) | Res. in Vehicle Mobility, AF22 | 0.6 | 0.9 |
| Army Materials & Mechanics Res. Center (AMMRC) | Materials and Mechanics, AH42 | 2.4 | 2.7 |
| Armament R&D Command (ARRADCOM)/ Ballistic Research Lab (BRL) | Res. in Ballistics, AH43 | 6.8 | 7.4 |
| Electronics R&D Command (ERADCOM)/ Harry Diamond Labs (HDL) | Fluidics, Nuclear Effects and ISTA Electronics, AH44 | 2.5 | 2.9 |
| Aviation R&D Command (AVRADCOM) | Air Mobility, AH45 | 5.8 | 6.8 |
| ERADCOM/Combat Surveillance & Target Acquisition Lab (CSTAL) | Res. in CSTA, AH46 | 0.2 | 0.3 |
| ERADCOM/Electronic Technology and Devices Lab (EDTL) | Electronic Devices Res., AH47 | 2.4 | 2.7 |
| Communications R&D Command (CORADCOM) | Communications Res., AH48 | 1.3 | 1.5 |
| Missile Command (MICOM) | Missiles and High Energy Laser Res., AH49 | 2.0 | 3.1 |
| Mobility Equipment R&D Command (MERADCOM) | Res. in Combat Support, AH51 | 1.0 | 1.2 |
| Natick R&D Command (NARADCOM) | Support of Equipment for the Individual Soldier, AH52 | 1.9 | 2.2 |
| Army Research Office (ARO)[b] | Scientific Problems with Military Applications, BH57 | 38.6 | 48.7 |
| ARRADCOM/Large Caliber Weapons Systems Lab (LCWSL) | Res. in Large Caliber Armament, AH60 | 5.5 | 6.5 |
| ARRADCOM/Fire Control and Small Caliber Weapon System Lab (FCSCWSL) | Res. in Small Caliber Armament, AH61 | 1.1 | 1.5 |
| ERADCOM/Electronics Warfare Lab (EWL) | Res. in Electronic Warfare, AH63 | 0.3 | 0.4 |
| ARRADCOM/Chemical System Lab (CSL) | Processes in Pollution Abatement, AH68 | 0.2 | 0.3 |
| Surgeon General | Health Effects, B504 | 0.5 | 0.5 |
| Surgeon General | Res. on Military Diseases, Injury and Health Hazards, B510 | 21.1 | 25.3 |
| Corps of Engineers (COE)/ Waterways Experiment Station (WES) | Soil and Rock Mechanics, AT22 | 0.6 | 0.6 |
| COE/Engineering Res. Lab (ERL) | Structural Systems, AT23 | 0.6 | 0.7 |
| COE/Cold Region Res. & Eng. Lab (CRREL) | Snow/Ice and Frozen Soil, AT24 | 1.4 | 1.7 |
| ERADCOM/Night Vision and Electro-Optics Lab (NVEOL) | Night Vision and EO Res., A31B | 6.5 | 7.6 |
| COE/Engineering Topographic Lab (ETL) | Mapping, Geodesy and Geographic Res., B52C | 1.5 | 1.6 |
| ERADCOM/Atmospheric Sciences Lab (ASL) | Atmospheric Sciences, B53A | 3.7 | 4.0 |
| ARRADCOM/CSL | Res. in Defense Systems for Chemical Biological Warfare, A71A | 1.6 | 2.2 |
| Human Engineering Lab (HEL) | Human Engineering, B74A | 1.5 | 1.8 |
| DCSPER/Army Research Institute (ARI) | Personnel Performance and Training, B74F | 2.1 | 2.2 |
| Total 61102A | | 113.7 | 137.3 |
| *Program Element 61101A—In-House Laboratory Independent Research (ILIR)* | | | |
| Total 61101A | | 17.5 | 19.6 |
| Total Army 6.1 | | 131.2 | 156.9 |

[a]Because of the Army's extensive mission-oriented in-house 6.1 program, funding by individual disciplines (e.g., physics) cannot be broken out without a detailed knowledge of the contents of each SPF.
[b]For detailed breakout of ARO funding (BH57), see table A-7.

### Table A-7. Army Research Office Funding, SPF Project Number BH57, Scientific Problems with Military Applications

| Task title and number | Funding ($M) | |
|---|---|---|
| | FY80 | FY81 |
| 01—Geosciences | 3.0 | 4.4 |
| 02—Biological Sciences | 1.5 | 1.9 |
| 03—Communication Engineering and Electronics | 8.4 | 9.9 |
| 04—Materials | 5.0 | 6.[illegible] |
| 05—Mathematics | 5.2 | 6.3 |
| 06—Mechanics and Aeronautics | 4.8 | 6.0 |
| 07—Physics | 5.9 | 7.4 |
| 08—Chemistry | 4.8 | 6.3 |
| Total BH57 | 38.6 | 48.7 |

### Table A-8. Navy Research Program

| Project number and title | Funding ($M) | |
|---|---|---|
| | FY80 | FY81 |
| *Program Element 61153N— Defense Research Sciences* | | |
| 11—General Physics | 24.4 | 28.6 |
| 12—Radiation Physics | 3.1 | 3.4 |
| 13—Chemistry | 11.7 | 14.0 |
| 14—Mathematical Sciences | 15.3 | 18.9 |
| 21—Electronics | 20.0 | 23.9 |
| 22—Materials | 18.8 | 22.0 |
| 23—Mechanics | 13.2 | 15.3 |
| 24—Energy Conversion | 9.2 | 11.2 |
| 31—Oceanography | 39.4 | 49.0 |
| 32—Terrestrial Sciences | 11.5 | 14.3 |
| 33—Atmospheric Sciences | 5.6 | 6.4 |
| 34—Astronomy and Astrophysics | 4.0 | 4.3 |
| 41—Biological and Medical Sciences | 15.3 | 18.1 |
| 42—Behavioral and Social Sciences | 6.3 | 8.0 |
| Total 61153N | 197.8 | 237.4 |
| *Program Element 61152N— In-House Laboratory Independent Research* | | |
| Total 61152N | 19.1 | 20.7 |
| Total Navy 6.1 | 216.9 | 258.1 |

### Table A-9. Air Force Research Program

| Subelement number and title | Funding ($M) | |
|---|---|---|
| | FY80 | FY81 |
| *Program Element 61102F— Defense Research Sciences* | | |
| [illegible] | 11.1 | 13.9 |
| [illegible] | 10.9 | 13.4 |
| [illegible] | 10.3 | 12.6 |
| [illegible] | 12.2 | 14.7 |
| [illegible] | 16.2 | 18.9 |
| [illegible] | 16.5 | 19.6 |
| [illegible] | 8.3 | 10.6 |
| [illegible] | 1.9 | 2.4 |
| 2310 Atmospheric Sciences | 7.2 | 8.5 |
| 2311 Astronomy & Astrophysics | 4.5 | 5.2 |
| 2312 Biological & Medical | 5.2 | 7.2 |
| 2313 Human Resources | 5.7 | 7.1 |
| Total 61102F | 110.0 | 134.1 |
| *Program Element 61101F— In-House Laboratory Independent Research* | | |
| Total 61101F | 9.0 | 10.2 |
| Total Air Force 6.1 | 119.0 | 144.3 |

### Table A-10 DARPA Research Program

| Subelement title | Funding ($M) | |
|---|---|---|
| | FY80 | FY81 |
| *Program Element 61101E— Defense Research Sciences* | | |
| Materials Sciences | 19.6 | 24.1 |
| Cybernetics Sciences | 8.4 | 9.9 |
| Computer and Communications Sciences | 21.0 | 27.4 |
| Unconventional Detection Research | 6.2 | 7.3 |
| Nuclear Test Verification | 10.3 | |
| Charged Particle Beam | 24.2 | 20.3 |
| Geophysical Research | — | 1.8 |
| Total 61101E | 89.7 | 90.8 |

***Points of Contact in Department of Defense Research Program***

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