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Department of Defense
Research and Engineering
Strategic Basic Research Plan
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Preface

The Department of Defense Research & Engineering Strategy (2007) provides a unified structure of shared purpose and shared goals for the defense research and engineering community. This Basic Research Plan articulates that Strategy in the area of basic research.

The Department of Defense (DoD) pursues scientific discovery and new knowledge by funding Basic Research in areas that offer great promise to advance DoD capabilities. The challenge is identifying discoveries and new knowledge that will develop into overwhelming capabilities against innovative threats.

It is impossible to predict when new knowledge will be discovered and who will discover it. The time needed to bring a discovery to practical application is measured in years or decades. Some discoveries are immediately useful and quickly enter the arsenal; most discoveries suggest lines of further inquiry that eventually lead to enhanced military capabilities. Some lines of high-risk, high-impact investigation will yield no obvious short term military value. A few discoveries are so unexpected that they change our very ideas of the possible. All of these give the DoD reason to pursue new knowledge through Basic Research.

While new knowledge fosters invention and innovation, the creation of new military capabilities generally depends on the engineering and synthesis of advances made in several disciplines. Persistence, as well as breadth, of investment is necessary in order to realize the full practical implications of a new discovery and thus ensure continued U.S. technological superiority over any adversary on any battlefield in any future engagement. Today’s Basic Research investments determine, in large measure, the equipment and capabilities we will depend upon a generation hence. That investment reduces cost and improves systems quality.

Where and how U.S. and allied interests will be threatened is unknown, and future adversaries will couple their ingenuity with the increasing worldwide availability of sophisticated technologies to create new threats. DoD must expand its range of military capabilities to adapt effectively and quickly to these new threats, new adversaries, and new battlefields while simultaneously retaining battlefield technological superiority over current and projected state peers or near-peers. The increasing range of potential threats demands expansion of the scope of relevant and potentially important Basic Research areas. The breadth of Basic Research investments is a strategic parameter in DoD planning.

Investments in DoD Basic Research over the past half-century have yielded the fundamental underpinning of today’s conventional force—a force so technologically dominant that adversaries now resort to nonconventional attacks. These investments both enhance systems quality for the warfighter and reduce systems cost to the taxpayer. We cannot know when a discovery will become a capability, but we know with absolute certainty that without discovery, our capabilities will remain static.

William S. Rees
Deputy Under Secretary of Defense (Laboratories & Basic Sciences)
1.0 Introduction to DoD Basic Research

Department of Defense (DoD) Basic Research involves systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts, without specific applications towards processes or products in mind.

Basic Research is the first stage in a continuum of DoD research, development, test, and evaluation (RDT&E) activities that produce the military systems employed by the DoD. Follow-on RDT&E develops technologies tailored for application in specific systems. The objective in Basic Research is to discover knowledge that may lead in due course to development of these products. When new threats arise, new missions are needed. New capabilities, required for new missions, spring mostly from new technology. In turn, new technology is the ripened fruit of broad, intensive Basic Research carried out consistently over an extended period.

DoD does not conduct Basic Research in every scientific area. By necessity, our emphasis is on engineering and physical sciences; however, DoD Basic Research must have a degree of latitude to study scientific areas that are broader than current missions. It is not possible, as research-driven technology grows, spreads, and diversifies, to predict with any certainty the next important discovery or who will make it. At its most elemental, Basic Research provides the foundation for future military systems and, in so doing, educates and trains the future generations of scientists and engineers who will continue the essential work of knowledge discovery and application for DoD. With time this knowledge gets stored up in the minds of talented people funded by the DoD, who at an appropriate time unleash it to provide totally new or enhanced capabilities for our warfighters.

Within DoD, Basic Research is part of the Defense Science and Technology (S&T) program, which includes Applied Research and Advanced Technology Development. The Deputy Under Secretary of Defense (Laboratories and Basic Sciences) is responsible to the Director, Defense Research and Engineering for oversight of DoD Basic Research activities (see Appendix B).

The Defense Basic Research Advisory Group (DBRAG) coordinates the DoD Basic Research program and assists in the clarification of issues and policy. Senior DoD Basic Research leaders are DBRAG members. The DBRAG is an activity of Reliance 21, the set of arrangements employed for coordination of all DoD S&T activities. Other activities within Reliance 21 ensure that all organizations are aware of S&T plans and activities within DoD Services, Components, and Agencies.
DoD conducts Basic Research to:

- Generate discoveries, new knowledge, and comprehensive understanding that are the foundation of future, improved military capabilities
- Prevent technological surprise
- Educate scientists and engineers in physical science and engineering disciplines needed for defense applications
- Sustain the human talent and research infrastructure necessary for continuing performance of cutting-edge defense programs.

Primarily, the Army, Navy, and Air Force fund DoD Basic Research with additional activities occurring within defense agencies and corporate programs. Universities accomplish the preponderance of DoD Basic Research. DoD Basic Research investments emphasize physical sciences and engineering, however in recent times there has been a shift toward more investment in the biological sciences.

1.1 Basic Research During the Cold War

From the late 1940s through the 1990s, DoD Basic Research and other RDT&E activities focused on developing the conventional and nuclear military capabilities needed to counter the Soviet Union. While there were other missions during this period that had a major impact on RDT&E investments, notably the Vietnam War, deterrence of the Soviet Union was the unquestioned priority.

The Cold War Defense S&T program was patterned on the successes achieved in RDT&E management and collaboration during World War II. Post-war, DoD emphasized decentralized execution, primarily within the military departments (Army, Navy, and Air Force) and the defense agencies (e.g., Defense Advanced Research Projects Agency). Given the large conventional forces deployed by the Soviet Union and the Warsaw Pact, the United States elected to counter quantity with quality—smaller numbers of forces equipped with superior technology.

For critical technologies that have come to have important civilian as well as military applications, DoD was in many cases the predominant (and often, the only significant) source for funding, particularly at early stages. Prominent examples include the Internet, satellites, space launch technology, advanced information technology (microelectronics hardware and software), and the Global Positioning System (GPS). Their related applications have become ubiquitous within the U.S. and around the world; consequently they are vulnerable to attack planning by current (and potential future) adversaries who use Internet cafés and satellite phones for communication, and who can download meter-resolution images taken by commercial satellites.
Since the end of the Cold War, globalization has been a key trend. Basic Research in the 21st century is a worldwide enterprise. In contrast to the situation during the Cold War, neither the DoD nor the U.S. are the principal or predominant organizations involved in the technical fields critical to DoD missions. In 2005, only four American firms were among the top ten recipients of patents granted by the United States Patent and Trademark Office.\(^1\) The U.S. has essentially become a net importer of high-technology products.

A concurrent trend involves shifts in support for S&T within the U.S. In the mid-1960s, the federal government funded more than 60% of research and development (R&D). Today, corporations are the primary funders, though they fund relatively little Basic Research. Furthermore, in recent years federal organizations that fund Basic Research in the U.S. have become more resource constrained.

At the conclusion of the Cold War with its predictable certainty of purpose, a peaceful new world order did not appear. After September 11, 2001, an era of predominant confrontation between superpowers with many subordinate conflicts gave way to an uncertain and unpredictable age with a diversity of confrontations and conflicts.

The Strategic Plan of the DoD (known as the Quadrennial Defense Review (QDR)) characterizes the potential challenges that the U.S. faces (Figure 1).

The core objective of DoD Basic Research is to discover knowledge that can be exploited to provide the U.S. with “technical overmatch” against any adversary, in any battlespace, at any time. Coping with tomorrow’s potential challenges requires moving the “centroid” of the Basic Research investment portfolio from the capabilities needed to counter traditional types of threats toward initiatives that address irregular, catastrophic, and disruptive challenges (Figure 2). Most national security missions, such as countering Weapons of Mass Destruction (WMD), require a range of capabilities that depend on technologies born of Basic Research.

This centroid shift will be accomplished with increased uncertainty concerning the specific threats that might be encountered today or in the future.

In future conflicts, the U.S. may face adversaries with comparable conventional military capabilities. Moreover, new types of highly capable adversaries will pose threats. In the past, only nation-states could raise the revenues, muster the armies, and organize the logistics to threaten the survival of another state. We are entering a period in which a small number of people, operating without overt state sponsorship but using the enormous power of modern computers, biogenetic pathogens, air transport, and even small nuclear weapons, will be able to exploit the tremendous vulnerabilities of contemporary open societies.\(^2\) Terrorist groups may be highly capable technology-enabled adversaries.

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In an era of scientific as well as economic globalization, significant technological breakthroughs occur in many countries and multinational enterprises. In the development of the DoD strategy for Basic Research and other S&T programs, new emphasis must be given to preventing technological surprise. DoD Basic Research managers must be conversant with worldwide technology developments. One of the necessary means to this end is to encourage DoD and DoD-sponsored Basic Research investigator involvement in publishing articles in peer-reviewed technical journals and presentations at academic conferences. To succeed, DoD must draw on the best basic research available.

In current circumstances, there are new expectations concerning the employment of U.S. armed forces—notably, increasingly discriminate attacks that achieve military objectives with minimum collateral effects on civilians and civil infrastructure. Such unprecedented capabilities demand new weapons built from exquisite technologies that are deeply rooted in the discoveries and new knowledge provided by DoD Basic Research. The DoD Basic Research program has as one of its priorities the continuing development and expansion of the scientific foundation to enable the execution of evermore complex military operations with greater speed and precision to devastate any adversary on any battlefield.
Shifting the centroid of the Basic Research program generates much greater emphasis on Joint and collaborative efforts to achieve maximum operational effects through the integration of department-wide research efforts. The 2007 Department of Defense Research & Engineering Strategic Plan \(^3\) provides guidance for DoD research and engineering (R&E) efforts.

Priorities for developing advanced military capabilities can be aggregated into a small number of high-level mission areas (See Figure 4).

- Total Battlespace Awareness
- Stability Operations, Cultural Awareness, and Force Management
- Command, Control and Information Management and Net-Centric Operations
- Protection
- Joint Training
- Tailored Force Applications.

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\(^3\) This plan is available at: <http://www.dod.mil/ddre/doc/Strategic_Plan_Final.pdf>. 
2.0 Opportunities for DoD Basic Research

Figure 3 shows the Conceptual Strategic Planning Process. The delimiters in the lower left portion of the figure are important. Not all operational capability shortfalls will require S&T solutions. Similarly, not all identified shortfalls in “Science and Technology” will need an investment in Basic Research. Finally, portions of the Services’ Basic Research program are applicable to other Service needs. The ability to identify Basic Research investment needs and the coordination of existing Basic Research programs are of overriding import for DoD. They are the essence of effective strategic planning. Of subordinate order, but certainly an important consideration, is that DoD must invest broadly in many other scientific areas to assure cognizance of scientific progress and discovery worldwide.

Figure 3. Conceptual Strategic Planning Process

Basic Research generates and exploits fundamental scientific discoveries and knowledge needed to envision, create, and develop new military capabilities. Later stage R&D (i.e., applied research and advanced technology development) uses the results of Basic Research to design and build specific components, equipment, weapons, systems, and joint combat capabilities. By its very nature, Basic Research involves:

- **Uncertainty**—Basic Research explores the unknown. It is common and prudent to examine multiple candidate paths before pursuing the most promising solution.

- **Persistence**—At the current level of understanding, many research efforts must be sustained over a period of years to achieve credible success.
Given the broader spectrum of 21st century threats to be countered, the increased uncertainty of technology trends, and the potential for surprising scientific discovery outside the U.S., DoD is pursuing a broader portfolio of Basic Research investments.

Figure 4. Desired Capabilities S&T Investment Areas Designated in the 2007 DoD Research and Engineering Strategic Plan

Following are brief overviews of the DoD’s current approach to Basic Research, with emphasis on:

- Fostering excellence in people
- Enabling collaboration and research synergies, both within DoD and with partners outside of the Department
- Improving core competencies in areas of enduring interest
- Laying the technical foundation for new capabilities.
This section explains how the Department of Defense conducts and manages Basic Research with specific activities cited as examples. A more comprehensive summary of the technical activities that comprise the DoD Basic Research program is available online.4

2.1 Fostering Excellence in People

DoD Basic Research managers must empower the scientists, engineers, faculty, and students within research-performing organizations to do the best possible research. DoD program managers must unflinchingly capitalize on worldwide research and technology developments to achieve effective, productive DoD Basic Research programs.

An important means to this end, which concomitantly ensures that DoD Basic Research is of the highest technical quality, is publication of Basic Research results in refereed journals and other professional publications.

It is essential that DoD overcomes at least three major challenges if it is to maintain its Basic Research (and other) competencies in an increasingly globalized, technology-rich, knowledge-based world.

- DoD laboratories expect retirement of over 10,000 physical scientists and engineers by the middle of the next decade.

- Competition within the U.S. for top scientists and engineers is increasing. DoD competes with U.S. and foreign industries for competent physical science and engineering talent.

- There are uncertainties and often downward trends in the number of degrees, in areas important to DoD, awarded to U.S. citizens who can qualify for the security clearances essential to DoD programs.

To offset these developments, DoD sustains its Basic Research program through the Services and Agencies who engage and support thousands of the nation’s best university faculty and students in DoD research efforts. Further, DoD funds major, specific educational programs that allow students and faculty to pursue initial and advanced technical degrees. DoD’s National Security Science and Engineering Faculty Fellowships fund the best university faculty researchers in pursuit of long-term critical research relevant to DoD missions. This competitive awards program funds the nation’s absolute best researchers and their assisting graduate and undergraduate students for up to 5 years. Grants are large enough and of sufficient duration to enable significant, measurable Basic Research results. Although the Basic Research will be unclassified, all faculty awardees will have security clearances and be exposed to DoD physical science and engineering challenges through the SECRET level.

The Presidential Early-Career Awards for Scientists and Engineers (PECASE) program recognizes some of the finest scientists and engineers who early in their research careers show exceptional potential for leadership at the frontiers of scientific knowledge. The awards support the continued development
of the awardees, foster innovative and far-reaching developments in science and technology, increase awareness of careers in science and engineering, give recognition to the scientific missions of DoD and other participating agencies, enhance connections between fundamental research and national goals, and highlight the importance of science and technology for the nation’s future.

The Science Mathematics and Research for Transformation (SMART) program provides scholarships and fellowships to security-clearable students in defense-critical disciplines. Awardees have employee status while enrolled and have a one-to-one payback in post-graduation civil service employment.

The National Defense Science and Engineering Graduate (NDSEG) Fellowship program identifies individuals whose scientific and engineering credentials will support study culminating in doctoral degrees. Its primary goal is to provide the U.S. with talented, doctoral-degreed Americans who will lead state-of-the-art research projects in disciplines of greatest benefit to national security.

The Services and Agencies also have other educational programs that help educate, recruit, and retain talented scientists and engineers for DoD work. (See Appendix C for web links to more information about these programs.)

**2.2 Enabling Collaboration and Research Synergies**

In relative terms, DoD Basic Research is a tiny fraction of the resources in the DoD R&E program and other federal, U.S. academic, commercial, and worldwide basic research. In the 21st century security environment of increased threat and uncertainty, collaborating to leverage the DoD investment is imperative. Collaborating involves a range of activities such as:

- Monitoring and capturing the best knowledge discovery, research, and technology development processes throughout the world
- Partnerships in which DoD and others jointly invest
- Transferring DoD-sponsored Basic Research results into higher RDT&E activities and, ultimately, into DoD acquisition programs.

DoD Components have established and staffed a network of overseas offices that seek out preeminent research activities and developments worldwide. These offices develop collaborative relationships and alert DoD to outstanding foreign research capabilities. DoD components also sponsor international science conferences that address DoD topics.

The DoD collaborates with other cabinet agencies and federal activities on Basic Research efforts of common interest. Examples include:

- Collaboration with the National Aeronautics and Space Administration (NASA) on National Aerospace programs
• Research activities by the Department of Homeland Security, Department of Energy, and other federal and non-federal organizations on technologies for detection of radiological and nuclear threats.

DoD guidance requires Components to consider other federal agencies’ Basic Research investments when making their own investment decisions, to avoid unintentional overlap and to leverage each agency’s investment effectively.

2.3 Improving Core Competencies in Enduring Areas of Interest

Over decades, the DoD has developed core competencies in selected areas of research S&T that provide the foundations for military capabilities. This section provides selected examples of these fundamental areas.

It is important to note that “enduring” is not synonymous with “static.” Some of the current and emerging threats are qualitatively different from those faced in the past. Notably, many military capabilities developed by others are strengthened by readily available civilian technologies. In addition to traditional nation-states, some transnational and national groups now possess some of these augmented threat capabilities. For example, in recent conflicts such groups have:

• Effectively employed state-of-the-art anti-tank guided missiles

• Used a radar-guided missile in a successful attack against a warship

• Employed encrypted communications

• Deployed a robust, responsive, distributed logistics system

• Employed Unmanned Aviation Systems (UASs)

• Possibly made use of publicly available online photographic and mapping information to target rocket strikes

• Conducted an effective information operations campaign

• Used commercial wireless technologies to enable remote firing of rockets from multiple, dispersed locations.
In the following pages, examples of DoD Basic Research are organized following the framework developed by the National Science Foundation (NSF) and now used throughout the federal government for reporting R&D investments to the Office of Management and Budget and NSF (See Table 1). This is a different framework than those employed in past editions of the DoD Basic Research Plan; the correspondence between the old and new frameworks is in Table 1. Appendix A provides a current programmatic overview.

An important caveat is that, as is the case for worldwide research, much of the DoD Basic Research program cuts across customary disciplinary boundaries. For example, research on neuroscience encompasses work in the fields of life sciences, computer sciences, and psychological research. The “binning” of the research examples presented involves use of appropriate (but not exclusive) categories.
Table 1. DoD Basic Research Taxonomy for OMB Reporting
(and previous Basic Research Plan framework)  

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<tr>
<th>NSF Taxonomy</th>
<th>Previous DoD Taxonomy</th>
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<tr>
<td><strong>Life Sciences</strong></td>
<td>Biological Sciences</td>
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<td>Biological level environmental</td>
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<td>Environmental biology</td>
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<td>Agricultural science</td>
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<td>Medical science</td>
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<td>Life sciences (not elsewhere classified)</td>
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<tr>
<td><strong>Physical Sciences</strong></td>
<td>Chemistry</td>
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<td>Astronomy</td>
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<td>Chemistry</td>
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<td>Physics</td>
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<td>Physical sciences (not elsewhere classified)</td>
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<tr>
<td><strong>Environmental Sciences</strong></td>
<td>Atmospheric &amp; Space Sciences</td>
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<td>Atmospheric sciences</td>
<td>Terrestrial Sciences</td>
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<td>Geological sciences</td>
<td>Ocean Sciences</td>
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<td>Oceanography</td>
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<tr>
<td>Environmental sciences (not elsewhere classified)</td>
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<tr>
<td><strong>Mathematics, Information Network, and Computer Sciences</strong></td>
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<td>Mathematics</td>
<td>Computer Sciences</td>
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<td>Computer Science</td>
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<td>Math * Computer sciences (not elsewhere classified)</td>
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<td><strong>Engineering</strong></td>
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<td>Aeronautical</td>
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<td>Mechanical</td>
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<td>Metallurgy and Materials</td>
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<tr>
<td>Engineering sciences (not elsewhere classified)</td>
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<tr>
<td><strong>Psychology and Social Sciences</strong></td>
<td>Cognitive &amp; Neural Sciences</td>
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<td>Psychology</td>
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<td>Social Sciences</td>
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5 While there are minor differences in wording between the NSF and DoD formats (e.g., NSF has “Social Science” and “Psychology” as separate categories which are combined by DoD), the mapping between the DoD framework and OMB/NSF Directive 16 is straightforward. For the purposes of providing selected examples in what follows, only the top-level (centered above) headings are employed.
Life Sciences

Research in Life Sciences provides the fundamental knowledge and scientific underpinning for the innovative use of biology to: (1) produce unique materials and processes of military relevance; (2) increase economic and environmental affordability through entirely new approaches for manufacturing, maintenance, and logistics concerns; and (3) prevent or greatly lessen the deleterious effects of chemical, biological, and physical agents from interfering with military operations. A corporate program manages Chemical and Biological Defense Program (CBDP) research to develop advanced medical countermeasures against WMD.

Basic research performed on (1) the mechanisms of action of enzymes, intracellular receptors, cell membrane receptors, array signal bioprocessing, and ion channel complexes; (2) cellular signal transduction and amplification pathways; and (3) energy transfer processes provides useful input for chemical and biological defense and for energy production and management. This research enables detection of trace chemical compounds, including explosives, nerve agents, other chemical threat agents, environmental toxicants, and medical diagnostics. It also provides unique advanced counterterrorism and battlefield capabilities for detection and identification of biological threats and chemical threats.

Research performed on photodynamic and motor proteins and other specialized-function biological macromolecules, self-assembly processes, control of the bioabiotic interface, and cell-based and biomolecular tools for synthesis and energy harvesting provides the strategies for design and the means for manufacturing advanced electronic, magnetic, and photonic materials. These materials can be used for enhanced memory devices, revolutionary sensing capabilities, persistent small electrical power sources, improved friend or foe identification, signature management, and new structural and functional (e.g., energetic) materials for improved and cost-effective performance, survivability, repairability, and quick replacement. With the addition of bionanostructures to the nanotechnology suite, new and smarter coatings, sensor arrays and devices, computational hardware, and energy sources are just some of the possibilities that will eventually change the nature of future military weapon systems and platforms.

Biological organisms constitute a ‘system of systems’ wherein Basic Research studies offer a route to ensure effective protection and functional efficacy of both the individual warfighter and the engineered system, and to enable advanced communication between the two. Research on particularly useful adaptive mechanisms exhibited in one animal species may offer a means to enhance human performance, sustainability, and health in the face of such hazards. For example, research on hibernation and hypometabolic stasis promises to provide useful insight into enhancement of an individual’s survivability in harsh environments and in response to injury, and to provide novel endurance capabilities. Advances in human genomics and proteomics, immunology, and stem-cell biology—together with a greatly enhanced understanding of the systemic physiology and pharmacology of pathways for cell-to-cell signaling, metabolism, and regulatory networks—offer substantial promise for the future. These advances will improve survivability, battlespace information capabilities (based on principles of fully integrated multimodal sensing capabilities), mechanisms of controlled stealth and individually tailored response to imaging, and autonomous networked mobility. The use of organisms
to create or become biomaterials expands our capabilities in advanced materials development both in structural and nonstructural applications. Research in biomimetics including low-speed flight dynamics for micro unmanned aerial vehicles (UAVs) and novel materials based on enhancements of natural materials, such as synthetic spider silk, could provide very novel capabilities.

**Physical Sciences**

Physical Sciences research is critical to developing advanced materials for specific DoD applications, developing suitable processes for producing these materials in cost-effective ways and controlling chemical reactivity relevant to numerous DoD systems and requirements. Examples of important DoD materials derived from chemistry research include materials for protection against chemical weapons, novel propellants and power sources, and anticorrosion materials and coatings as well as development of novel materials for cooling. This ability to tailor material properties to meet DoD needs arises from an understanding at the atomic and molecular levels of the relationships between structure and properties. From a process perspective, understanding and controlling thermodynamics and kinetics of chemical reactions yield significant benefit to DoD. Chemical reactivity and dynamics play important roles in controlling combustion in fuels, decoys, and propellants—providing environmentally friendly or cost-effective processing methods for production of DoD materials and for control of fouling, corrosion, and degradation of various DoD platforms and systems. This understanding of atomic and molecular processes and properties established through chemistry research enables the design of optimally performing components for military systems.

*Chemistry research* focuses on the molecular design and synthesis of materials with properties that can be tailored to specific DoD requirements. Structure/property relationships are determined to enable the design of optimal material systems. In addition to the applications cited above, other widespread applications of materials chemistry research include the development of materials for marine and aerospace environments, strong and lightweight composite materials, novel electronic materials and devices, semiconductors, thermoelectrics, electrochemically active materials, and barriers for chemical and biological weapons.

The ability to control the interaction between materials and their environments (e.g., controlling friction and adhesion, corrosion, signatures, fate and transport of chemicals, and the release of energy) can be exploited for many DoD applications. Molecular processes are also being exploited to develop compact fuel cells as portable, clean power sources; develop chemical lasers for directed-energy weapons; control ignition and detonation of munitions; sense and sequester contaminants in situ; and store energy in propellants.

Efforts include research on:

- Systems related to chemical and biological defense (e.g., permeability, reactive and catalytic polymers)
- Elastomers (There is heavy use of rubbery components in land vehicles.)
- Novel materials synthesis methods. In particular, research in inorganic polymers holds promise
of a new class of versatile materials that operate in extreme environments. Research to counter hard maritime environments is also underway (e.g., adhesion and surface properties relating to ship antifouling coatings; novel cooling technologies; understanding and mitigating effects of operation on ocean and shore environments; materials that maintain their integrity in extreme environments)

- Lightweight chemical lasers
- Processes that affect operations in the atmosphere and in space
- Energetic materials (e.g., polynitrogen propellants)
- Optical polymers for rapidly disseminating and displaying information
- Polymers and elastomers to develop materials with properties tailored for chemical and biological defense needs
- Destruction of munitions and the catalytic oxidation and hydrolysis of chemical agents and toxins, as well as techniques for detecting trace amounts of chemical hazards
- Energy and power (e.g., hydrogen, methanol, and liquid hydrocarbon fuel cells; novel solid-state power sources and energy transfer media)
- Carbon nanotube and organic composites for electronic and structural material applications
- Analysis, detection, and prevention of aircraft corrosion and environmentally compliant protection systems
- Tribochemistry to provide a fundamental understanding of the role of surface structure and chemistry in friction and wear. Current research emphasizes friction at very small scales and under extreme conditions.

Energy production and electromagnetic radiation research focuses on power generation for various applications and sources of electromagnetic radiation—from radio waves to gamma rays. Advanced radiation sources are needed to satisfy DoD requirements, including those for command, control, communications, and intelligence (C3I), radar, sensors, electronic warfare, and directed-energy weapons. In addition to radiation sources, this area involves the propagation of radiation in different military environments. Thrusts include:

- Directed-energy techniques for optical compensation of atmospheric distortion and propagation of electromagnetic signals through the ionosphere
- Photonic-band engineering for illuminators that can pierce through the battlefield environment
- Advanced pulse power sources and ultra-high electromagnetic fields
- Tunable infrared (IR) lasers
- Nonlinear optics
- Ultra-fast electro-optics
- Free-electron radiation sources.

Matter and materials research focuses on materials from nanoscale (single-atom- or molecule-sized devices) to macroscale (bulk materials such as high-temperature (Tc) superconductors) that impact many DoD systems. Basic research activities include investigation of:
• Atom optics and quantum effects to develop ultrasensitive detectors, as well as unprecedented computational and communication capabilities
• Nanoscience research to develop ultra small sensors and materials with unique properties for signature control, electronics, and armor
• Antiprotons and antihydrogen as lightweight, high-energy-density fuels for advanced aircraft systems
• High-Tc superconductors to improve power budgets for air and space platforms
• Novel liquid-crystal and adaptive gating-based optical limiters for battlefield sensor protection
• Soft condensed matter research for a variety of applications in soldier protection and sensing
• Ultra-sensitive atom optics-based detectors and unconventional optics techniques such as integrated computational imaging to improve target detection
• Compact ultra-precise atom gyroscopes for GPS-like undersea navigation and guidance, and, more generally, atomoptic-based accelerometers for all platforms
• Armor for Light Combat Systems.

Sensing and detection research thrusts include:

• Scientific underpinning of optical image processing and automatic target recognition
• Quantum entanglement and novel quantum states of light that can be exploited to image under stealthy or obscured conditions
• Tools to forecast space weather storms
• Advanced sensors to see through dust on the battlefield, which requires advances in detectors, optics, and imaging science and in understanding of phenomenology
• Physical acoustics and underwater acoustics involving propagation and transducers. Application of nonlinear dynamics to signal detection and classification and novel stochastic resonance detectors is also of high interest.
• Optical compensation for the imaging of space objects through the atmosphere
• Visible laser technology for possible use in optical countermeasures
• Sensor protection from laser radiation for all sensors, including soldiers.

Environmental Sciences

DoD Basic Research in Environmental Sciences involves Atmospheric and Space Sciences, Terrestrial Sciences, and Ocean Sciences.

Research in Environmental Sciences develops the basic technical foundations for use in battlespace environment applications important to DoD through efforts involving meteorology (dynamical, physical, and modeling), space science (ground-, air-, and space-based), and remote sensing (active and passive). This work is done in collaboration with other federal agencies, notably the National Oceanic and Atmospheric Administration, NASA, and NSF.

DoD’s atmospheric research effort develops the basic understanding of global and theater weather needed to construct reliable prediction models used by operational military commands. For blue-water operations, special attention is directed toward understanding the behavior and evolution of
tropical cyclones in general and in the Western Pacific in particular, where DoD has the lead forecast responsibility for the U.S. Plans are to improve knowledge concerning motion (track), structure (size), and intensity (wind speed) of these important phenomena. The research program balances theoretical modeling, analytical case studies, and experimental observations while exploring the limits of forecast predictability.

Space science research focuses include precision time-keeping and ionospheric physics. Precision time-interval and time-transfer technology is required for precise targeting and synchronization of secure communications and other systems. Ionospheric and upper atmospheric neutral density research will address needs for improved GPS accuracies. Optical interferometers are being pursued to provide positional accuracies of astronomical sources below the milliarc-second level. These advances, combined with improved astrometric reference frames and continuing improvements in compact electronics, will support operational requirements for systems with increased precision guidance and autonomous satellite navigation.

The high bandwidth and secure communications features of the Milstar satellites are the result of large 6.1 investments in radiation-hardened electronics, broadband communications, space weather specification and forecasting, and lightweight power generation. Continuing efforts in these areas, coupled with ongoing developments in mobile wireless band communications, will result in a new generation of smaller, lighter, and more affordable satellites. The next generation and block upgrades of DoD missile early-warning satellites will not be possible without continuing investment in focal plane technology, onboard signal processing capabilities, and the ability to acquire and track very dim targets against highly cluttered backgrounds. The potential ability to exploit basic knowledge of plume signatures and varying background radiance in the design of spectrally agile electro-optical sensor systems may even enable the detection of cruise missiles from space-based platforms.

Solar and heliospheric research is directed toward understanding the mechanisms for generation of solar extreme electromagnetic fluxes, solar flares, coronal mass ejections, and the propagation of these phenomena from the Sun to the Earth’s magnetosphere and ionosphere. The resulting ionosphere variability affects radio frequency (RF) communications over a very wide range of frequencies. A better understanding of solar and space physics, and the ability to accurately forecast even earlier the effects of solar activity, are the goals of the interagency National Space Weather Program. Upper atmospheric neutral density is also a function of solar activity, and future research will result in improved specification and forecast of satellite drag, orbital tracking, and vehicle reentry times—improving the U.S. Strategic Command’s ability to maintain and upgrade its Space Object Catalog.

Remote sensing measures and characterizes signals, environmental parameters, and target signatures critical to the performance of surveillance, acquisition, tracking, and hit-to-kill sensors and weapons. It also provides critical chemical/biological warfare support. In meteorology, wind profiler technology provides details regarding the fine structure of wind, temperature, humidity, and aerosols within the atmospheric boundary layer. Of special importance is the ability to model and predict marine refractivity profiles and surface base ducts.
DoD research in Environmental Sciences is also directed toward the study of the broad spectrum of land-based phenomena that affect U.S. forces as they operate upon the Earth’s surface and its ephemeral natural surface covers. DoD research in terrestrial sciences falls in three subareas: terrain properties and characterization; terrestrial processes and landscape dynamics; and terrestrial system modeling and model integration.

Terrain properties and characterization provides the ability to understand and utilize the variable topographic and physical characteristics of the landscape, and is critical to mobility/counter mobility, communication, survivability, and troop and weapon effectiveness. Both fundamental data on the distribution and character of natural and manmade features, and information about the dynamic condition of the terrain are required for rapid mapping, installation support, and environmental stewardship. A major goal of this effort is rapid generation, analysis, and utilization of remotely sensed terrain data describing dynamic battlefield conditions.

Terrestrial processes and landscape dynamics research develops enhanced understanding and numerical description of terrestrial processes affecting DoD operations. Improved measurements and theoretical treatments are needed to treat the complex, often nonlinear dynamics governing these processes, which often operate over a wide range of discontinuous scales of time and space, making them extremely difficult to characterize and quantify. Of particular research interest are those operational environments (i.e., cold region, desert, tropic, coastal, mountains, and urban) that are most restrictive. Geomorphic activity exerts a driving feedback on the hydrologic cycle. These fluid–terrain interactions and feedbacks are highly nonlinear and operate over a very broad range of spatial and temporal scales. Sensor and signature energy interaction with the dynamic terrain environment dramatically influences the performance of weapon and sensor systems, particularly those reliant on IR, acoustic, seismic, or millimeter-wave technologies. Civil engineering aspects of protective structures and sustainable design require in-depth knowledge of such diverse areas as blast effects and the impact of climate change. Critical to developing an engineering-scale understanding of the properties and behavior of surface environments is a fundamental knowledge about the processes that operate on surface materials at a variety of scales. Field observation, laboratory experimentation, and computational modeling must be integrated to solve well-formulated problems. Predictive geotechnical models, based on well-characterized constitutive relationships, are required to identify controlling processes and parameters across a spectrum of scales.

Terrestrial system modeling and model integration research develops models and simulators. Three areas of particular interest are vehicle terrain interaction, dynamic terrain reasoning, and sustainable land use. There is an acute need to understand the influence of terrain properties and behavior on feature identification, mobility and maneuverability, and sensor interaction in the context of providing planning and rehearsal decision-making tools, real-time trafficability/mobility assessments, and optimized system performance. It is also necessary to understand the interrelated impacts of land-based military training and testing on terrain, hydrologic networks, geomorphic response quality, and ecosystems; and to develop integrated models that can be applied to sustainable military facility and land management, environmental quality considerations, and natural resources conservation.
Ocean processes that directly affect DoD operations include tides, currents, water temperature and density, waves (surface and internal), and the distribution and concentration of the dissolved and particulate matter that affects how light and sound are transmitted through the ocean. The domain of interest is the entire theater of naval and marine operations, from coastal land areas to the central ocean gyres, and from the air–ocean interface to the sea floor. The primary areas of investment are in sensors and platforms, which enable the warfighter and researcher to monitor and assess the ocean environment in new and novel ways; focused field and laboratory investigations designed to provide a better understanding of dynamic ocean processes; and the development of accurate ocean process models that enable the user to simulate and forecast important oceanographic conditions.

Fundamental knowledge about the ocean arises primarily from observations, and understanding can progress no further than the current database of observations. Continued refinements to existing sensors and development of the next generation of sensors are necessary investments for any area of oceanographic research. Once a process is understood sufficiently enough that a predictive model has been developed, model accuracy is completely dependent on the ability to define the initial and boundary conditions (i.e., to make key on-scene observations at specified times and locations). This means needing not only accurate, robust sensors, but also developing the platforms that will transport those sensors within the model domain. Toward this end, significant investments and advancements are being made in autonomous sampling systems, including sensors, platforms, and communications. In the view of many top-ranked oceanographers, this technology has the potential to revolutionize how we sample the ocean.

Many ocean processes—biological, chemical, and physical—are beyond our ability to model accurately because we lack the fundamental understanding necessary to describe them within a mathematical framework. To achieve a forecast capability, focused, multiyear, multidisciplinary investigations are conducted. These include controlled laboratory experiments and intensive field campaigns. Because field campaigns are expensive, many of them are designed to span several programs within DoD and often include collaborative efforts with other federal, state, and local funding agencies. Often, a field campaign will result in the documentation of a process or phenomenon that does not fit into our idea of how the ocean works. Examples are the recent discovery of thin biological stratifications within many coastal environments, very intense solitons generated within marginal seas, and strong fluorescence signatures associated with the shallow ocean floor.

The ultimate goal of any oceanographic investigation is to understand the process in question so completely that with key observations a condition can be predicted at some time in the future. From the DoD perspective, this predictive capability would then be used to: (1) take advantage of the natural environment to the extent possible with planning operations, and (2) develop technologies that will reduce or eliminate any confounding influence on the part of the environment. A significant portion of the ocean science investments is directed at computational methods and resources and theoretical and applied mathematics. However, the modeling work does not stop with a believable simulation. In fact, the most difficult, time-consuming, and expensive part of developing a predictive model is the validation process—comparing predictions with observations.
Mathematics, Information Network, and Computer Sciences

Mathematics provides the analytical and computational methods for the biological sciences, information science, life science, operations research, and the physical sciences. New methods have become increasingly important for the understanding of multiple-scale, nonlinear, strongly interactive, dynamical systems in materials, photonics, sensor fusion, nanotechnology, and network security, to name a few. Computer science provides the methodologies to implement the nonlinear mathematics into intelligent software agents, battlefield decision aids, computer vision, and the processing of heterogeneous and distributed databases.

The scaling behavior of complex systems for modeling and simulation—together with considerations of realism, interoperability, and synchronization—is vital for military needs. The design of intelligent agents, the foundations of heterogeneous and distributed databases, and the design and evolution of software systems and real-time algorithmic and architectural issues for battlefield decision aids are all important areas of DoD interest that involve mathematics and computer science in critical ways.

DoD supports basic research in mathematics on nonlinear dynamics, complexity/computation theory, and multiple-scale phenomena for such applications as novel materials for advanced armor and antiarmor systems, ocean modeling and wavelet-based image processing, and control and guidance.

Adaptive methods constitute a significant part of the computational mathematics research activity, with less emphasis on traditional linear filtering and more development in the area of nonlinear filtering. Operations research is one of the DoD drivers of mathematical programming and the modeling of discrete-event systems—indicative of the need for improved algorithms for large, complex planning problems and logistics, probabilistic methods for automatic/aided target recognition modeling of compressible and hypersonic flow, and computation of incompressible flows for hydrodynamic design.

General sub-areas within Mathematics research are:

*Modeling and mathematical analysis*—The fundamental knowledge derived from experiments in the physical, biological, and life sciences. This knowledge increases DoD’s ability to develop advanced ground vehicles, aircraft, and naval vessels, and to identify their failure modes along with those of delivery systems, radar, sonar, sensors and actuators, and other military equipment.

*Computational mathematics*—The predictive ability of any set of constitutive equations depends on the ability to reliably increment those equations forward in time. Thus, computational mathematics impacts DoD’s capabilities in ballistics, target penetration, vulnerability of ground vehicles, aircraft and naval vessels, as well as combustion, detonation, and stealth technology.

*Stochastic analysis and operations research*—The systematic treatment of error, uncertainty, and chance is fundamental in the control and prediction of complex systems. Research in this area impacts DoD capability in design, testing, and evaluation of systems; making decisions under conditions of uncertainty; and logistics and resource management.
Research in the Computer Sciences falls into three general sub-areas: intelligent systems; software; and architecture and systems.

Research in intelligent systems focuses on the control of complex dynamical phenomena, particularly in engineering systems. The understanding and control of intelligent systems directly affects DoD capabilities in automated C3I systems; guidance and control of semi-automated and automated platforms; automatic target recognition; and real-time warfare management decision aids.

Research in software addresses the perceived engineering technology needs of the future and defines the DoD critical-path, open-research issues to be resolved. This research influences DoD capabilities in automation, decision support, combat systems, warfare management systems, distributed interactive simulation, digitization of the battlefield, training, and man–machine interaction.

The broad area of research into the use of hybrid system architectures and advanced distributed simulation affects DoD capabilities in warfare management, real-time data acquisition, training, C3I, geographic information systems, automatic target recognition, system automation, distributed interactive simulation, and vulnerability and lethality analysis.

**Engineering**

Research in solid-state and optical electronics will provide the warfighter with novel or improved electronic and optical hardware (including nanoelectronic hardware) for surveillance, target acquisition, tracking, electronic controls, radar and communication, displays, data processors, and advanced computers. Research in solid-state electronics emphasizes topics of limited commercial interest such as radiation-hardened, low-power, low-voltage applications for soldier or space support; ultra-high-frequency devices to be applied in secure communication; remote detection devices for personnel and chemical or biological agents; versatile, wideband, multifunctional RF technology; or robust building blocks for future generations of efficient, ultra fast, dedicated supercomputers. Optical electronics, including photonics, takes advantage of the very high transmission bandwidth and aims at massive optical storage and parallel channels as critical building blocks of photonic computation. Other optical research is directed to multifunction IR and ultraviolet (UV) devices for target and threat detection and avoidance.

Information electronics efforts push the performance envelope for wireless communications and decision-making by advancing mobile wireless networking, simulation and modeling, coding, digital signal processing, and image/target analysis and recognition. Research in information electronics is dedicated to signal processing for wireless applications and image recognition and analysis. Under development are coding schemes for secure communication and robust communication networks; and unique cellular arrays for image processing to bypass software and algorithm bottlenecks. Optimum control of distributed information processing and transmission is also receiving substantial attention. Innovative approaches to modeling and simulation of devices and circuits are being pursued. Modeling and sensor fusion, as well as control and adaptive arrays, are also being emphasized.
Progress in electromagnetics will advance DoD capabilities in signal transmission and reception such as found in radar, high-power microwaves, or secure communications in built-up areas. The electromagnetics research program is focused on fundamentals of antenna design, dispersion-free beamsteering, scattering and transmission of electromagnetic (EM) signals, vacuum electronics modeling and simulation, and efficient and low-energy RF components for use pre-dominantly in multifunctional and wireless applications. Computational electromagnetics is receiving strong emphasis, along with novel approaches to time-domain modeling of electromagnetic wave generation, transmission, and propagation. A substantial part of the program is focused on modeling of millimeter-wave phenomena by optical means. New adaptive, reconfigurable RF radio/sensor concepts are also being explored.

The overall scientific goal is to understand and control the mechanical behavior of military systems, including combat vehicles and weapons. Such understanding leads to revolutionary system-level improvements in performance, survivability, and costs. Research efforts will result not only in the benefits cited above, but also in advances in analytical design and testing methods, including modeling and simulation tools and diagnostic instrumentation.

Engineering research is closely tied to the issue of complexity. Complexity manifests itself in several ways, such as the extremely large range of scales present in a phenomenon, the plethora of simultaneous interactions that govern its dynamics, and the mathematical nonlinearity and anisotropy in the descriptive mathematical models. Research in mechanics is focusing on understanding: (1) relationships between microscale phenomena and macroscale response, and (2) submicroscale mechanical response devices for micro- and nanotechnology and for obtaining service-history data. Research also seeks to: (1) invent new concepts for predicting and controlling strongly nonlinear/dynamic phenomena; (2) conduct multidisciplinary research among the different disciplines of mechanics and with complementary capabilities in physics, chemistry, biology, and mathematics; and (3) create novel simulation and diagnostic tools at an appropriate level of complexity relevant to engineering. These characteristics, alone or in combination, are present in all DoD research in Mechanics.

Engineering research supports solid and structural mechanics, fluid dynamics, and propulsion and energy conversion. Efforts include research on dynamics and smart structures, the stability and control of rotorcraft structures, underwater explosion effects and structural acoustics, fixed-wing aeroelasticity, and engine dynamics.

Research in solid and structural mechanics deals with the identification, understanding, prediction, and control of multiscale phenomena that affect the performance and reliability of modern DoD structures. The research includes: (1) structures that range in size from those on nano- and microscales to large space/air/sea/land platforms; (2) structures that are made from metals, ceramics, polymers, composites, and functionally graded materials; (3) structures that are intended to perform multiple tasks, are subjected to various combined loadings, and contain various “smart” or active materials; and (4) aeroelastic structures that operate in a range of Mach numbers from low subsonic to hypersonic. The anticipated outcomes of research are physics-based models for response prediction, an enhanced understanding of unsteady behavior, and robust active control leading to integrated optimal designs of materials, structures, and, in some cases, flow control. Emphasis is on integrating knowledge from the
micro- to the macrolevel and on macro-optimization. The phenomena range from fracture and fatigue initiated at micromechanical levels to multiple-scale interactions that need to be quantified in order to optimize the dynamics of complex structures. The issues of life prediction/extension of engineered structures are approached by relying on the disciplines of solid mechanics of finite deformation and failure, penetration mechanics, and computational mechanics. Research on “smart” structures integrates actuators, sensors, and control systems into the structure to accomplish damage control, vibration reduction, noise reduction, and reconfigurable shapes. Opportunities exist for optimizing lift-to-drag ratio, increasing lift, expanding the flight envelope, and reducing required installed power on DoD aerospace vehicles. Reliability of ship structures, underwater explosion effects, structural acoustics and dynamics, shock isolation/vibration reduction in machinery, and noise control are addressed. A growing area of interest is the micromechanics of devices that are used for power distribution, maneuvering, and structural health monitoring. In many cases throughout this research, emphasis is placed on nonlinear phenomena, multifunctional applications, and quantifying the uncertainty inherent in all modeling.

The design, performance, and stealth of DoD weapons, platforms, and subsystems depend on tailoring the distributed fluid mechanical loads that control their dynamics. Modern supercomputers, whole-field laser diagnostics, sophisticated turbulence models, and microelectro-mechanical actuators are used, alone or in combination, to produce validated prediction/control methods. Central to fluid dynamics research is the understanding, prediction, and control of turbulent flows with high Reynolds numbers. Such flows can be rotorcraft wakes, unsteady flows around maneuvering fighters, or multiphase flows around marine propulsors. Increased attention is being given to the understanding of compressibility, aero-optic disturbances caused by turbulence, and full-scale Reynolds number effects in aerodynamics and hydrodynamics. Simulations of high-speed flows in complex configurations relevant to hypersonic vehicles are being pursued, with emphasis on integrated approaches to inlets, supersonic combustion, and nozzles. Interdisciplinary research explores intelligent flow control strategies using microelectromechanical systems (MEMS) for thrust vectoring, high lift, drag reduction, and noise/signature reduction. A continuing effort involves simulations of free-surface/two-phase flows around surface ships, including wave breaking and bubble generation/transport, and submerged wakes in a sheared, stratified, and turbulent environment.

Research in propulsion and energy conversion is crucial to the performance, stealth, reliability, affordability, and maintainability of DoD weapons or platforms. The research is inherently and strongly multidisciplinary, combining knowledge from chemical kinetics, multiphase turbulent reacting flows, thermodynamics, detonations, plasmas, and control. Increased emphasis is being given to active sensing, actuation, and control for engines, including integration into an intelligent engine model; high-pressure kinetics; and combustion diagnostics. Another research focus involves synthesizing new energetic materials/fuels, characterizing their behavior, and controlling their energy release rates for specific DoD weapon applications. Research on the physical, chemical, and material interactions in solid propellants at realistic pressure environments addresses their combustion mechanisms. Active combustion control is being pursued for tailoring tactical missile motor behavior and compact shipboard incinerators. High-performance aircraft require engines with high operating temperature and pressure. Research to achieve more efficient and durable combustion dynamics and to utilize high-thermal-capability fuels at supercritical thermodynamic states is being conducted. High-speed propulsion and access to space are areas of renewed emphasis.
Advanced materials research includes both need-driven and opportunity-driven elements that will impact virtually all DoD mission areas in the future. This is an aggressive, integrated research program that is leading to new classes of materials possessing, increased strength and toughness, lighter weight, greater resistance to combinations of severe chemical and complex loading environments, and improved optical, magnetic, and electrical properties. These advances are focused on meeting the transformational warfighting needs by providing access to higher performance and superior weapon systems together with improved readiness, decreased need for logistic support, increased reliability, and lower lifetime cost. The DoD Basic Research Program in Materials Science includes two subareas: structural materials and functional materials. Research in both subareas includes elements of synthesis, processing, structure, properties, theory, and modeling.

Research in structural materials is needed to satisfy operational requirements of DoD systems such as armor and penetrators; durable, high-temperature components of high-performance engines used in hypersonic air vehicles, and high-performance, low-cost spacecraft materials; and lightweight, tough, corrosion-resistant hulls of naval ships. Structural materials of principal interest are metallic materials, ceramics, composites, and polymers. The structural aspects pertain primarily to service under mechanical loads. Research is focused on designing and processing advanced materials to achieve higher performance and improved reliability at lower costs, developing new materials with unique microstructures, providing improved understanding of material behavior under a variety of complex loading and environmental conditions, optimizing interface chemistry and mechanics, and developing innovative nondestructive techniques for characterizing materials and investigating the interrelationships that couple material processing and performance.

Some of the research areas of growing importance pertinent to these thrusts include computational design, aging systems, biomimetics, blast protection, and nanoscience. The area of aging systems is of particular concern for all three services in that research results may provide new opportunities for affordably maintaining and upgrading aging assets. Each of the services is investing in multidisciplinary research focused on meeting this long-term need. Research is focused in the areas of integrating materials design with engineering component design—including life prediction and life management, corrosion and degradation, and failure mechanisms—with each service concentrating on the special materials and structural aspects of its unique platforms and collaborating in areas that are more generic.

DoD systems that are affected by research in functional materials include a host of electronic devices and components; mobile and fixed electro-optical communication equipment; radars, sonars, and other detection devices; displays; readers; and power-control devices. Research in this area is focused on understanding and controlling materials processes to achieve affordable products and reliable performance, attaining materials-by-design capability to provide new materials with unique properties, investigating the principles of defect engineering, and exploring the potential of nanoscience. For example, in the area of smart systems, novel material approaches that include very high strain single-crystal piezoelectrics and magnetic materials are being pursued. These materials offer new opportunities for dynamic control of structures in advanced aircraft, rotorcraft, ships, and submarines. Further, such materials will enable the development of very sensitive devices for perimeter sensing, sonar systems, and mine detection.
Areas of growing importance include nanoscience, smart systems, and thermoelectrics. For example, in the area of thermoelectrics, novel material approaches that include lead telluride-based superlattices, skutterudites, and organic composites are being pursued. These materials offer new opportunities for low-temperature cooling of night-vision equipment and electronics, and for high-temperature applications for shipboard cooling and power generation.

**Psychology and Social Sciences**

The DoD-wide program of research in Cognitive and Neural Science develops the science base that enables the optimization of the services’ personnel resources. Areas of application include testing, training, and simulation technologies; display support for target recognition and decisionmaking; techniques to sustain human performance; human factors; and team/organizational design and evaluation methodologies. DoD basic research activities in Cognitive and Neural Science involve two subareas: *human performance* and *reverse engineering*. Research has also developed the basis for tools that support planning and operations.

Research in *human performance* influences the services’ approach to personnel selection, assignment, and training and is an essential requirement for the effective design of systems that include humans. It also explores ways to augment personnel performance in military environments; develop new ways of organizing better, more effective teams; and design more efficient systems for command and control. Topics include: group–leader processes, coordination in distributed groups, models for evaluating organizational design, and communication strategies and interfaces important to maintaining situational awareness.

In the areas of cognition, learning, and memory, focuses include the training principles that underlie acquisition, retention, and transfer of soldier skills; artificial intelligence (AI); social networks; AI-based models of cognitive architecture; on sensory integration, performance in synthetic task environments for command and control, and information fusion for decision-making support.

In stress and performance research, performance issues and the circadian timing system underlying fatigue, performance, and the change from sleep to arousal are investigated. Additional topics include:

- Optimization of the user interface in visual control of vehicles and reducing the effects of intense sound
- Tele-operated undersea requirements
- Automatic target recognition for precision strike missions
- Auditory pattern recognition for sonar signal analysis
- Generic principles of human image communication and sound localization.

The *reverse engineering* sub-area exploits the unique designs of biological neural systems by discovering novel information processing architectures and algorithms potentially implementable in engineered systems. These efforts seek to imbue machine systems with capabilities for sensing, pattern recognition, learning, locomotion, manual dexterity, and adaptive control that approximate human functionality. Research thrusts include:
• A program in reverse engineering combines neurosciences and computational modeling in five topical areas: vision, touch/manipulation, locomotion, acoustics/biosonar, and learning
• Use of animal models to explore new approaches to developing machine analogs
• Examination of biological sensor system specificity and sensitivity to provide, for example, new technologies for ambient-temperature, lightweight, low-cost IR sensors by examining the mechanisms used by animals to detect IR signals.

2.4 Laying the Technical Foundation for New Capabilities

The preceding sections provided overviews of current and planned DoD Basic Research that will generate the knowledge upon which new military capabilities needed to counter the foreseeable 21st century threats may be established. This section addresses the questions, “What’s next?” and “What are the additional Basic Research activities that could have strategic import?”

The 2007 DoD Research & Engineering Strategic Plan defines the need for development of improved capabilities (and in many of those cases, Basic Research) to achieve four strategic outcomes:

• Defeat terrorist networks
• Defend the homeland in depth
• Shape the choices of countries at strategic crossroads
• Prevent use of weapons of mass destruction.

This 2007 plan identifies a number of specific improved capabilities to achieve these strategic outcomes. Basic Research cannot leap directly to these specific capabilities. Generally, to attain these capabilities, new or vastly improved technologies must be created. Basic research discovers the elemental physical phenomena, experiments to capture the fundamental knowledge, and improves the essential understanding that forms the bedrock of these new technologies. Basic Research provides the knowledge base for technology development to be quantified, developed, and transformed into reality. With tractable, efficient technologies at hand, new capabilities follow.

These technology foci correspond to key National Research and Development priorities designated by the Director, Office of Science and Technology Policy, Executive Office of the President, and the Acting Director, Office of Management and Budget, Executive Office of the President, and they have recommended real increases (above inflation) in high-leverage DoD Basic Research.6 Some specific Basic Research examples are:

• Transformational capabilities for the standoff detection of nuclear materials
• Biometrics for counterterrorism, homeland security, and other federal uses
• Realizing the potential of nanotechnology.

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• Use of animal models to explore new approaches to developing machine analogs
• Examination of biological sensor system specificity and sensitivity to provide, for example, new technologies for ambient-temperature, lightweight, low-cost IR sensors by examining the mechanisms used by animals to detect IR signals.

Further, the areas of Basic Research emphasized in this Plan can develop transformational capabilities for the mission areas cited in the DoD Strategic Plan (QDR). A few of the many possible examples are the following:

**Defeat Terrorist Networks**

**Biometrics.** New technologies are needed for detection and tracking of terrorists. Basic Research is now exploring improvements in remote (non-contact) biometrics and studying the reliability of biometric-based identification techniques, methods, and combinations thereof.

**Nanosensors.** Reliable tagging and tracking of terrorist suspects and their vehicles, associates, and equipment requires new technologies. Basic research in nanosensor principles and behavior, as well as manufacturing techniques offer the prospect of qualitatively new tagging/tracking capabilities that can be applied remotely and are difficult for adversaries to detect and defeat.

**Defend the Homeland in Depth**

**Advanced electronics (including nano- and molecular electronics).** Identification and intercept of threats before they reach the United States is an objective in homeland defense.

Technologies involved in this capability include a worldwide sensor network and the collection, fusion, and interpretation of huge quantities of data collected through disparate means in as close to real-time as possible. Clearly, Basic Research can contribute investigations of new sensor principles, behaviors, and improvements in material, software, and hardiness. Fundamental research in higher-level mathematics, physics, electromagnetic transmission, and communications will be fundamental to a sensor network that can function seamlessly, reliably in this real-time mission.

**Capabilities to defeat terrorist networks**
- **Total Battlespace Awareness**
  - Persistent surveillance (penetrate and loiter)
  - Locate, tag, and track terrorists and WMD in denied areas
  - Human intelligence (HUMINT)
  - Predict, detect, neutralize, and mitigate Improvised Explosive Devices (IEDs)
  - Foliage/structure/surface penetrating sensors
  - ISR through walls and underground
  - Counter-sniper, motor, and rocket

**Stability Operations and Cultural Awareness**
- Improved language and cultural awareness
- Post-combat operations (security, stability, transition, and reconstruction (SSTR))
- Human, social, cultural and behavior modeling
- Strategic communications

**Command, Control, and Information Management**
- Joint command and control and network-enabled operations
- Robust, secure self-forming networks

**Tailored Force Application**
- Pre-combat operations (real time mission rehearsal course of action development and analysis)
- Tailored lethality with non-lethal options
- Urban warfare capabilities (C3I and ISR)
- Prompt global strike
- Small unit and riverine warfare capabilities
Computing sciences. Advanced sensors provide oceans of data today. With global, persistent sensor networks generating even more data, mathematics, computer, network, and information sciences must find methods and technologies that will sort, find, synthesize, and highlight the critical bits of information needed by human operators. Photonic crystals are a hardware technology that might enable significant improvements in ultra-small photonics, for optical computing, optical communications, networking, and sensor systems, all operating at incredible speed on datasets that dwarf all the text in the Library of Congress many times over. Improved algorithms are equally important to effective data fusion at the semantic level.

Shape the Choices of Countries at Strategic Crossroads

Nanotechnology. One way to shape the behavior of other groups or nations is through persistent surveillance, making it evident that the U.S. is watching. New capabilities are required for continuous, high-resolution monitoring of situations of national security interest. Nanotechnology is an enabling technology for the new classes of sensors, such as novel focal plane arrays, communications, and information processing systems needed for qualitative improvements in persistent surveillance.

Materials. Another way to shape behavior is to increase the U.S.’s ability to hold targets at risk with conventional weapons. Since conventional munitions chemistry is mature, (some deployed munitions were developed decades ago), another objective is to develop a new class of smaller, lighter-weight munitions with improved lethality. Conducting Basic Research in energetics and materials and developing technology into and below the nanoscale has high potential. Such advanced energetics technology would allow smaller numbers of forward deployed and/or immediately deployable systems, with lighter loads and diminished logistics columns, to influence the calculations of states at strategic crossroads. Comparable advances, derived from Basic Research and associated technology development, may payoff in powerful new propellants in all forms.

Plasmonics. Basic research in this esoteric field could enable the United States armed forces to have unmatched sensor capabilities. For example, plasmonic antennas may enable development of IR focal plane arrays with reduced size, weight, and lower cost that are capable of operating at room temperature—a capability that does not exist today.
Prevent Use of Weapons of Mass Destruction

Remote detection of fissile materials. Preventing the highest consequence terror attack necessitates detection at the greatest possible distance, interception, and defeat of nuclear and radiological threats. Basic Research can provide significant improvements in the materials employed in detection devices resulting in qualitatively better performance (e.g., greater sensitivity, longer range, higher probability of detection). Basic Research in Physics identifies new detection principles, proofs those principles, and establishes the feasibility of incipient technologies for standoff detection of these threats.

Detecting and defeating fissile materials at the ingredients stage. With the proper capabilities, clandestine assemblers of nuclear and radiological weapons can be identified and neutralized before they can produce operable weapons. High-confidence detection and proper characterization of their ingredient materials demands a new generation of devices suitable for use by operational personnel in the field. Basic Research in Physics and Materials Science research can pursue entirely new detection techniques of a size, weight, power consumption, reliability, and performance suitable for this mission.

In conclusion, the DoD Basic Research investment should emphasize and fund work that has direct bearing on near term challenges and threats, but the real power of Basic Research is its ability to discover the phenomena and knowledge that will become the cornerstones and mortar in the foundations of military capabilities unimagined today. For this reason, DoD Basic Research must be funded in areas beyond those defined by current threats. As fundamental discoveries cannot be predicted in science, future missions cannot be predicted for the military.

The business of R&E for DoD is a continuing conversation between military personnel who know what they want and the science and engineering community who knows what is technically possible. Basic Research informs the science and engineering community about what could be feasible, and this knowledge is a vital boundary to the continuing conversation. The future’s unpredictable military missions, that will require new capabilities to execute, may depend on technologies that spring from Basic Research areas considered irrelevant in past conflicts.
Appendix A.
DoD Basic Research Program Structure

DoD Basic Research involves both Department-wide activities and efforts within DoD Components (i.e., Military Departments, Defense Agencies, and DoD Field Activities). Major Basic Research programs within the Components are:

**Defense Research Sciences (DRS):** DRS provides the technical foundation for long-term National Security enhancement through the discovery of new scientific phenomena and new knowledge that may be of interest to the Department. It supports the scientific study and experimentation that is the basis for advanced knowledge and understanding in the general disciplines of physical sciences and engineering.

**In-house Laboratory Independent Research (ILIR):** The ILIR program funds Defense research laboratories to pursue internal research projects in support of their assigned defense missions. This program helps to develop a cadre of active research scientists and engineers who can distill and extend results from worldwide research and apply them to Defense problems.

**University Research Initiatives (URI):** URI provides support for multidisciplinary Basic Research at U.S. universities in a wide range of scientific and engineering disciplines that enable the DoD to maintain technological superiority, for university research instrumentation needed to maintain and improve the quality of university research important to the defense of our Nation. The Multidisciplinary University Research Initiatives program (MURI) is a multi-agency DoD program that supports research teams whose efforts intersect more than one traditional science and engineering discipline. Multidisciplinary team effort can accelerate research progress in areas particularly suited to this approach. Multidisciplinary research can help hasten the transition of research findings to practical application. The Defense University Research Instrumentation Program (DURIP) program acquires major equipment to augment current, or develop new, research capabilities of interest to the DoD. The competition is open only to U.S. institutions of higher education, with degree granting programs in science, math, and/or engineering. Instrumentation proposals may range from $50,000 to $1,000,000. Awards are typically one year in length. The Air Force Office of Scientific Research, the Army Research Office, and the Office of Naval Research administer the URI programs that include NDSEG, ASSURE, and PECASE.

DoD corporate programs include:

**Chemical/Biological Defense (Basic Research) program** improves the operational performance of present and future DoD Components by promoting theoretical and experimental research in the chemical, biological, medical, and related sciences. This is a Joint program managed by the Defense Threat Reduction Agency.

**The National Defense Education Act program** supports development, recruitment, and retention of individuals with expertise in physical science disciplines critical to the DoD, and DoD employment of scholars in over-strength positions while pursuing their studies and for up to two years after completion.
Due in part to historical reasons, there are some minor differences between the program element structures of the principal funders of Basic Research—the three military departments. There are also differences in the military departments’ management structures for Basic Research. These basic research programs are executed by the U.S. Army through the Research Development and Engineering Command, Army Research Laboratory, Army Research Office, the Army Corps of Engineers, the Army Medical Research Medical Command, and the Army Research Institute. The Office of Naval Research plans, programs, funds, and manages Basic Research for the U.S. Navy and Marine Corps. The Air Force Office of Scientific Research manages the basic research investment for the Air Force to ensure the transition of research results to support U.S. Air Force needs.

Table A-1 lists the current DoD Basic Research program elements. For those unfamiliar with reading DoD program element (PE) codes, the first four digits indicate that the PE funds Basic Research (6.1) by indicating PE 0601. The next three numbers are service specific serial numbers and the final letter(s) designate the responsible DoD Component or DoD corporate activity that is responsible for the money allotted to that PE.

Information concerning the activities conducted within each of these program elements is available online at <http://www.dtic.mil/descriptivesum/>.
<table>
<thead>
<tr>
<th><strong>Table A-1. DoD Basic Research Program Elements</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Government/Industry Co-sponsorship of University Research</strong></td>
</tr>
<tr>
<td><strong>National Defense Education Program</strong></td>
</tr>
<tr>
<td><strong>University Research Initiatives</strong></td>
</tr>
<tr>
<td><strong>In-House Laboratory Independent Research</strong></td>
</tr>
<tr>
<td><strong>Defense Research Sciences</strong></td>
</tr>
<tr>
<td><strong>DTRA Basic Research Initiative</strong></td>
</tr>
<tr>
<td><strong>Defense Research Sciences</strong></td>
</tr>
<tr>
<td><strong>Chemical and Biological Defense Program</strong></td>
</tr>
<tr>
<td><strong>Defense Research Sciences</strong></td>
</tr>
<tr>
<td><strong>In-House Laboratory Independent Research</strong></td>
</tr>
<tr>
<td><strong>University Research Initiatives</strong></td>
</tr>
<tr>
<td><strong>University and Industry Research Centers</strong></td>
</tr>
<tr>
<td><strong>Defense Research Sciences</strong></td>
</tr>
<tr>
<td><strong>High Energy Laser Research Initiatives</strong></td>
</tr>
<tr>
<td><strong>University Research Initiatives</strong></td>
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</table>

**Legend**

<table>
<thead>
<tr>
<th><strong>A</strong></th>
<th>Army</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BP</strong></td>
<td>Joint Chemical/Biological Defense Program (DoD corporate activity)</td>
</tr>
<tr>
<td><strong>BR</strong></td>
<td>Defense Threat Reduction Agency</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>Defense Advanced Research Project Agency</td>
</tr>
<tr>
<td><strong>F</strong></td>
<td>Air Force</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>Navy</td>
</tr>
<tr>
<td><strong>Z</strong></td>
<td>Corporate DoD activity</td>
</tr>
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</table>
Table A-2. DoD Basic Research Investments for FY07

<table>
<thead>
<tr>
<th>Life Sciences</th>
<th>ARMY</th>
<th>NAVY</th>
<th>AF</th>
<th>DARPA</th>
<th>DTRA</th>
<th>OSD CHEM BIO</th>
<th>OSD WHS</th>
<th>DoD TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBTOTAL:</td>
<td>64.9</td>
<td>37.6</td>
<td>13.1</td>
<td>41.2</td>
<td>1.5</td>
<td>83.9</td>
<td>2.4</td>
<td>244.4</td>
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</table>

<table>
<thead>
<tr>
<th>Physical Sciences</th>
<th>ARMY</th>
<th>NAVY</th>
<th>AF</th>
<th>DARPA</th>
<th>DTRA</th>
<th>OSD CHEM BIO</th>
<th>OSD WHS</th>
<th>DoD TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBTOTAL:</td>
<td>42.0</td>
<td>131.2</td>
<td>106.9</td>
<td>0.0</td>
<td>4.2</td>
<td>16.0</td>
<td>4.0</td>
<td>304.3</td>
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</table>

<table>
<thead>
<tr>
<th>Environmental Sciences</th>
<th>ARMY</th>
<th>NAVY</th>
<th>AF</th>
<th>DARPA</th>
<th>DTRA</th>
<th>OSD CHEM BIO</th>
<th>OSD WHS</th>
<th>DoD TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBTOTAL:</td>
<td>18.8</td>
<td>102.7</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3.1</td>
<td>0.3</td>
<td>126.9</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Mathematics, Information, Network and Computer Sciences</th>
<th>ARMY</th>
<th>NAVY</th>
<th>AF</th>
<th>DARPA</th>
<th>DTRA</th>
<th>OSD CHEM BIO</th>
<th>OSD WHS</th>
<th>DoD TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBTOTAL:</td>
<td>69.1</td>
<td>61.6</td>
<td>92.7</td>
<td>26.9</td>
<td>0.9</td>
<td>0.9</td>
<td>7.7</td>
<td>259.8</td>
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</table>

<table>
<thead>
<tr>
<th>Engineering</th>
<th>ARMY</th>
<th>NAVY</th>
<th>AF</th>
<th>DARPA</th>
<th>DTRA</th>
<th>OSD CHEM BIO</th>
<th>OSD WHS</th>
<th>DoD TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBTOTAL:</td>
<td>114.2</td>
<td>142.4</td>
<td>184.1</td>
<td>77.1</td>
<td>3.2</td>
<td>0.0</td>
<td>23.0</td>
<td>544.0</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Psychology and Social Sciences</th>
<th>ARMY</th>
<th>NAVY</th>
<th>AF</th>
<th>DARPA</th>
<th>DTRA</th>
<th>OSD CHEM BIO</th>
<th>OSD WHS</th>
<th>DoD TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBTOTAL:</td>
<td>41.0</td>
<td>16.4</td>
<td>9.8</td>
<td>0.0</td>
<td>0.3</td>
<td>0.4</td>
<td>0.6</td>
<td>68.5</td>
</tr>
</tbody>
</table>

| TOTAL 6.1:       | 350.0| 491.7| 408.6| 145.2 | 10.0 | 104.3        | 38.0   | 1,547.8   |

*DoD Component reports of FY07 6.1 TOA (Nov 2007)*
Appendix B.
DoD Governance of Basic Research

DoD Instruction 3210.1, Administration and Support of Basic Research by the Department of Defense, of September 16, 2005, provides guidance for the governance of DoD Basic Research. The operative portion is quoted below:

“5.1. The Director of Defense Research and Engineering shall:

5.1.1. Provide technical leadership and oversight; issue guidance for plans and programs; develop policies; conduct analyses and studies; and make recommendations for DoD basic research.

5.1.2. Recommend approval, modification, or disapproval of the DoD Components’ basic research programs and projects to eliminate unpromising or unnecessarily duplicative programs, and to stimulate the initiation or support of promising ones.

5.1.3. Recommend, through the Under Secretary of Defense for Acquisition, Technology, and Logistics to the Secretary of Defense, appropriate funding levels for DoD basic research.

5.1.4. Develop and maintain a metrics program to measure and assess the quality and progress for DoD basic research, a required element of which is an independent technical review:

5.1.4.1. At least biennially; and,

5.1.4.2. With participation by all the Military Departments and all the other DoD Components that have basic research programs.

5.1.5. Monitor the implementation of this Instruction and issue any additional direction and guidance that may be necessary for that purpose.”
Appendix C. 
Service and Agency Educational Program Websites

1. AF Visiting Scientist Program

2. Awards to Stimulate and Support Undergraduate Research Experiences (ASSURE) program
   http://www.afosr.af.mil/ASSURE/assure_home.htm

3. Defense Experimental Program to Stimulate Competitive Research (DEPSCoR)

4. Defense University Research Instrumentation Program (DURIP)
   http://www.onr.navy.mil/sci_tech/3t/corporate/durip.asp

5. DoD High Performance Computing Services
   http://www.hpcmo.hpc.mil/

6. DoD STARBASE Program
   http://starbasedod.org/index.php

7. Faculty Sabbatical Leave Program

8. Historically Black Colleges and Universities and Minority Institutions (HBCU/MI) Future Engineering Faculty Program
   http://www.onr.navy.mil/sci_tech/3t/corporate/hbec.asp

9. Mathematics Summer Employment Program (MSEP)
   http://www.nsa.gov/careers/students_1.cfm#msep

10. Multidisciplinary Research Initiative (MURI)

    https://www.asee.org/ndseg/

12. The Naval High School Science Awards Program (NSAP)
    https://onronline.onr.navy.mil/pls/NSA/NSA

13. Naval Research Enterprise Intern Program
14. Naval Research Science & Technology for America’s Readiness (N-STAR)
   http://nstarweb.com

15. Navy Postdoctoral Fellowship Program

16. Navy Science and Engineering Apprentice Program (SEAP)
   http://www.asee.org/seap/index.cfm

17. Partnerships for Research Excellence and Transition (PRET)

18. Presidential Early Career Award in Science & Engineering (PECASE)

19. Science, Mathematics and Research for Transformation (SMART)
   https://www.asee.org/smart/

20. Summer Faculty Fellowship Program (SFFP)
   http://www.asee.org/sffp/

21. Uniformed Services University of the Health Sciences (USUHS)
   http://www.usuhs.mil/

   http://www7.nationalacademies.org/rap/

23. U.S. Army Educational Outreach Program (USAEO)
   http://www.usaep.com

24. Young Investigator Program (YIP)
## Appendix D. Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF</td>
<td>Air Force</td>
</tr>
<tr>
<td>AI</td>
<td>artificial intelligence</td>
</tr>
<tr>
<td>C3I</td>
<td>command, control, communications, and intelligence</td>
</tr>
<tr>
<td>CBDP</td>
<td>Chemical and Biological Defense Program</td>
</tr>
<tr>
<td>CBRNE</td>
<td>chemical, biological, radiological, nuclear, and enhanced high explosive</td>
</tr>
<tr>
<td>DARPA</td>
<td>Defense Advanced Research Projects Agency</td>
</tr>
<tr>
<td>DBRAG</td>
<td>Defense Basic Research Advisory Group</td>
</tr>
<tr>
<td>DoD</td>
<td>Department of Defense</td>
</tr>
<tr>
<td>DTRA</td>
<td>Defense Threat Reduction Agency</td>
</tr>
<tr>
<td>EM</td>
<td>electromagnetic</td>
</tr>
<tr>
<td>EMP</td>
<td>electromagnetic pulse</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HUMINT</td>
<td>human intelligence</td>
</tr>
<tr>
<td>IEDs</td>
<td>Improvised Explosive Devices</td>
</tr>
<tr>
<td>IR</td>
<td>infrared</td>
</tr>
<tr>
<td>ISR</td>
<td>intelligence, surveillance, and reconnaissance</td>
</tr>
<tr>
<td>JWSTP</td>
<td>Joint Warfighting Science and Technology Plan</td>
</tr>
<tr>
<td>ManTech</td>
<td>manufacturing technology</td>
</tr>
<tr>
<td>MEMS</td>
<td>microelectromechanical systems</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NDSEG</td>
<td>National Defense Science and Engineering Graduate</td>
</tr>
<tr>
<td>NSF</td>
<td>National Science Foundation</td>
</tr>
<tr>
<td>OMB</td>
<td>Office of Management &amp; Budget</td>
</tr>
<tr>
<td>OSD</td>
<td>Office of the Secretary of Defense</td>
</tr>
<tr>
<td>PE</td>
<td>program element</td>
</tr>
<tr>
<td>PECASE</td>
<td>Presidential Early-Career Awards for Scientists and Engineers</td>
</tr>
<tr>
<td>QDR</td>
<td>Quadrennial Defense Review</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>research and development</td>
</tr>
<tr>
<td>R&amp;E</td>
<td>research and engineering</td>
</tr>
<tr>
<td>RDT&amp;E</td>
<td>research, development, test, and evaluation</td>
</tr>
<tr>
<td>RF</td>
<td>radio frequency</td>
</tr>
<tr>
<td>S&amp;T</td>
<td>science and technology</td>
</tr>
<tr>
<td>SMART</td>
<td>Science Mathematics and Research for Transformation</td>
</tr>
<tr>
<td>SPG</td>
<td>Strategic Planning Guidance</td>
</tr>
<tr>
<td>SSTR</td>
<td>security, stability, transition, and reconstruction</td>
</tr>
<tr>
<td>Tc</td>
<td>temperature</td>
</tr>
<tr>
<td>UASs</td>
<td>Unmanned Aviation Systems</td>
</tr>
<tr>
<td>UAVs</td>
<td>unmanned aerial vehicles</td>
</tr>
<tr>
<td>UV</td>
<td>ultraviolet</td>
</tr>
<tr>
<td>WMD</td>
<td>Weapons of Mass Destruction</td>
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