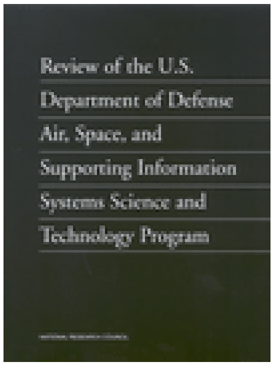

Review of the U.S. Department of Defense Air, Space, and Supporting Information Systems Science and Technology Program

Committee on Review of the U.S. Department of Defense, Air and Space Systems Science and Technology Program, National Research Council

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Committee on Review of the U.S. Department of Defense
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Department of Military Science and Technology
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Preface

Since the mid-1940s, when Vannevar Bush and Theodore von Karman wrote *Science, the Endless Frontier* and *Toward New Horizons*, respectively, there has been a consensus that strong Department of Defense support of science and technology (S&T) is important to the security of the United States. During the Cold War, as it faced technologically capable adversaries whose forces potentially outnumbered U.S. forces, the United States relied on a strong defense S&T program to support the development of technologically superior weapons and systems that would enable it to prevail in the event of conflict. Since the end of the Cold War, the United States has relied on its technological superiority to maintain a military advantage while at the same time reducing the size of its forces. Over the past half-century, creating and maintaining a technologically superior military capability have become fundamental to U.S. national security strategy, and investment in S&T has become a basic component of the defense budget.

In late 1998, Congress asked the Secretary of Defense to conduct a study, in cooperation with the National Research Council (NRC), on the S&T base of the U.S. Department of Defense (DoD). Congress was particularly concerned about areas of the S&T program related to air systems, space systems, and supporting information systems. Its concern was based on the Air Force's reduction of its S&T program from the largest of the three military service programs to the smallest. Congress also wanted to ensure that the Air Force maintained an appropriately sized S&T workforce. In late 1999, the Deputy Under Secretary of Defense for Science and Technology asked the NRC to conduct a study to explore these issues.

The committee thanks the congressional staff members, the Deputy Under Secretary of Defense, her staff, and representatives of the military services and defense research agencies who met with the committee and provided their support for its effort. The committee is also grateful to Robert Heaston, the committee liaison from the NRC Board on Army Science and Technology, who contributed greatly to the study and report. Finally, the committee thanks the NRC staff for its assistance in conducting the study and preparing this report.

Eugene E. Covert, *Chair*
Committee on Review of the U.S. Department of Defense Air and Space Systems Science and Technology Program

Acknowledgment of Reviewers

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

Curt Carlson, SRI International, Menlo Park, California
Edward M. Greitzer, Massachusetts Institute of Technology, Cambridge
Norman Hackerman, Robert A. Welch Foundation, Houston, Texas
John McElroy, University of Texas, Arlington
John D. Warner, Boeing Company, Seattle, Washington
Leo Young, Consultant, Baltimore, Maryland

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Alexander Flax, National Academy of Engineering, and Gilbert F. Decker, Walt Disney Imagineering Research and Development, Inc. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Acronyms

ACTD	advanced concept technology demonstration
AFA	Air Force Association
AFIT	Air Force Institute of Technology
AFMC	Air Force Materiel Command
AFRL	Air Force Research Laboratory
AFRL/IF	Air Force Research Laboratory/Information Directorate
ATTD	advanced technology transition demonstration
BMDO	Ballistic Missile Defense Organization
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
DARPA	Defense Advanced Research Projects Agency
DoD	U.S. Department of Defense
DUSD (S&T)	Deputy Under Secretary of Defense for Science and Technology
FY	fiscal year
GOCA	government-owned, collaborator-assisted
GOCO	government-owned, contractor-operated
GPS	Global Positioning System
IPA	Intergovernmental Personnel Act
ISR	intelligence, surveillance, and reconnaissance
IST	information systems technology
MS&C	modeling, simulation, and collaboration
NASA	National Aeronautics and Space Administration
NRC	National Research Council
O&M	operations and maintenance
ORD	operational requirements document
OSD	Office of the Secretary of Defense
RDT&E	research, development, test, and evaluation
RIF	reduction in force

S&E	science and engineering
S&T	science and technology
TARA	technology area review and assessment
TCT	time-critical target
TEO	technology executive officer
TOA	total obligational authority
UAV	unmanned air vehicle
UCAV	unmanned combat air vehicle

Executive Summary

TASK AND APPROACH

In November 1999, in response to congressional direction to the Secretary of Defense appearing in Section 214 of the Strom Thurmond National Defense Authorization Act for Fiscal Year 1999 (P.L. 105-261), the Deputy Under Secretary of Defense for Science and Technology (DUSD (S&T)) requested that the National Research Council (NRC) conduct a study on the technology base of the Department of Defense. The statement of task for this study was as follows:

> The NRC will conduct a study that
>
> a) builds upon projections made by the DoD, as included in planning documents and through dialogue with DoD principals, to define and project an "adequate technology base" in the areas of air and space systems, and in the supporting information technology, in the 2010 to 2020 timeframe,
>
> b) determines in a qualitative sense the level of investment required to attain/maintain the technology base defined above (i.e., will current S&T budgetary projections be sufficient to attain/maintain this base), and
>
> c) examines the academic degree requirements and numbers of members of the services required to maintain adequate in-house research in areas where industry does not provide support, and management oversight expertise in areas of research where industry is performing sufficient research.

Congress was particularly concerned about the declining Air Force investment in science and technology (S&T) since the end of the Cold War and about continuing reductions in the number of Air Force S&T personnel.

To conduct the study, the NRC established a committee of recognized experts in the areas of air, space, and information systems; personnel; resources; and defense S&T. In accordance with the statement of task, the Committee on Review of the U.S. Department of Defense Air and Space Systems Science and Technology Program met with U.S. Department of Defense (DoD) principals, reviewed DoD S&T planning documents, and examined other studies concerned with DoD S&T. Although other service and defense research agency S&T programs include some air and space systems-related investments, it was clear from Section 214 and from discussions with congressional representatives that the focus of Congress's concern was the Air Force. The study committee thus focused its attention on Air Force S&T.

The request to determine "in a qualitative sense the level of investment required" suggested to the committee that the study's sponsor recognized the inherent difficulty of making any hard and fast recommendations on level of investment and therefore wanted the committee to use its best judgment in recommending an appropriate level of investment to secure an adequate technology base for DoD. Based on committee members' knowledge gained from their extensive experience with DoD and Air Force S&T and on the information reviewed during the study, the conclusions and recommendations presented in this report reflect the committee's qualitative rationale and collective judgment.

FINDINGS

DoD Investment in S&T for Air and Space

The DoD budget today is about 25 percent lower in real terms than at the end of the Cold War.[1] This reduction reflects attempts to realize a post-Cold War peace dividend and to deal with federal budget deficits in the 1990s. The Air Force budget is down even more over the same period, about 32 percent in real terms. For both DoD and the Air Force, budgets have been reduced in all major categories, including procurement, operations and maintenance, military personnel, and research, development, test, and evaluation (RDT&E), of which S&T is a part. The overall DoD S&T investment also shrank during the 1990s; however, it grew during FY00 and FY01 so that by FY01 it was about 2 percent greater, in real terms, than it was at the end of the Cold War. This increase in the DoD S&T investment did not come at the expense of other important defense needs. S&T now makes up only 3 percent of the total defense budget.

The trend at DoD toward greater investment in S&T is reflected in Army, Navy, and defense research agency investments in S&T, which have risen between 17 and 47 percent in real terms since FY89. The sole exception is the Air Force, whose real S&T investment is down by 46 percent. As a percentage of its total budget between FY89 and FY01, Air Force funding for S&T fell from about 2.2 percent to about 1.7 percent.

The Air Force has been under increasing financial stress since the Cold War ended. Operational requirements and tempo have increased, not fallen. Operations in the Gulf War, Bosnia, Kosovo, and the Northern and Southern Watch over Iraq have strained Air Force resources. Modernization programs, such as those for the F-22 and the Joint Strike Fighter, have required large outlays and will require even more resources as those programs enter production. At the same time, in what has been called a "death spiral," aging air and space systems are becoming more and more expensive to maintain and operate, leaving little money to cover the cost of their replacements. Under these conditions, it is not surprising that the Air Force has tried to find or divert money from every possible source, including its S&T investment, to pay these expenses.

Given this financial stress and the collapse of the Soviet Union, it could be argued that the need for Air Force investment in S&T has diminished and that the Air Force could thus afford to reduce that investment. The committee believes, however, that such reasoning does not take into account the changing nature of the global threat and the S&T challenges it presents. Although the Cold War impetus for the development of some advanced systems has diminished, continued S&T investment is still necessary, both to support advanced systems and to extend the lifetimes of aging systems until new systems can replace them. A new operational concept calling for rapid deployment and reduced dependence on overseas bases for force projection will require new technologies. The threats posed by the rapid spread of information technologies and the possible acquisition of weapons of mass destruction by international terrorist groups or nations that cannot otherwise afford large armed forces will require technological solutions. Accordingly, the committee believes that the Air Force, instead of reducing S&T investment, would have been better served by reorienting its existing investments and possibly increasing them in some areas to deal with threats that have arisen since the Cold War.

A key factor in Air Force S&T investment decisions is the effectiveness of S&T representation and advocacy at the corporate policy and decision-making level of the Air Force. Currently, the highest S&T-dedicated military position in the Air Force is the 2-star Air Force Research Laboratory (AFRL) commander position at Wright-Patterson AFB near Dayton, Ohio. The AFRL commander reports directly to a general (4-star), the commander of the Air Force Materiel Command (AFMC), of which AFRL is a part. AFMC headquarters is also located at Wright-Patterson. The AFMC commander's responsibilities are very broad, including the programs at four product centers, five air logistics centers, three test centers, and two major specialized centers, in addition to AFRL. The AFRL commander is also dual-hatted as the Air Force tech-

[1]The terms "real dollars" and "constant dollars" refer to dollar amounts expressed in terms of their equivalent values in some base year. Expressing monetary values in these terms allows comparison of dollar amounts from different years that take into account the effects of inflation. The term "current dollars" refers to dollar amounts expressed in terms of their actual values in the years in which they are used. Comparing current-dollar amounts from different years does not take into account the effects of inflation and can be misleading. For dollar amounts given in this report, the reader is advised to note whether they are expressed in real/constant dollars or current dollars.

nology executive officer (TEO) and as such reports as well to the Assistant Secretary of the Air Force for Acquisition, whose office is in the Pentagon.

The strength of S&T representation in the Air Force is weakened by the relatively small size of the S&T program compared with the Air Force's total program and compared with the broad scope of responsibilities held by the assistant secretary for acquisition and the AFMC commander. The relatively small size of the S&T investment affects perceptions of its value and the amount of attention paid to it. The Assistant Secretary of the Air Force for Acquisition is responsible for representing this S&T investment and is a member of the Air Force Council. However, he is also responsible for representing all Air Force acquisition programs, which constitute the "D" part of the RDT&E investment and are much larger combined than the S&T program. The broad scope of responsibilities of the AFMC commander and the Assistant Secretary of the Air Force for Acquisition, combined with the relatively small size of the S&T program, can prevent effective advocacy for Air Force S&T at the corporate policy and decision-making level of the Air Force. The Air Force itself has recognized this problem and has recently taken actions to increase the level of S&T advocacy within the Air Force.

Air and Space Systems

Many challenges currently face air systems S&T. Unmanned air vehicles, ranging in size from micro air vehicles to high-altitude, long-endurance platforms, require research in planning and decision-making algorithms, onboard image processing, and software-based systems integration. Highly maneuverable unmanned combat air vehicles require research in materials, structures, and aerodynamics. Hypervelocity weapon systems to provide global time-critical strike capability and strike capability against deeply buried targets require research in propulsion and guidance and control. Although the Air Force recognizes these needs, it is not investing in air systems S&T at the level necessary to meet them. At the start of the 21st century, the Air Force air systems S&T budget was less than half its level only 10 years earlier. Moreover, a large part of the remaining investment is constrained by Office of the Secretary of Defense (OSD) mandates. Finally, the Air Force has diverted part of its air systems S&T investment to increase its investment in space systems S&T.

There is substantial agreement in the U.S. national security community that, as other developed and developing nations have increased their capabilities to use space not only for peaceful purposes but also to threaten the United States or its vital interests, so also has the need increased for the U.S. military to patrol, protect, and use U.S. space assets. DoD and the Air Force recognize this need, as well as the need for increased research in space technologies. Nevertheless, their increased emphasis on space is not reflected in the Air Force's current S&T investments.

The committee found that the Air Force does, indeed, plan to double the percentage of its total S&T investment that is oriented toward space. However, this does not necessarily mean that the space S&T program is being doubled or even significantly changed. Looking at the numbers shows that a large part of the increase in the Air Force space S&T investment appears to be due to the Air Force's transfer of the relatively large Space-Based Laser and Discoverer II space-based radar programs, previously considered to be demonstration/validation programs, into the S&T appropriation. If this accounting change is set aside, the Air Force's planned space S&T investment will be about the same five years from now as it is today.

OSD continues to rely on the Air Force for the bulk of the department's space S&T investment. However, the Air Force is not the only service affected by the growing space threat. DoD space policy recognizes that this is a department-wide concern and a defense arena that should be emphasized throughout the department. Therefore, OSD should help the Air Force increase its space S&T investment by providing additional S&T funding; moreover, OSD should increase the non-Air Force DoD space S&T investment as well.

Supporting Information Systems

In recent years, the Joint Chiefs of Staff and the services have recognized information systems technology as an impetus for the revolution in military affairs and as a key enabler of their visions for the future. Information systems have become pervasive throughout the military. They are changing the equations of warfighting and are replacing sheer mass, which can be very expensive and difficult to apply in some situations, with equal or greater lethality and survivability achieved by greater speed, deeper and wider knowledge, increased precision, and tighter control.

Information systems are also pervasive in civilian society. On a personal level, almost everyone has some familiarity with information technology through the use of personal computers at work and at home, the Internet, and electronic commerce. Information systems technology is one of the most conspicuous aspects of the U.S. economy and, at a trillion dollars per year, the commercial, non-DoD investment in information technology is a significant driver of the U.S. economy. But the rapid spread of information technology is more than just a U.S. phenomenon. The use of information technology is proliferating around the globe, providing a basis for global technological and economic development and increasing connectivity within and between nations.

At the same time, however, the rapid spread of information technology is increasing the global threat because it can provide to other militaries the same power that it gives to the U.S. military. As dependence on information systems increases, societies also become more vulnerable to attack. Information systems can also support an asymmetric threat. Potentially hostile nations that cannot afford a large military force can afford today's advanced information systems, as can terrorist groups. With these technologies, access to the world through global connectivity, and hostile intent, such adversaries can cause great harm at low cost.

To deal with this accelerating threat, DoD needs to have a strong information systems S&T program that includes leveraging commercial advances where possible and investing in DoD-unique S&T. The annual trillion-dollar commercial investment in information technology is three orders of magnitude larger than DoD's billion-dollar budget for information systems technology. DoD needs to be prepared to take maximum advantage of these commercial advances. At the same time, however, DoD cannot forego its own investment in information systems S&T. Commercial hardware is normally not rugged enough for military use. Commercial software is frequently not reliable enough to use for mission-critical systems nor secure enough against determined adversaries. Commercial technology also spreads rapidly, which eliminates military advantages.

DoD information systems S&T should focus on computing and software technologies for high-performance, software-intensive DoD systems; seamless communications technologies to interconnect command echelons, services, and allies worldwide; decision-making technologies to conduct joint mission planning, rehearsal, execution monitoring, battlefield visualization, and situational assessment; information assurance technologies to protect information and information systems; and modeling and simulation technologies that support all of these areas and the development of other technologies. Thus it is important for DoD to invest in the long-term basic research that the near-term, market-driven commercial sector does not find profitable. DoD also needs to invest in the applied research and advanced technology development required to move DoD and leveraged commercial advances into warfighters' hands as quickly as possible. The pervasiveness of information systems in military systems and in visions for future warfighting and the accelerating threat information technology poses require that DoD have a strong information systems S&T program.

The committee found the opposite to be the case, however, in its review of the Air Force S&T investment. Since at least the mid-1990s, the Air Force S&T investment in information systems has declined steadily, despite recurring annual plans to increase it.

At roughly \$2.5 million per year, the Air Force investment in in-house basic research for information systems is not enough to ensure support for real advances in in-house projects or to maintain the scientific expertise of the in-house workforce. The Air Force budget for applied research and advanced technology development in information systems accounts for only about 5 percent of the total Air Force S&T budget. Although the Air Force investment is supplemented by larger amounts of funding for information systems development that the Air Force manages for the Defense Advanced Research Projects Agency (DARPA) and other agencies, Air Force funding covers only in-house operating expenses and is not sufficient to pay for the transitioning of DARPA and other agency technology advances into Air Force systems. The committee believes that the Air Force investment in information systems S&T is insufficient to meet emerging threats and to satisfy the Air Force's current visions for future warfighting.

Air Force S&T Workforce

Many studies have been done through the years on the health of government S&T laboratories, and all of them have concluded that the government needs to maintain a strong internal competence in research and development (see Appendix D). These studies have also noted quality problems in government laboratories and have recommended actions to solve these problems. Very recent studies by the Defense Science Board and the Air Force chief scientist continue this trend of expressing concerns about the quality and retention of DoD and Air Force technical personnel and proposing solutions. The NRC study committee found these concerns to be valid.

As the defense budget shrank after the Cold War, so did the number of Air Force personnel, including S&T personnel. In light of the need to maintain DoD's technology base in air, space, and supporting information systems, current concerns about the decline in the Air Force's S&T workforce are justified. The Air Force can contract with academic and industry partners to conduct a large part of the research and development it needs, but some of this research needs to be done in-house to ensure that it is focused on transitioning advances into Air Force systems and to strengthen and maintain the scientific and engineering expertise of the Air Force's technical workforce.

The need for additional S&T might not be a concern if the Air Force had scientists and engineers to spare. It does not. From 1996 to 2000, the percentage reduction in AFRL personnel was twice as large as for the Air Force as a whole. This steep decline in personnel, paired with the reduced Air Force S&T budgets, means that the Air Force is being forced to do more with less.

Finally, to conduct a high-quality S&T program, the services need to be able to retain and recruit the highest-quality personnel. As the Defense Science Board and Air Force chief scientist studies pointed out, the post-Cold War drawdown, the growing economy based on high technology, and Civil Service rules governing the management and recruiting of government personnel have combined so as to almost ensure that the highest-quality DoD S&T personnel are the first to be lost. To counter these problems, Congress has tried to help. For example, Section 246 of the 1999 National Defense Authorization Act (P.L. 105-261) provides for three-year pilot programs to revitalize the service laboratories by waiving many of the restrictions regarding personnel recruiting and hiring, as well as restrictions on the use of outside technical experts. The committee endorses approaches of this kind.

OVERARCHING CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations reflect the common themes of the study as a whole. Specific conclusions and recommendations in each area are included in the body of the report.

Investment in S&T

Conclusion 1. The committee believes that the reductions made by the Air Force to its S&T investment since the end of the Cold War did not take into account the changing nature of the global threat and the S&T challenges it presents. While the need for an Air Force S&T investment oriented to the Soviet threat was diminished at the end of the Cold War, the need for overall Air Force investment in S&T was not. The committee believes that the Air Force's current (FY01) investments in air, space, and information systems S&T are too low to meet the challenges being presented by new and emerging threats.

Recommendation 1. The Secretary of Defense and the Secretary of the Air Force should continue to increase the Air Force investment in science and technology (S&T) to reach one-and-a-half to two times its current (FY01) level. Investments in S&T for air, space, and information systems should all be increased. Increasing one by decreasing the others will not satisfy current S&T program shortcomings and may create new ones.

S&T Representation and Advocacy Within the Air Force

Conclusion 2. The committee strongly believes that the Air Force needs authoritative, S&T-focused and -dedicated representation and advocacy at the corporate policy and decision-making level of the Air Force to help make informed trade-offs and budget decisions. Without corporate-level understanding and consideration of the effects its S&T investment can have on the Air Force's future, the committee believes that the Air Force faces undue risk that its S&T investment will not provide the technologies and systems needed to meet future threats. The committee is encouraged by the actions that the Air Force has recently taken to increase the level of S&T advocacy in the Air Force and believes these actions can result in a stronger S&T program. Additional actions could make Air Force S&T even stronger.

Recommendation 2. In addition to the actions they have already taken, the Secretary and the Chief of Staff of the Air Force should continue to look for ways and take actions to further strengthen S&T representation and advocacy at the corporate policy and decision-making level of the Air Force. There are a number of options they can consider, including (1) formally designating the Air Force science and technology (S&T) program as a corporate program, (2) having the current AFRL commander/TEO position report directly to the Chief of Staff or be a member of the Air Force Council, and (3) establishing an Air Force Council member position (normally an assistant secretary or a 3-star deputy chief of staff) to be filled by a person in the Pentagon who is focused on, dedicated to, responsible for, and authorized to represent and advocate S&T within the Air Force, formulate Air Force S&T budgets, and participate in Air Force corporate policy and decision-making activities. The Air Force can also benefit from carefully examining the special roles accorded the Chief of Naval Research and the Office of Naval Research in the Department of the Navy to consider how these roles could be adapted to the AFRL commander/TEO and AFRL to strengthen Air Force S&T. These options or others the Air Force identifies can address remaining weaknesses in Air Force S&T representation and advocacy and build upon the recent successes of the Air Force.

S&T Workforce

Conclusion 3a. The reductions in the Air Force's S&T workforce since the end of the Cold War and the rules governing the hiring, firing, and management of S&T workers have helped to undermine the quality and health of the Air Force's S&T program. They threaten the S&T program's ability to deliver the technologies, enable the strategies, and satisfy the visions of the future military.

Conclusion 3b. Personnel management rules threaten the quality of the Air Force's S&T program.

Conclusion 3c. The talents of DoD's technically educated officer corps are not being fully exploited, the benefits of locating uniformed personnel with their warfighter perspectives close to DoD S&T performers and S&T investment decision makers are being lost, and the number of officers throughout DoD who understand the importance of S&T to U.S. military superiority is decreasing.

Recommendation 3a. The Secretary of Defense should request that Congress extend the three-year pilot program for revitalizing the service laboratories (under Section 246 of the 1999 National Defense Authorization Act [P.L. 105-261]) by at least three years to allow laboratory programs to implement changes and evaluate the results. The Secretary of Defense, service secretaries, and service chiefs of staff should seize the opportunity that Congress created with Section 246 to improve the quality and health of their science and technology (S&T) workforces as much as possible. The services should take maximum advantage of the flexibility offered by Section 246 to try innovative approaches to managing their S&T workforces.

Recommendation 3b. The Secretary of Defense, service secretaries, and service chiefs of staff should work aggressively to improve the development and use of their military science and technology (S&T) workforce. Officers should be encouraged to carry out S&T assignments, which should be viewed positively during consideration for promotions. High-grade career-advancement opportunities for S&T officers should be made visible.

Recommendation 3c. The Secretary of Defense, service secretaries, and service chiefs of staff should implement the remedial actions proposed by previous reports. These actions include establishing personnel demonstration projects, increasing the presence of leading national (perhaps also international) non-Department of Defense (DoD) scientists and engineers in DoD laboratories through Intergovernmental Personnel Act assignments, and using alternative laboratory management and staffing approaches, such as government-owned, collaborator-assisted arrangements.

Recommendation 3d. The Secretary of Defense, service secretaries, and service chiefs of staff should work with Congress and with other agencies to enact targeted modifications to Civil Service rules that directly affect the quality and health of the science and technology workforce.

1

Introduction

BACKGROUND

Section 214

In October 1998, the Strom Thurmond National Defense Authorization Act for Fiscal Year 1999 became law (P.L. 105-261). Section 214 of the act, "Sense of Congress on the Defense Science and Technology Program" (reprinted in Appendix A), expressed congressional concerns about the U.S. Department of Defense (DoD) science and technology (S&T) program. These concerns included the growth rate of future DoD S&T funding; university involvement in the DoD S&T program; the relationship between DoD S&T and commercial research and technology; and management of the DoD S&T program. Three distinct recommendations included in Section 214 were related to management. First, it was the sense of Congress that the priority and leadership level for S&T for all three military departments should be raised. Second, the military departments should maintain a long-term focus on new technology areas and provide for periodic reviews to determine if the results of research should be transitioned into development, if the research should be continued, or if the research should be discontinued. Third, each military service, particularly the Air Force, should ensure that sufficient numbers of officers and civilians hold advanced technical degrees. These recommendations, expressed as the "sense" of Congress, were not binding. The last part of Section 214 did include a binding directive requiring the Secretary of Defense, in cooperation with the National Research Council (NRC) of the National Academy of Sciences, to conduct a study of DoD's technology base.

The study was required to cover three specific areas related to congressional concerns: the minimum requirements for maintaining a technology base that would enable the military to maintain its superiority in air and space weapon systems and in information technology; the effects of reducing future DoD S&T funding below a real growth rate of 2 percent per year; and appropriate levels of staff with advanced degrees and the optimal ratio of civilian and military staff with advanced degrees.

Congressional Concerns

Congressional concerns arose during the 1990s in response to reductions in DoD's S&T program, particularly the substantial reductions in the Air Force S&T program and in the number of Air Force S&T personnel. From 1989 to 1999, the Air Force S&T budget declined almost 55 percent in real terms compared to a decline in the total DoD budget of about 27 percent (Gessel, 2000). The Air Force S&T program, which had been almost as large as the Army and Navy S&T programs combined, was reduced to the smallest of the three (Tuohy, 1999). From 1996 to 2000, the overall number of DoD and Air Force personnel declined as part of the post-Cold War military drawdown. The percentage reductions in DoD as a whole and in the Air Force were almost identical in terms of overall personnel. The percentage reduction in Air Force S&T personnel at the Air Force Research Laboratory (AFRL), however, was almost twice that of the overall Air Force reduction (Gessel, 2000).

Since passage of Section 214 in 1998, congressional concerns have been raised repeatedly. In Section 212 of the National Defense Authorization Act for Fiscal Year 2000 (P.L. 106-65), Congress expressed its sense that the Secretary of Defense had failed to comply with the funding objective for defense S&T, especially for Air Force S&T. Senate and House of Representatives reports accompanying the Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001 (P.L. 106-398) (S.R. 106-292, H.R. 106-616) expressed Congress's continuing concerns about the Air Force S&T investment. To follow up on those concerns, Section 252 of the FY01 act required the Secretary of the Air Force to conduct strategic planning for Air Force S&T and report back to Congress. In December 2000, members of Congress sent a letter to the Secretary of the Air Force asking him to explain his long-term S&T plans (Inside the Air Force, 2001).

STATEMENT OF TASK

In November 1999, the Deputy Under Secretary of Defense for Science and Technology (DUSD (S&T)) asked the NRC to conduct a study on DoD's technology base. The statement of task for this study was as follows:

The NRC will conduct a study that

a) builds upon projections made by the DoD, as included in planning documents and through dialogue with DoD principals, to define and project an "adequate technology base" in the areas of air and space systems, and in the supporting information technology, in the 2010 to 2020 timeframe,

b) determines in a qualitative sense the level of investment required to attain/maintain the technology base defined above (i.e., will current S&T budgetary projections be sufficient to attain/maintain this base), and

c) examines the academic degree requirements and numbers of members of the services required to maintain adequate in-house research in areas where industry does not provide support, and management oversight expertise in areas of research where industry is performing sufficient research.

STUDY APPROACH

It was immediately apparent that the Committee on Review of the U.S. Department of Defense Air and Space Systems Science and Technology Program could not, with the resources available, do a thorough, detailed review of the Air Force S&T program or model and project the supporting S&T workforce requirements with any real precision. In discussions with the sponsor's representative during the first committee meeting, an agreement was reached that the committee would respond to the statement of task as allowed by the available resources. As a result, the committee addressed the program's directions from an overall perspective, focusing on the level of investment in S&T, which was the primary concern of the Congress, and providing its expert opinion on actions DoD and the Air Force can take to deal with problems related to the quality and quantity of the S&T workforce.

The committee believes that in asking the committee to determine "in a qualitative sense the level of investment required," the study's sponsor recognized the inherent difficulty in recommending any hard, quantitative investment and therefore wanted the committee to use its best judgment in recommending the appropriate level of investment in S&T to meet recognized requirements. Based on committee members' knowledge gained from their extensive experience with DoD and Air Force S&T and on the information they reviewed during the study, the conclusions and recommendations presented in this report reflect the committee's qualitative rationale and collective judgment.

The committee recognized that the term "science and technology" has different meanings to different agencies and in different contexts. For this study, the committee defined defense S&T as the basic research, applied research, and advanced development programs included in the oversight and management responsibilities of the DUSD (S&T). DoD refers to these programs as 6.1 (basic research), 6.2 (applied research), and 6.3 (advanced development) programs, respectively. (The numbering is derived from the first two digits of the corresponding DoD budget categories.)

Information provided to the committee covered only DoD's "unclassified," or publicly acknowledged, S&T programs. The committee was not given direct access to information about "classified," or covert, S&T programs. However, some committee members who had insight into classified programs through their professional experience and affiliations were able (without introducing classified information) to ensure that the committee's conclusions and recommendations made sense in the broad context of public and covert programs.

Committee members included recognized experts in the following areas: air, space, and information systems; personnel; resources; and defense S&T. Concise committee member biographies are provided in Appendix B.

As directed by the statement of task, the committee turned to DoD as the primary source of data and information for the study. Beginning in late 1999, the committee also received information, in oral and written form, from several guest speakers, including congressional staff members, the DUSD (S&T), her staff, and members of the military services and defense research agencies. Guest speakers who met with the committee are listed in Appendix C. The committee also obtained information from numerous publications, including some non-DoD documents.

CONTENT OF THIS REPORT

Chapter 2 presents historical data concerning defense S&T funding and highlights the trends that aroused congressional concerns. Chapter 2 also includes a discussion of the changing utility of defense investments in S&T and offers recommendations for future investment strategies. Chapters 3 through 5 focus on the specific areas with which this study was concerned: air and space systems; information systems; and the S&T workforce. Finally, Chapter 6 presents the committee's overarching conclusions and recommendations. Appendixes provide supplementary information as described in the report.

REFERENCES

Gessel, M. 2000. Congressional Perspectives, presentation by Michael Gessel, executive assistant to Congressman Tony Hall, to the Committee on Review of the Department of Defense Air and Space Systems Science and Technology Program, Holiday Inn Georgetown, Washington, D.C., January 24, 2000.

Inside the Air Force. 2001. Lawmakers demand answers on the future of Air Force S&T programs. Vol. 12, Issue 1, January 5, pp. 2-3. Inside Washington Publishers, Washington, D.C.

Tuohy, R. 1999. Review of Department of Defense Air and Space Science and Technology Program, presentation by Robert Tuohy, director, DoD Science and Technology Plans and Programs, to the Committee on Review of the Department of Defense Air and Space Systems Science and Technology Program, Wyndham Bristol Hotel, Washington, D.C., December 16, 1999.

2

Investment in Science and Technology

CONGRESSIONAL CONCERNS

Congressional concerns arose during the 1990s about reductions in the DoD S&T program, particularly in the Air Force S&T program. Figure 2-1 shows the relative changes in the total DoD budget since 1989. The decline in the total DoD budget by about 25 percent in real terms from FY89 to FY01 reflects attempts by Congress to realize a post-Cold War peace dividend and to deal with growing federal budget deficits in the 1980s and 1990s.

Figure 2-1 also shows that over the same period, the Air Force reduced its S&T program by about 50 percent—about twice the reduction in the overall DoD budget. In 1989, the Air Force S&T program was almost as large as the Army's and the Navy's S&T programs combined; by 2000, it was the smallest program of the three (see Figure 2-2) (Tuohy, 1999), whereas the Navy's S&T program had actually increased.

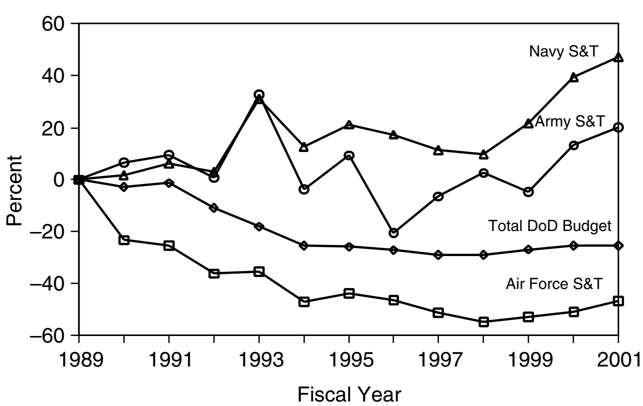

FIGURE 2-1 Percentage change in total DoD budget and service S&T funding since 1989. Data from Tables 2-2 and 2-3, constant dollars.

According to congressional staff members who met with the committee, the Air Force had proposed even deeper reductions but had been prevented from making them by the Director of Defense Research and Engineering. In addition, in 1999 the Air Force moved two relatively large programs, the Discoverer II space-based radar demonstration and the Space-Based Laser Program, which had previously been funded outside S&T, into its S&T funding line. But because total S&T funding was not increased, these two programs were funded at the expense of ongoing and new S&T programs (Gessel, 2000).

From FY89 to FY98, the Air Force reduced its S&T investment to about 46 percent of its FY89 level in real terms. From FY98 to FY01, the Air Force increased its S&T investment. By FY01 it had been increased to 54 percent of its FY89 level. Despite the turnaround, congressional concerns remained.

TRENDS IN FUNDING FOR DoD S&T

The committee examined overall DoD S&T funding trends during the 1990s to provide a context for evaluating the Air Force's funding reductions. Tables 2-1 and 2-2 show the breakdown of DoD S&T funding in current and FY01 constant dollars, respectively, for FY89 to FY01. Table 2-3 shows DoD funding by major budget category in both current and FY01 constant dollars for the same time period; Table 2-4 gives the same information for the Air Force. Table 2-5 shows changes in

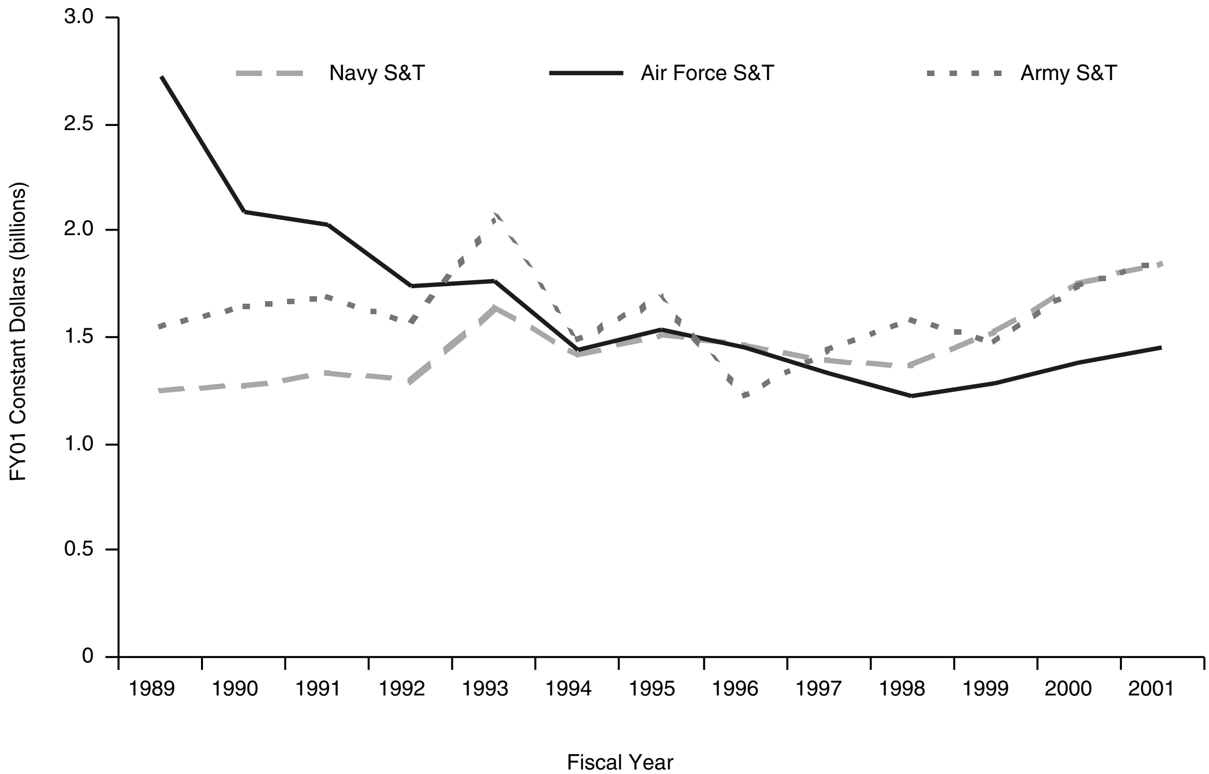

FIGURE 2-2 Service investments in S&T (6.1, 6.2, and 6.3). FY89 to FY00, appropriated; FY01 to FY05, President's budget request. SOURCE: Tuohy, 1999.

funding for DoD budget categories (1) as the average annual percentage change since FY89, (2) in terms of the largest annual percentage reduction in each budget category, and (3) as the annual percentage change between FY97 and FY01 for each budget category; Table 2-6 shows the same data for the Air Force. Table 2-7 uses the same three indicators to show the percentage changes in funding for each defense S&T category.

The tables show reductions, in real terms, in almost all categories of defense and Air Force funding since 1989: The total DoD budget is down approximately 25 percent in real terms (Table 2-5). The total Air Force budget is down 32 percent (Table 2-6). Total DoD research, development, test, and evaluation (RDT&E) funding, of which S&T is a part, is down about 21 percent (Table 2-5). Air Force RDT&E funding is down 26 percent (Table 2-6).

From FY97 to FY01, there was a significant turnaround. The total Air Force budget, driven by a strong increase in procurement funding (39 percent) and operations and maintenance funding (10 percent), increased about 7 percent overall (Table 2-6). Even in those five years, however, Air Force RDT&E declined another 8 percent (contributing to an 18 percent cut since FY90). Air Force S&T investment declined from FY97 to FY99 (in real terms) but rose in FY00 and FY01, resulting in a 9 percent increase for the five-year period (Table 2-7).

If DoD S&T funding is examined by agency, some differences are evident (Table 2-7). The Army shows an overall real increase in S&T funding of about 20 percent over the entire 12-year, post-Cold War period, with a 29 percent increase in the last five years. The Air Force shows an overall reduction of 46 percent for the entire period. The Navy shows a 47 percent increase in S&T funding over the 12-year period. The positive shifts in Navy funding are mainly the result of increases in advanced technology development (6.3), which increased more than 212 percent from FY89 to FY01. All three services experienced reductions in basic research over the 12 years. Army and Navy applied research grew during the period. Air Force applied research declined. Defense-wide S&T funding, which includes S&T funding directed by the Office of the Secretary of Defense and funding by the Defense Advanced Research Projects Agency

TABLE 2-1 DoD S&T Funding, Total Obligational Authority, FY89 to FY01 (current dollars, millions)

Component	Science and Technology Category	Dollar Type	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01
Army	Basic Research	Current	172	178	180	197	214	202	214	182	175	177	176	202	210
Army	Applied Research	Current	573	549	639	680	729	618	595	451	542	663	613	793	832
Army	Advanced Technology Development	Current	461	608	604	470	863	516	738	580	651	678	635	721	815
Total			1,207	1,335	1,423	1,347	1,806	1,336	1,547	1,213	1,368	1,518	1,425	1,716	1,857
Navy	Basic Research	Current	352	363	390	392	426	412	408	369	346	332	354	367	394
Navy	Applied Research	Current	430	444	485	488	578	438	502	536	514	463	551	610	662
Navy	Advanced Technology Development	Current	197	230	244	238	440	417	481	466	462	521	570	739	786
Total			979	1,037	1,119	1,118	1,443	1,267	1,391	1,371	1,322	1,316	1,474	1,717	1,843
Air Force	Basic Research	Current	197	193	205	206	239	225	225	216	182	188	197	208	213
Air Force	Applied Research	Current	587	570	578	618	617	601	643	627	631	546	584	587	657
Air Force	Advanced Technology Development	Current	1,343	936	926	677	694	468	538	517	446	441	462	564	587
Total			2,127	1,699	1,709	1,501	1,549	1,295	1,406	1,361	1,260	1,176	1,243	1,359	1,456
DoD-wide	Basic Research	Current	228	197	380	345	434	340	328	331	330	317	336	359	498
DoD-wide	Applied Research	Current	955	849	1,016	1,188	1,300	1,093	1,189	1,217	1,130	1,239	1,311	1,426	1,534
DoD-wide	Advanced Technology Development	Current	1,366	1,121	1,669	1,673	2,187	2,477	2,054	2,028	2,061	2,110	1,820	1,754	1,785
Total			2,549	2,167	3,065	3,206	3,920	3,910	3,572	3,576	3,521	3,666	3,467	3,539	3,816
Grand Total			6,861	6,238	7,316	7,172	8,719	7,807	7,916	7,520	7,470	7,676	7,610	8,332	8,973

NOTE: Rounded amounts may not add to the correct totals shown.

SOURCE: Personal communication, Stanley Trice, staff member, ODUSD (S&T), February 23, 2001.

TABLE 2-2 DoD S&T Funding, Total Obligational Authority, FY89 to FY01 (FY01 constant dollars, millions)

Component	Science and Technology Category	Dollar Type	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01
Army	*Basic Research*	*Constant*	*221*	*219*	*214*	*227*	*243*	*225*	*233*	*195*	*184*	*185*	*182*	*206*	*210*
Army	*Applied Research*	*Constant*	*733*	*676*	*758*	*786*	*828*	*688*	*650*	*483*	*572*	*692*	*634*	*807*	*832*
Army	*Advanced Technology Development*	*Constant*	*590*	*748*	*718*	*543*	*980*	*574*	*806*	*621*	*687*	*708*	*656*	*734*	*815*
Total			*1,544*	*1,643*	*1,691*	*1,557*	*2,051*	*1,487*	*1,689*	*1,229*	*1,444*	*1,585*	*1,472*	*1,746*	*1,857*
Navy	*Basic Research*	*Constant*	*451*	*447*	*463*	*453*	*483*	*459*	*446*	*396*	*365*	*347*	*366*	*374*	*394*
Navy	*Applied Research*	*Constant*	*550*	*546*	*576*	*564*	*656*	*488*	*548*	*574*	*543*	*483*	*569*	*621*	*662*
Navy	*Advanced Technology Development*	*Constant*	*252*	*284*	*290*	*275*	*499*	*464*	*525*	*499*	*488*	*544*	*589*	*752*	*786*
Total			*1,252*	*1,276*	*1,329*	*1,292*	*1,639*	*1,411*	*1,518*	*1,469*	*1,395*	*1,374*	*1,524*	*1,747*	*1,843*
Air Force	*Basic Research*	*Constant*	*251*	*237*	*243*	*239*	*271*	*251*	*246*	*232*	*192*	*196*	*204*	*212*	*213*
Air Force	*Applied Research*	*Constant*	*751*	*702*	*687*	*715*	*701*	*669*	*702*	*672*	*666*	*571*	*604*	*597*	*657*
Air Force	*Advanced Technology Development*	*Constant*	*1,718*	*1,152*	*1,099*	*782*	*788*	*521*	*588*	*554*	*471*	*461*	*477*	*574*	*587*
Total			*2,721*	*2,091*	*2,029*	*1,735*	*1,760*	*1,441*	*1,535*	*1,458*	*1,330*	*1,228*	*1,285*	*1,383*	*1,456*
DoD-wide	*Basic Research*	*Constant*	*292*	*243*	*451*	*399*	*492*	*378*	*358*	*355*	*349*	*331*	*347*	*366*	*498*
DoD-wide	*Applied Research*	*Constant*	*1,221*	*1,045*	*1,207*	*1,373*	*1,477*	*1,216*	*1,298*	*1,304*	*1,192*	*1,294*	*1,355*	*1,451*	*1,534*
DoD-wide	*Advanced Technology Development*	*Constant*	*1,747*	*1,380*	*1,982*	*1,933*	*2,483*	*2,758*	*2,242*	*2,173*	*2,175*	*2,204*	*1,881*	*1,785*	*1,785*
Total			*3,260*	*2,668*	*3,640*	*3,705*	*4,452*	*4,352*	*3,899*	*3,831*	*3,716*	*3,829*	*3,582*	*3,601*	*3,816*
Grand Total			*8,776*	*7,687*	*8,689*	*8,288*	*9,902*	*8,691*	*8,641*	*8,056*	*7,885*	*8,016*	*7,863*	*8,477*	*8,973*

NOTE: Rounded amounts may not add to the correct totals shown.

SOURCE: Personal communication, Stanley Trice, staff member, ODUSD (S&T), February 23, 2001.

TABLE 2-3 DoD Funding by Major Budget Category, FY89 to FY01 (current and FY01 constant dollars, millions)

Budget Category	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01
Current Dollars, Millions													
Research, Development, Test, and Evaluation	37,306	35,793	34,714	37,879	37,677	34,508	34,422	35,115	36,481	37,184	38,104	38,582	37,862
Procurement	79,412	79,709	71,416	61,919	53,621	43,761	43,084	43,432	43,149	44,884	50,770	54,998	60,270
Military Construction	5,680	5,158	5,496	4,988	3,905	6,477	5,874	7,358	6,003	5,469	5,148	4,993	4,568
Operations and Maintenance	86,623	88,431	109,764	92,145	90,767	89,091	93,989	93,233	91,834	95,856	102,661	106,564	109,044
Military Personnel	78,448	78,864	83,974	81,055	75,983	71,293	71,473	69,699	70,187	69,686	70,731	73,690	75,802
Family Housing	3,350	3,165	3,385	3,705	3,822	3,566	3,728	4,312	4,122	3,931	3,553	3,583	3,480
Revolving and Management Funds	772	237	1,871	3,504	3,881	2,643	1,645	1,903	2,411	2,114	1,764	1,800	1,304
DoD Total	291,540	291,356	310,620	285,195	269,655	251,339	254,215	255,052	254,186	259,123	272,729	284,210	292,332
FY01 Constant Dollars, Millions													
Research, Development, Test, and Evaluation	47,715	44,056	41,229	43,774	42,790	38,414	37,576	37,615	38,508	38,831	39,372	39,254	37,862
Procurement	98,667	95,721	83,331	70,631	59,973	48,066	46,552	46,250	45,432	46,825	52,317	55,877	60,270
Military Construction	7,156	6,270	6,486	5,754	4,429	7,171	6,401	7,880	6,364	5,740	5,329	5,082	4,568
Operations and Maintenance	119,994	118,453	135,530	113,859	109,173	104,396	108,069	104,836	101,137	102,962	108,326	110,450	109,044
Military Personnel	112,997	111,868	113,502	106,701	95,810	87,724	85,841	81,859	80,096	77,076	75,931	76,068	75,802
Family Housing	4,263	3,889	3,985	4,263	4,304	3,931	4,041	4,590	4,329	4,089	3,659	3,648	3,480
Revolving and Management Funds	929	292	2,216	4,128	4,448	3,034	1,894	2,128	2,615	2,266	1,811	1,828	1,304
DoD Total	391,722	380,548	386,280	349,111	320,927	292,736	290,374	285,150	278,481	277,790	286,744	292,206	292,332

NOTE: Rounded amounts may not add to the correct totals shown.

SOURCE: DoD, 2000.

TABLE 2-4 Air Force Funding by Major Budget Category, FY89 to FY01 (current and FY01 constant dollars, millions)

Budget Category	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01
Current Dollars, Millions													
Research, Development, Test, and Evaluation	14,551	13,553	11,890	13,051	12,789	12,178	11,605	12,518	14,090	14,278	13,732	14,580	13,686
Procurement	30,611	30,104	24,514	23,539	21,505	17,501	15,829	16,619	14,388	15,328	18,209	18,612	20,939
Military Construction	1,408	1,334	1,142	1,217	1,036	1,587	1,081	1,282	1,576	1,570	1,399	1,471	968
Operations and Maintenance	25,157	25,493	29,020	22,829	22,870	24,542	24,537	23,405	22,795	25,131	27,068	26,025	28,056
Military Personnel	21,854	21,773	22,717	21,306	20,201	18,133	19,593	19,276	19,171	19,099	19,366	20,235	20,892
Family Housing	946	876	962	1,106	1,164	985	1,123	1,130	1,119	1,103	1,058	1,162	1,050
Revolving and Management Funds	187	111	945	0	0	12	5	0	31	33	31	28	0
Air Force Total	94,713	93,244	91,189	83,048	79,566	74,938	73,773	74,230	73,170	76,543	80,862	82,113	85,590
FY01 Constant Dollars, Millions													
Research, Development, Test, and Evaluation	18,593	16,664	14,085	15,603	14,441	13,503	12,626	13,361	14,809	14,869	14,146	14,819	13,686
Procurement	38,240	36,290	28,674	26,875	24,054	19,219	17,076	17,651	15,103	15,948	18,742	18,901	20,939
Military Construction	1,751	1,600	1,331	1,387	1,158	1,740	1,165	1,361	1,658	1,636	1,441	1,494	968
Operations and Maintenance	34,751	34,331	34,940	28,478	27,617	29,048	28,749	26,800	25,431	27,104	28,704	27,357	28,056
Military Personnel	31,587	30,954	30,809	28,081	25,473	22,331	23,554	22,655	21,915	21,146	20,805	20,890	20,892
Family Housing	1,202	1,073	1,127	1,270	1,308	1,084	1,215	1,202	1,175	1,146	1,089	1,184	1,050
Revolving and Management Funds	240	137	1,119	0	0	13	6	0	32	35	32	29	0
Air Force Total	126,365	121,049	112,085	101,154	94,051	86,939	84,390	83,030	80,123	81,884	84,959	84,674	85,590

NOTE: Rounded amounts may not add to the correct totals shown.

SOURCE: DoD, 2000.

TABLE 2-5 Percentage Changes in Funding for DoD Budget Categories (FY01 constant dollars)

	Since FY89	Deepest Annual Cut	FY97 to FY01
Total Budget	–25	–10	+5
Procurement	–39	–20	+33
O&M	–9	–16	+8
Military Personnel	–33	–10	–5
RDT&E	–21	–10	–2
S&T	+2	–12	+14
Basic Research	+8	–12	+21
Applied Research	+13	–16	+24
Advanced Technology Development	–8	–17	+4

TABLE 2-6 Percentage Changes in Funding for Air Force Budget Categories (FY01 constant dollars)

	Since FY89	Deepest Annual Cut	FY97 to FY01
Total Budget	–32	–10	+7
Procurement	–45	–21	+39
O&M	–19	–18	+10
Military Personnel	–34	–12	–5
RDT&E	–26	–15	–8
S&T	–46	–23	+9
Basic Research	–15	–17	+11
Applied Research	–13	–14	–1
Advanced Technology Development	–66	–34	+25

(DARPA), the Ballistic Missile Defense Organization, and other defense research agencies, grew 17 percent (in real terms) following the end of the Cold War.

Table 2.2 shows that defense S&T funding fluctuated over the past 12 years. Overall, however, defense S&T funding was higher by FY01, including total DoD, Army, Navy, and DoD-wide S&T funding. The sole exception was Air Force S&T funding, which by FY01 was 46 percent lower.

VALUE OF DEFENSE S&T INVESTMENTS—COUNTERING A RANGE OF THREATS

To address the question of the level of investment necessary to maintain an adequate technology base in the areas of air, space, and supporting information systems, the committee examined how the value, or utility, of the defense S&T investment has changed since the end of the Cold War. The most striking characteristic of defense S&T resources, which represent only 2 to 3 percent of total expenditures for national security, is their astonishing impact on the shape of DoD. Since World War II, for example, investments in S&T have led to the introduction of intercontinental ballistic missiles, stealthy aircraft, and reconnaissance satellites. One could legitimately ask whether the war against Japan would have ended by August 1945, the Cold War in 1989, or the Gulf War only 100 hours after the allied ground campaign started if key S&T investments had not been made. Today, however, the national security situation has changed radically, requiring a reconsideration of both the level of national security expenditures and the proportion that should be devoted to S&T.

By their very nature, S&T resources entail management problems. Significantly useful S&T programs are almost always unique. The nature of the personnel and other resources involved make it particularly difficult to establish schedules and to predict financial requirements. The military payoffs of S&T programs cannot always be specified with certainty at their initiation and, in fact, are usually difficult to quantify even in retrospect because they gain utility in "system of systems" applications. Despite these difficulties, management must estimate the magnitude and direction of the defense S&T investment to provide a basis for determining the best mix of weapon systems to meet current and future security threats. Those threats have changed since the Cold War.

The Soviet Union had military systems and capabilities competitive with those of the United States, as well as potentially superior numbers of forces. Although there were other potential adversaries around the world, the overwhelming focus of U.S. military strategy, forces, and systems was countering the single adversary that could conceivably match the United States blow for blow in a full-scale nuclear or conventional conflict.

The symmetry of capabilities, combined with potentially superior numbers of forces, drove the United States to pursue weapons and systems development programs, as fast as possible and at almost any cost, to create and maintain a technologically superior military capability. In keeping with this single-adversary orientation, defense S&T programs were oriented toward developing technologies that pushed the limits of weapon system performance, range, lethality, precision, and survivability.

TABLE 2-7 Percentage Changes in Funding for DoD S&T Categories (FY01 constant dollars)

	Since FY89	Deepest Annual Cut	FY97 to FY01
S&T			
Total	+2	–12	+14
Army	+20	–27	+29
Navy	+47	–14	+32
Air Force	–46	–23	+9
DoD-wide	+17	–18	+3
Basic Research			
Total	+8	–12	+21
Army	–5	–13	–16
Navy	–11	+14	+8
Air Force	–15	–17	+11
DoD-wide	+71	–23	+43
Applied Research			
Total	+13	–16	+24
Army	+14	–26	+45
Navy	+20	–26	+22
Air Force	–13	–14	–1
DoD-wide	+26	–18	+29
Advanced Technology Development			
Total	–8	–17	+4
Army	+38	–41	+19
Navy	+212	–7	+61
Air Force	–66	–34	+25
DoD-wide	+2	–21	–18

With the fall of the Soviet Union, however, some of the impetus for the development of advanced systems has diminished. Despite Russia's formidable conventional and nuclear forces and the improving military capabilities of other countries, the U.S. military, for the time being, is the predominant military force in the world. This does not mean, however, that the threats faced by the United States are simpler or less dangerous. In fact, the opposite is true.

Instead of a monolithic adversary whose capabilities and strategies are similar to those of the U.S. military, the United States now faces a growing number of threats. First, other nations continue to improve and increase their military capabilities in many areas such as intercontinental ballistic missiles and chemical and biological weapons of mass destruction. Although these nations could not yet prevail against the United States in a full-scale conflict, they can threaten and significantly harm the vital interests of the United States and its allies. In addition, international terrorism is increasing, and the U.S. military and U.S. allies are favored targets.

The asymmetry between these threats and U.S. military capabilities compounds the problem. The worldwide availability of advanced technologies has enabled relatively small forces or groups to wield great destructive power for striking at nonmilitary populations as well as military forces. As the U.S. military and the world are learning, a large, technologically superior military designed to fight a similar enemy is not necessarily well prepared to deal with these asymmetrical threats. The attack on the *USS Cole* illustrates how an asymmetric threat can seriously damage an opponent that was once considered overwhelming and invulnerable. Civilian societies are also vulnerable. For example, attacks on the electrical power, financial, or transportation systems through their supporting information systems could cause great damage. Concerns about whether the United States is prepared to defend itself against such attacks are now widespread.

No one knows which of these potential threats will become real, which terrorist group will be the first to possess a weapon of mass destruction, when and where it will strike, and what constraints will be imposed on a defense against them. The growing number of threats, their asymmetric nature, and their uncertainty have increased the complexity and difficulty of defending against them—and, as a consequence, the potential utility of S&T in helping to meet these challenges.

IMPETUS FOR ONGOING INVESTMENT IN DEFENSE S&T

Given the demonstrated value of DoD S&T programs over more than the past half-century and the need for strong capabilities to meet a changing global threat, the committee concluded that the post-Cold War trend toward reductions in S&T spending should be reexamined in light of the need to deal with the threats that have arisen since the Cold War. First, if current defense systems cannot defend against the new threats, new systems must be developed, which will require reoriented and increased investment in defense S&T. Because the nature and scope of these threats are uncertain, the S&T investment should be broad and flexible.

Second, increased S&T investments are needed to support aging military systems, many of which are decades old but are expected to last many more years until new systems can replace them. All of the services, including the Air Force, have already discovered that S&T programs will be necessary to extend the lifetimes of these systems.

Third, rapid deployment and reduced dependence on overseas bases in force projection will require capabilities beyond those provided by current operational technologies. The Air Force's Expeditionary Aerospace Force concept is a case in point. The S&T requirements to support new operational concepts are just beginning to be understood.

Fourth, although the impetus for the development of some advanced systems has diminished, continued investment in S&T supporting advanced systems is still necessary. Russia and other developed nations possess technologically competitive systems and, just as important, the capability to improve them. Other countries could buy these systems, thus increasing both their military capabilities and their own technology bases. The United States still relies on technological superiority to reduce casualties and provide a military advantage in the event of conflict. Therefore, maintaining the defense S&T base to ensure these advantages is prudent and necessary.

DoD and Air Force S&T programs are as important as ever, perhaps more important. In light of the current threats faced by the United States, the prospective utility of the U.S. investment in defense S&T has actually increased.

NONDEFENSE PAYOFFS

Although nondefense applications are not a primary criterion in the allocation of DoD resources, these payoffs have been, and can continue to be, extensive. Among the many recent nondefense economic and social benefits that have accrued as a result of military technologies being transferred to the nondefense public and private sectors are the Global Positioning System, the ARPANET (the forerunner of today's Internet), communication satellites, fiber optics, laser technology for medical and manufacturing uses, and composite materials for sports equipment and automotive vehicles, to name only a few. Defense S&T programs have contributed directly to a stronger economy, safer automobiles and aircraft, and more cost-efficient logistics. Such nondefense payoffs are directly related to the investment in defense S&T.

Unique aspects of the public welfare such as national security require that the government make high-risk, sometimes long-term, investments that industry cannot or will not make. Most defense S&T programs are high-risk capital investments with a high potential for failure. Even large firms accustomed to taking risks can find it difficult to justify such programs on a commercial profit-and-loss basis.

Accounting in advance for the incremental economic benefits to be gained from defense S&T spending is problematic. The modeling of projected economic and social benefits is extremely complex and difficult to do. However, Congress should remain aware of the nondefense benefits that frequently accrue from defense S&T programs.

LEVEL OF AIR FORCE REPRESENTATION AND ADVOCACY FOR S&T

Currently, the highest S&T-dedicated military position in the Air Force is the 2-star AFRL commander position at Wright-Patterson AFB near Dayton, Ohio. The AFRL commander reports directly to a general (4-star), the commander of the Air Force Materiel Command (AFMC), of which AFRL is a part. AFMC headquarters is also located at Wright-Patterson. The AFRL commander is also dual-hatted as the Air Force technology executive officer and as such also reports to the Assistant Secretary of the Air Force for Acquisition, whose office is in the Pentagon.

The strength of S&T representation in the Air Force is weakened by the relatively small size of the S&T program compared with the Air Force's total program and compared with the broad scope of responsibilities held by the assistant secretary for acquisition and the AFMC commander. In FY01, the Air Force total obligational authority (TOA) was approximately $85.6 billion. The TOA for RDT&E was approximately $13.7 billion, or about 16 percent. Of this amount, S&T TOA was approximately $1.2 billion, about 9 percent of RDT&E, or slightly more than 1 percent of Air Force TOA for FY01. The relatively small size of the S&T investment affects perceptions of its value and the amount of attention paid to it. The assistant secretary is a member of the Air Force Council, which is the Air Force corporate policy and decision-making body just beneath the Secretary and Chief of Staff of the Air Force, and is responsible for representing this S&T investment as the council makes its investment decisions.

However, he is also responsible for representing all Air Force acquisition programs, which comprise the "D" part of the RDT&E investment and are much larger combined than the S&T program.

The AFMC commander also has broad responsibilities. The commander is responsible for about 120,000 people, including approximately 5,700 people in AFRL, and the programs at four product centers, five air-logistics centers, three test centers, and two major specialized centers. In addition, until very recently, AFMC was not responsible for formulating the Air Force S&T program and budget or for including and representing them during the annual budget cycle. Instead, the S&T budget was formulated and represented by the assistant secretary's office.

The broad scope of responsibilities of the AFMC commander and the Assistant Secretary of the Air Force for Acquisition, combined with the relatively small size of the S&T program, can prevent them from effectively advocating for Air Force S&T at the corporate policy and decision-making level of the Air Force. The AFRL commander is focused and dedicated to S&T; however, his position is several levels below the Air Force Council and he is located in Ohio instead of the Pentagon. His ability to effectively represent and advocate S&T during corporate decision-making is, therefore, limited.

The Air Force itself has recognized this problem and recently acted to increase the level of S&T advocacy within the Air Force. It announced plans to make the AFMC commander the advocate for S&T in the Air Force. In addition, starting in the FY03 budget, AFMC plans to include Air Force S&T in its budget formulation. These changes reflect efforts to increase the level at which S&T is advocated in the Air Force. However, the breadth of the AFMC commander's responsibilities will not be diminished, and S&T will continue to represent a relatively small part of his overall responsibilities. Moreover, moving the responsibility for S&T budget formulation and advocacy from the assistant secretary's office in the Pentagon to AFMC at Wright-Patterson also will distance the S&T voice from the locus of Air Force policy and decision making. Including the Air Force S&T budget in the AFMC budget also increases the possibility that S&T funding will be tapped to help pay AFMC's bills, in addition to bills from Air Force headquarters. This would compound the effects of reductions that have already been made in S&T funding.

CONCLUSIONS

Decline in Air Force S&T

Conclusion 2-1. Although the DoD investment in S&T has fluctuated since the end of the Cold War, it was higher by FY01, except for Air Force S&T, which accounted for the bulk of DoD S&T support for air and space systems. Air Force investment in S&T declined disproportionately during the period, exceeding the rate of the overall DoD budget decline and the rate of the overall Air Force budget decline.

Impact of S&T

Conclusion 2-2. Despite the relatively small share of total defense resources allocated for S&T, that investment has had major impacts on defense. The United States relies on its defense S&T base for the technological superiority that provides a military advantage and reduces casualties in the event of conflict.

New Threats

Conclusion 2-3. Since the end of the Cold War, threats facing the United States have changed considerably. New threats are diverse, asymmetric, and fraught with uncertainty. Cold War-era forces were not designed to meet these threats, and countering them will require broad capabilities that can best be provided by a broad program of defense S&T.

Nondefense Spin-offs

Conclusion 2-4. Defense S&T often has important nondefense benefits, especially in high-risk areas where industry cannot prudently invest on its own.

S&T Representation and Advocacy

Conclusion 2-5. The committee strongly believes that the Air Force needs authoritative, S&T-focused and -dedicated representation and advocacy at the corporate policy and decision-making level of the Air Force to help make informed trade-offs and budget decisions. Without corporate-level understanding and consideration of the effects its S&T investment can have on the Air Force's future, the committee believes that the Air Force S&T investment faces undue risk that it will not provide the technologies and systems needed to meet future threats. The committee is encouraged by the actions that the Air Force has recently taken to increase the level of S&T advocacy in the Air Force and believes these actions can result in a stronger S&T program. Additional actions could make Air Force S&T even stronger.

RECOMMENDATIONS

Restore S&T Dollars

Recommendation 2-1. The Secretary of Defense and the Secretary of the Air Force should continue to increase the Air Force investment in science and technology (S&T) to reach one-and-a-half to two times its current (FY01) level. Investments in S&T for air, space, and information systems should all be increased. Increasing one by decreasing the others will not satisfy current S&T program shortcomings and may create new ones.

Redirect S&T for Evolving Threats

Recommendation 2-2. The U.S. Department of Defense (DoD) and the Air Force should continue to reorient their science and technology (S&T) programs toward discovery and development of technologies to meet evolving threats, enable evolving operational concepts, and support the aging military systems that are expected to last over many more years. In addition, DoD and the Air Force should ensure that their S&T programs remain broad and flexible to deal with the uncertainties of current threats. At the same time, DoD and the Air Force need to maintain an adequate S&T base to ensure the technological superiority of U.S. forces over potential adversaries with advanced systems.

Promote Technology Transfer to Nondefense Sectors

Recommendation 2-3. The U.S. Department of Defense and the Air Force should remain aware of the nondefense benefits that could accrue from defense investments in science and technology and should actively promote the transfer of research results and technologies to the nondefense public and private sectors.

Strengthen S&T Advocacy Within the Air Force

Recommendation 2-4. In addition to the actions they have already taken, the Secretary of the Air Force and the Chief of Staff of the Air Force should continue to look for ways and take actions to further strengthen S&T representation and advocacy at the corporate policy and decision-making level of the Air Force. There are a number of options they can consider, including (1) formally designating the Air Force science and technology (S&T) program as a corporate program, (2) having the current AFRL commander/TEO position report directly to the Chief of Staff or be a member of the Air Force Council, and (3) establishing an Air Force Council member position (normally an assistant secretary or a 3-star deputy chief of staff), to be filled by a person in the Pentagon who is focused on, dedicated to, responsible for, and authorized to represent and advocate S&T within the Air Force, formulate Air Force S&T budgets, and participate in Air Force corporate policy and decision-making activities. The Air Force can also benefit from carefully examining the special roles accorded the Chief of Naval Research and the Office of Naval Research in the Department of the Navy to consider how these roles could be adapted to the AFRL commander/TEO and AFRL to strengthen Air Force S&T. These options or others the Air Force identifies can address remaining weaknesses in Air Force S&T representation and advocacy and build upon the recent successes of the Air Force.

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3

Air and Space Systems

AIR SYSTEMS

Scope of Air Force Air Systems S&T

The Air Force claims six core competencies: aerospace superiority, global attack, rapid global mobility, precision engagement, information superiority, and agile combat support (USAF, 2000). Although they support all six competencies, the traditional air systems technologies will also have to be modified to ensure new capabilities, including the following (Borger, 2000):

- Unmanned air vehicles (UAVs) for targeting and surveillance. These platforms, ranging from micro air vehicles to high-altitude, long-endurance vehicles, either are remotely piloted or have autonomous flight-management systems whose operation will require new algorithms for planning and decision making, onboard image processing, and software-based systems integration.
- Unmanned combat air vehicles (UCAVs) for suppression of enemy air defenses. These highly maneuverable platforms will carry weapons and will require additional research in the areas of materials, structures, and aerodynamics.
- Inexpensive guided weapons to improve pilot survivability and reduce collateral damage. Because traditional guidance systems are expensive, targeting will be separate from the weapon system. Onboard guidance systems use the Global Positioning System, backed by inertial navigation, to reduce vulnerability to jamming. Command and control between the sensor and the shooter will be an integral part of the weapon system.

The range of sizes of these vehicles, as well as their use, will require additional research in all of the classical aeronautical disciplines. The aerodynamics of microvehicles lies in a Mach number-Reynolds number regime about which scientific understanding is weak. Basic research will be needed to provide a solid foundation on which to base aerodynamic design. Similarly, the structural design of UAVs and UCAVs, as well as propulsion systems and guidance and control systems, will have to meet new standards and perhaps will require new materials. For example, long-endurance, long-range, very-high-altitude reconnaissance and surveillance aircraft will require very lightweight, large-volume structures. The cooling aerodynamics of propulsion and power-generating systems will be especially demanding, particularly if a relatively slow flight is needed to ensure the accuracy of information.

The requirements for developing UCAVs are very different from those for UAVs and conventional aircraft. Currently, however, development of the technologies needed to achieve either UAVs or UCAVs presents serious challenges to the S&T community because of the lack of an adequate base of fundamental scientific knowledge (Neighbor, 1999). Therefore, 6.1 and 6.2 programs will be necessary to develop the requisite knowledge base.

The budget for air systems S&T also includes funding for technologies in the gray area between air and space systems, such as hypervelocity weapons. Hypervelocity weapons would provide a time-critical strike capability and would be effective against deeply buried targets. Hypersonic propulsion and guidance and control techniques are key technologies for hypervelocity weapons (NRC, 1999). Bringing hypervelocity weapons into the DoD inventory will require advances in propulsion systems. With the exception of rocket-based propulsion, none of the extant propulsion systems has demonstrated a capability for producing net thrust in flight. The development of advanced propulsion systems is a primary prerequisite for increasing the range of hypervelocity weapons and increasing fuel efficiency (and thus reducing the size of the weapon).

Level of Funding

The total DoD investment in air systems S&T includes 6.1, 6.2, and 6.3 programs and funding from the three services and DARPA. The committee received DoD air systems S&T funding data from several sources; however, there remained some difficulty in determining with precision the level of the DoD investment in air systems S&T. The underlying cause of the difficulty was that different organizations "slice the pie" differently, resulting in differences in their answers to the same question.

OSD divides the DoD S&T programs into 10 technology areas plus basic research. Under the DoD S&T community's "Project Reliance," there exists a defense technology area planning panel for each technology area (plus a basic research panel for basic research) for cross-service, cross-agency S&T program coordination and planning. Unfortunately, the OSD taxonomy does not aggregate into a single category all DoD S&T that supports air systems. The air platforms technology area panel chair represented the DoD air systems S&T program to the committee. He pointed out, however, that other DoD technology areas also support air systems (e.g., materials and processes, human systems, and sensors). Nevertheless, he attempted to represent the air systems portions of those areas as well; however, he cautioned the committee that there was a large degree of uncertainty in the numbers that he presented.

Despite this uncertainty, the DoD air platforms technology area panel chair was able to state that the Air Force is "the primary DoD corporate sponsor for aeronautics-related S&T" (Borger, 2000). The other services and DARPA also invest in air systems S&T; however, the Air Force investment accounts for the major share of the total DoD investment. For example, the planned Air Force investment in air platforms S&T in FY01 was almost 60 percent of the total planned DoD investment in that year (DTIC, 2000).

The Air Force divides its S&T programs into technology areas, many of which are similar to the OSD technology areas, as well as into three additional categories: S&T that primarily supports air systems, S&T that primarily supports space systems, and S&T that supports both air and space systems. The committee found it difficult to reconcile the OSD data with the Air Force data. Others have also been frustrated by the absence of consistent data (e.g., Gessel, 2000; AFA, 2000).

Despite this difficulty, the committee was able to make several observations:

- The Air Force is the main contributor to DoD air systems S&T. However, as a result of the continual reductions made to Air Force investment since the Cold War, the Air Force now has the lowest total S&T budget of the three services (Borger, 2000; Etter, 2000).
- The air systems S&T investment has declined along with the total Air Force S&T investment. The Air Force FY00 air systems budget of about $494 million was only 48 percent of the budget for FY90.
- To increase its emphasis on space, the Air Force shifted funds from air systems S&T to space systems S&T. For example, in FY00 the Air Force shifted approximately $180 million from air to space systems S&T.
- OSD actions have reduced flexibility in the Air Force air systems S&T investment. In FY00, OSD instructed the Air Force to support S&T on air-systems propulsion technology but did not provide a corresponding increase in the S&T budget. The mandated investment was $180 million in FY00, increasing to $250 million in FY05 (Etter, 2000). Although propulsion S&T is certainly needed, this large mandated investment, without an accompanying increase in funding, severely constrains the Air Force's pursuit of other S&T on air systems.
- DARPA funding for air systems is oriented toward relatively large, advanced technology demonstrations. DARPA's annual investment in air systems S&T fluctuates significantly with the initiation and completion of these programs (Figure 3-1 shows year-to-year percentage changes as large as 400 percent).

SPACE SYSTEMS

Emphasis on Strategic Value of Space

DoD space policy highlights the increased strategic significance of space as a vital defense arena (DoD,

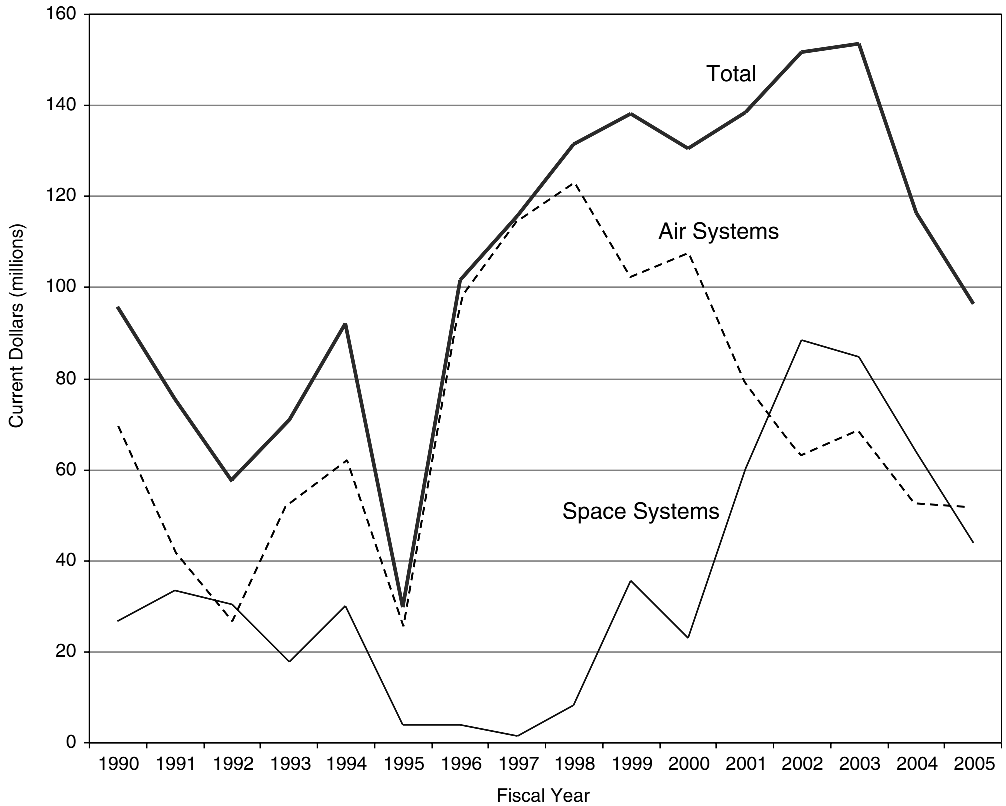

FIGURE 3-1 DARPA air and space systems S&T funding. SOURCE: Adler, 2000.

1999). The policy states that any interference with U.S. space systems will be considered an attack upon the United States; it defines a mission for an operational U.S. space force to patrol and protect U.S. space assets; and it expresses a need for both expanded research in space technologies and more test flights for military spacecraft, launch vehicles, and experimental craft for defense-related purposes.

This policy is reflected in DoD and Air Force plans. In its long-range plan, the U.S. Space Command has defined a vision and doctrine for 2020 of dominating the space dimension of military operations to protect U.S. interests and investments and integrating space forces into warfighting capabilities across the full spectrum of conflict (Byrne, 2000). The Air Force Space Command (a component command of the U.S. Space Command) strategic plan and vision include the following missions: space superiority, space support, space control, space force enhancement, and space force application. The Air Force Research Laboratory's *Air Force Science and Technology Plan, Fiscal Year 2000* clearly describes the need for a greater emphasis on space (USAF, 1999). This plan documents the Air Force's S&T investment strategy from FY00 to FY05 to ensure that present and future warfighters have the best technologies to achieve that vision.

These plans will not be fulfilled, however, if funding is not made available. Since 1993, the Air Force has been the principal player in DoD space S&T. The Air Force investment in space systems S&T makes up two-thirds of the total DoD investment. However, even with the Air Force investment, DoD's investment in space S&T is only one-thirtieth of the overall DoD S&T program (see Figure 3-2), hardly enough to pursue an aggressive space technology initiative. Although DoD has increased its emphasis on the strategic value of space, it has not provided any new resources. DoD strategy appears to rest heavily on Air Force reprioritization of Air Force S&T investments. It appears to this committee, however, that without additional funds, the Air Force will not be able to implement the new policy.

The Air Force wants to double the percentage of its total S&T investment that is oriented toward space and

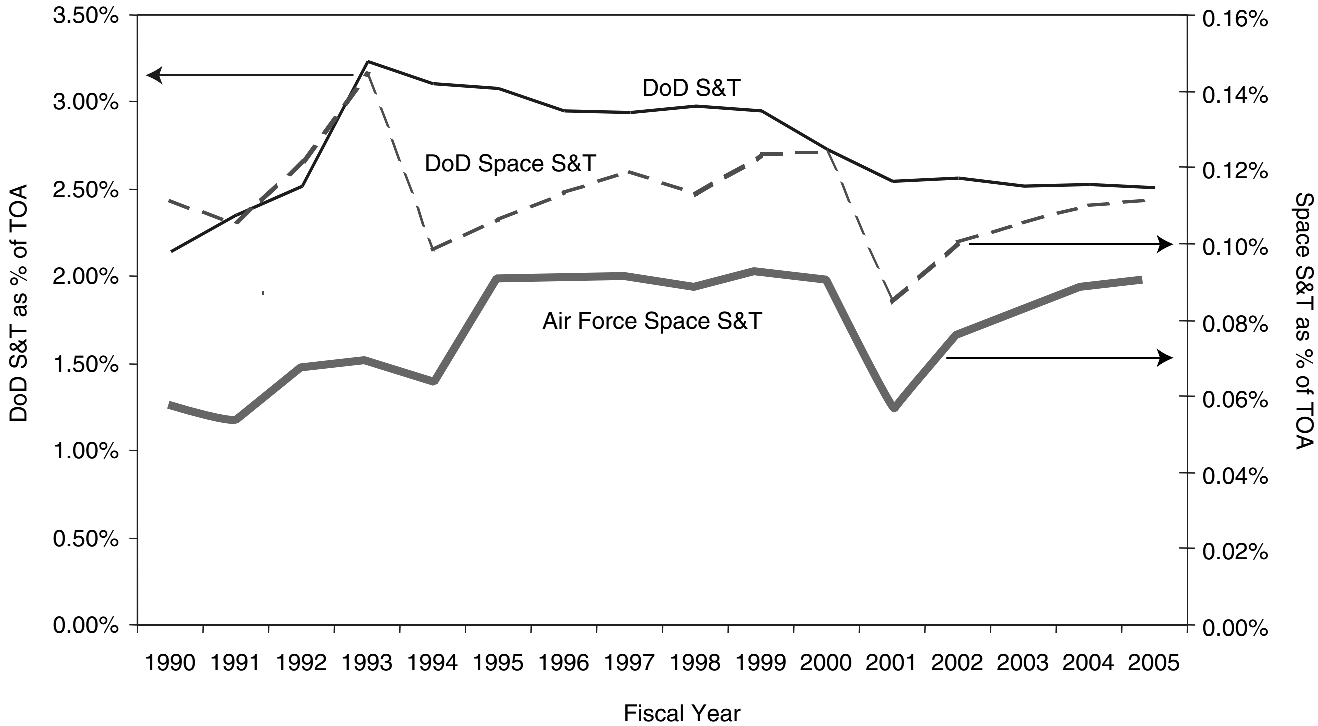

FIGURE 3-2 DoD total S&T funding and space S&T funding as a percentage of DoD total obligational authority (TOA).
SOURCE: Byrne, 2000.

proposes increasing space S&T from 13 percent of its total S&T program in FY99 to more than 27 percent by FY05 (Neighbor, 1999). The Air Force space S&T investment strategy has three primary pillars: funds transfers, focused demonstration programs, and enabling technologies.

Transfer of Funds

The Air Force plans to increase its investment in space S&T by transferring funds from air systems S&T. In FY00, the Air Force shifted approximately $180 million from air to space systems S&T. In addition to this deliberate transfer of funds, the proportion of funding allocated to the space part of the Air Force S&T program was increased in the late 1990s when the Air Force decided to use S&T funds (rather than the demonstration/validation funds used previously) to support two large space-related demonstration/validation programs, the space-based laser, and the Discoverer II space-based radar. At that time the Air Force did not simultaneously increase its total S&T budget; therefore, these two large programs used funds that had been intended for other air and space S&T projects. Because the two programs had not previously been considered to be S&T programs, it can be argued that funding the space-based laser and Discoverer II programs with S&T funds constitutes an apparent, rather than a real, increase in Air Force space S&T funding. Even after the decision was made to fund the programs using S&T funds, they were not moved into the Air Force S&T program, which is managed by AFRL. Instead, they remained in the Air Force acquisition program chain of command. If these two programs are not thought of as representing part of the Air Force space S&T investment, the planned investment in space S&T for FY05 will be about the same, in real terms, as it was for FY99 (AFA, 2000).

QUALITY IN AIR AND SPACE SYSTEMS S&T

Quality of Research

The quality of research in air and space systems is directly related to the quality of researchers and the quality of their leadership. Several recent reports have indicated that the current S&T workforce, both civilian and military, has undergone severe attrition. In addition, recruiting high-level, quality people is very difficult (AFA, 2000; DSB, 1998; Tangney, 2000). Although the defense industry as a whole suffers from similar difficulties, the effect on the services is more severe. A contributor to the problem is the Civil Service compensation structure, which is discussed in Chapter 5 (DSB, 1998; Tangney, 2000).

In a recent report, the Air Force Association (AFA) raised questions about the commitment of the Air Force leadership to technical excellence (AFA, 2000). Specifically, the AFA suggested that the creation of the Air Force Materiel Command in 1992 weakened advocacy for S&T at the highest levels, which had the direct effect of forcing S&T investments toward near-term solutions. In addition, elimination of opportunities for promotion has undermined the motivation of technically capable junior officers to remain in the service. High-level leadership will be critical, not only to advocate for S&T funding at the level at which policy decisions are made, but also to encourage junior officers to pursue advanced technical degrees and to continue to serve the nation as members of the Air Force.

Relationship to Industry and Academia

Successful DoD programs like the integrated, high-performance turbine-engine technology program depend on industry's willingness to share knowledge and/or cost (Etter, 2000). However, the services cannot count on industry cooperation in areas that are unique to DoD and in which the future return on investments is thus unclear (AFA, 2000). In those areas, cooperation can be solicited more easily from academia and independent laboratories anxious to ensure the relevancy of their research and to generate fresh ideas.

Peer Review

A world-class research, development, and engineering organization is one that is recognized internationally by peers and competitors as one of the best in the field in several key attributes. Ad hoc peer review teams composed of independent, external peers assess the alignment of the strategic vision of the S&T program vis-à-vis the world-class organization's mission, as well as the quality of the technical work. Periodic peer reviews such as these should be an integral part of the practice of evaluating the Air Force S&T investment, and the findings and recommendations of these reviews should be published.

CONCLUSIONS

Conclusion 3-1. Although DoD air systems S&T programs are funded by all three services and DARPA, the Air Force contribution is by far the largest. This emphasis is logical because air systems technologies are necessary to support all six Air Force core competencies. Funding for air systems S&T is essential not only to provide traditional airframes but also to enable the development of new capabilities, including uninhabited vehicles and guided weapons. Nevertheless, Air Force funding for air systems S&T is at an all-time low and is being diverted to support space systems S&T.

Conclusion 3-2. Attrition in the civilian technical core is increasing, and motivation for junior officers to pursue advanced technical training is eroding.

Conclusion 3-3. Since the formation of the Air Force Materiel Command, the strength of Air Force S&T representation and advocacy near the Pentagon where Air Force corporate policy and decisions are made has diminished.

Conclusion 3-4. DoD and the Air Force appear to be in substantial agreement about the need to increase the emphasis on space and space systems S&T. DoD is relying on the Air Force to lead in both. In the committee's view, however, it does not appear that sufficient resources are being allocated to space systems S&T to achieve DoD and Air Force visions for space as an arena of significant strategic value.

RECOMMENDATIONS

Recommendation 3-1. The Air Force should establish technical leadership at the highest level, including representation in the Air Force corporate structure, to define the most effective technical investment plan and provide strong advocacy for investments in science and technology (S&T). Strong Air Force advocacy would bring stability to the Air Force S&T program and would provide leadership to the other services in the area of air systems.

Recommendation 3-2. The Air Force should encourage junior officers to pursue advanced technical degrees by creating and publicizing career opportunities for these officers.

Recommendation 3-3. The U.S. Department of Defense should identify the science and technology resources required to achieve its vision of space for strategic defense and direct the services to protect these resources within their budgets.

Recommendation 3-4. The U.S. Department of Defense should consider allocating additional Air Force funding consistent with the high priority of space systems.

Recommendation 3-5. The Air Force should be designated as the U.S. Department of Defense's (DoD's) executive agent for space science and technology and should assume the lead role in developing a plan to modernize DoD's space capabilities.

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4

Information Systems

New technologies have dramatically enhanced our ability to both prepare for and execute military actions. By supporting advances in information technologies, sensors, and simulation, we strengthen our ability to plan and conduct military operations, quickly design and produce military systems, and train our forces in more realistic settings. These technologies are also central to greater battlefield awareness, enabling our forces to acquire large amounts of information, analyze it quickly, and communicate it to multiple users simultaneously for coordinated and precise action. As [former] Defense Secretary William J. Perry has noted, these are the technological breakthroughs that are "changing the face of war and how we prepare for war." (NSTC, 1995)

OVERVIEW

This chapter addresses DoD's efforts to develop information systems technology (IST) to support air and space operations, as well as other military operations. Information systems are becoming pervasive throughout the battlespace. Although some IST development projects are uniquely applicable to air and space operations, many overlap, perform the same functions, or rely increasingly on IST being developed for ground and sea operations. For example, advanced visualization capabilities for "seeing" the battlespace will be as important to the commander of air or space operations as to the commander of ground or sea operations. The same capability can be used across the whole IST spectrum.

The complex relationship of air, sea, and ground information systems made it difficult for the committee to identify unique air and space S&T on IST in the Army and Navy. The committee assumed that all of the Air Force's IST S&T projects would support air and space operations and that IST development at DARPA aligned with the Air Force would primarily support air and space operations.

Visions for air and space operations are becoming increasingly dependent on information systems, yet Air Force IST S&T budgets continue to decline each year. Although projected Air Force IST S&T funding through FY05 appears to be increasing, the annual trend has been to disregard the investment strategy and reduce the "then-year" funding while proposing an increase in future funding (see Figure 4-1).

A common assumption is that commercial IST developments can reduce the impact of these reductions. This belief is based on industry's huge investment in commercial information technology and the many hardware and software breakthroughs that have changed the way we do business, indeed, the way we live (Etter, 2000). However, leveraging these developments is not as easy as it appears. For example, commercial hardware is normally not rugged enough for military use, and software is not protected from determined adversaries or viruses (e.g., "Melissa" in 1999 and the "I Love You" virus in 2000). Commercial technologies can satisfy only some DoD needs, provide only near-term solutions, do not have stable investments in research and development (and have very little investment in long-range basic research), and may not be able to provide long-term support. Although DoD should leverage commercial technology where appropriate, it also needs to maintain a capability advantage over commercial technologies to counter the spread of commercial information technologies to all nations and interest groups. DARPA's S&T efforts are intended to support the joint needs of the services, but inadequate service funding and differences between DARPA's investment planning and execution processes and the services' investment planning and execution processes have made it difficult to transition DARPA successes to the services.

Service visions are not as well coordinated as they could be. For example, they do not address the issue of interoperability with, and the leveraging of, air and space IST developments by NASA, the National Reconnaissance Office, and the Ballistic Missile Defense Organization. Interoperability is a huge issue that can-

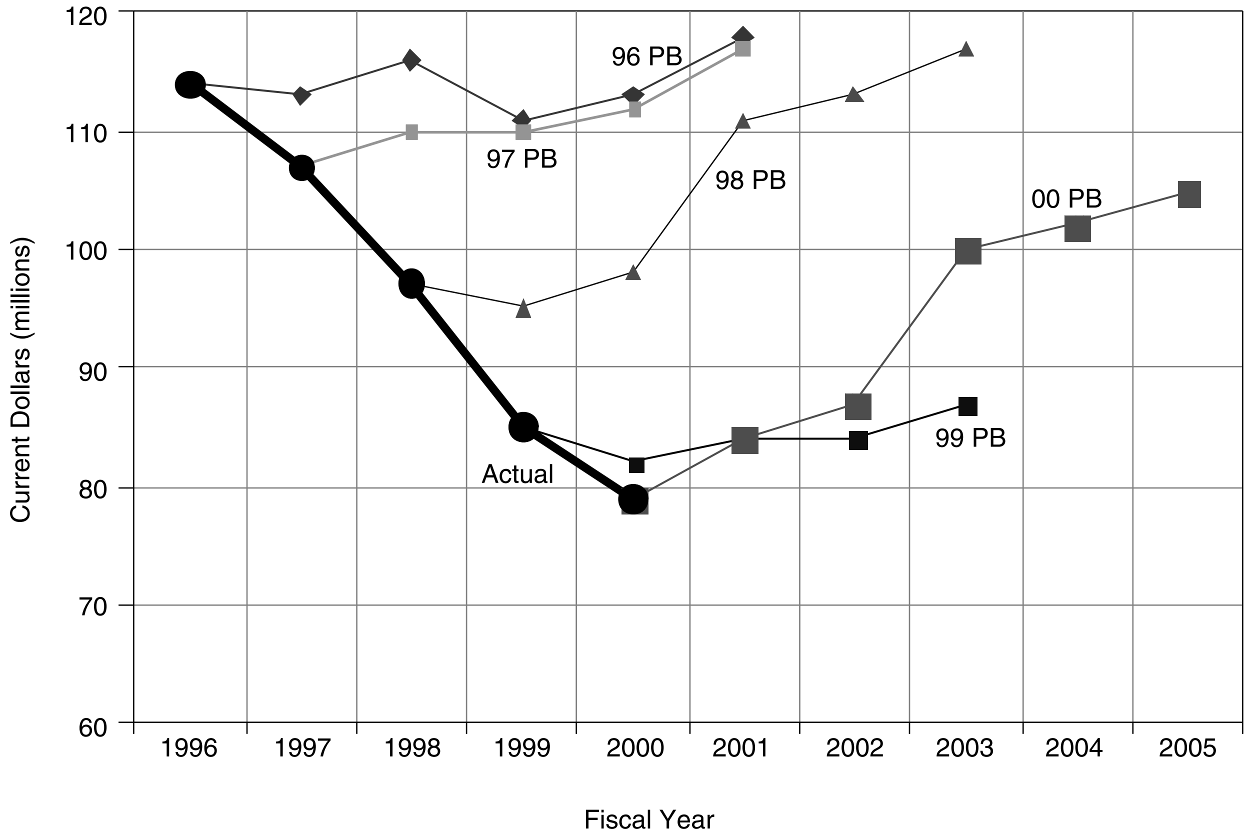

FIGURE 4-1 Decline in Air Force Research Laboratory Information Systems Directorate S&T budget, FY96 to FY00, compared with President's budget (PB) request. SOURCE: DSTAG, 2000a.

not be fully addressed with current levels of funding. Finally, each service would benefit from a high-level advocate who has an understanding of the state of the art of information systems and can formulate service S&T budgets, participate in corporate policy and decision-making activities, and work closely with other DoD and non-DoD organizations.

The DoD IST vision should be joint, should emphasize interoperability, and should include programs from NASA, the National Reconnaissance Office and BMDO. Additionally, there should be a high-level advocate in each service; increased, stable funding; a stronger basic research program; an applied research and technology development program that takes advantage of DARPA successes but does not depend solely on those efforts; and an S&T program supported with a very flexible budget to leverage the best commercial technology yet maintain a strong technological capability advantage over commercial capabilities to ensure military superiority.

DEFINITIONS

For purposes of this study, IST is defined differently from commercial information technology. IST is one of the most important enabling technologies for DoD's command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) military capability. IST is defined as technologies that support the collection of data; the processing of data (transforming data to information to knowledge); and the dissemination, protection, and presentation of data (tailoring information to meet user needs) to support battlefield information superiority, mission planning and rehearsal, training, and system acquisition. Technology areas (Box 4-1) include computing and software, seamless communications, decision making, information assurance, and modeling and simulation (DDR&E, 1996).

Information superiority is described by the Joint Chiefs of Staff as the "degree of dominance in the in-

Box 4-1
Definitions of Technology Areas

Computing and software technologies. Computing and software technologies are the core components of the high-performance, software-intensive DoD systems needed to ensure information superiority. Among the requirements for such systems are compatible software architectures, improved software tools to enable affordable systems evolution, embedded high-performance computing, intelligent agents, and technologies for information presentation and interactive communication.

Seamless communications technologies. Seamless communications span the globe, interconnecting command echelons, services, and allies worldwide by implementing common transport protocols and dynamic network management. These technologies can transport critical warfighting information to warriors anywhere in the world, using wide-bandwidth capabilities linked to current narrow-band tactical systems in a way that maintains the accuracy of information during transmission.

Decision-making technologies. Decision-making technologies include common, modular tools that connect joint mission planning, rehearsal, execution monitoring, and common pictures of the battlespace. They provide battlefield visualization and situational assessment products that support real-time operations.

Information assurance technologies. Information assurance technologies enable information operations that protect and defend information and information systems by ensuring their availability, integrity, reliability, authenticity, and confidentiality, and their robustness against nonrepudiation. Information assurance includes providing for restoration of compromised information systems by incorporating capabilities for protection, detection, and reaction.

Modeling and simulation technologies. Modeling and simulation technologies provide a means for continuous, predictive planning; a capability for assessing and guiding the development of particular technologies; and a tool for testing interoperability between live C4I systems for mission planning, rehearsal, and training. Modeling and simulation technologies can advance the state of the art for technologies used for training, assessment, and simulation-based acquisition and have the potential to enable conceptual models of the mission space; data standardization; authoritative representations of natural environments, systems, weapons effects, and human behavior; and simulations of individual combatant and small-unit operations.

SOURCES: DDR&E, 1999b, 2000; USD (A&T), 1995.

formation domain that permits the conduct of operations without effective opposition" (DDR&E, 2000). Information superiority is a combination of command, control, communications, and computers (C4); intelligence, surveillance, and reconnaissance (ISR); and information operations (IO). Command and control (C2) is the "exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission" (DDR&E, 2000). The ISR component of information superiority should provide near-real-time awareness of the location and activity of friendly, hostile, and neutral forces throughout the battlespace.

TRENDS AND FUTURE VISIONS

Because battlespace information systems are pervasive in all of the services and DoD agencies, visions for DoD information systems in support of air and space operations should be joint visions or describe how they would support joint efforts. Therefore, the investment strategies for IST developments should be joint strategies. In a recent DoD technology area review and assessment (TARA) of IST projects, the service and agency vision statements defined both joint and individual service needs, yet the development and execution of these visions did not appear to have joint cooperation. The following discussion describes IST needs based on various air and space visions (DSTAG, 2000a, 2000b, 2000c).

Future Air Force concepts are driven by information and information systems, which are becoming the "force multiplier" for the Air Force of the future. The increased emphasis on information and associated trends are reflected in Air Force warfighting concepts. These concepts include (DSTAG, 2000a):

- dynamic aerospace command
- joint battlespace infosphere
- information operations
- integrated aerospace operations
- the Expeditionary Aerospace Force
- effects-based operations

More detailed listings, definitions, and associated IST drivers can be found in Appendix E.

The Navy's visions for information systems are similar to those of the Air Force. The evolutionary concept of network-centric warfare, the most well defined vision, depends increasingly on network nodes (users) that can communicate with each other. Most naval nodes, including aircraft, are currently not capable of participating in network-centric warfare because of inadequate communications capability. This concept, as well as the Navy initiative called Information Technology for the 21st Century, depends heavily on satellite communications that are not currently available according to the Military Satellite Communications Emerging Requirements Database, the military strategic and tactical relay (MILSTAR) satellite program operational requirements document (ORD), the "Tactical Ballistic Missile Defense ORD," and other Navy documents. The needs of naval aviators are similar to those of Air Force aviators; both depend on intelligence obtained through air and space assets. The Navy's visions for other information systems are also similar to those of the Air Force. These include decision-making tools, information assurance technologies, seamless communications, computing and software, modeling and simulation, and sensors (DSTAG, 2000c).

The Army's visions also depend increasingly on information systems. The "digitized force" is based on advancements in IST. Recent visions of lighter, air-transportable, strategic forces (the Future Combat Systems concept) promote the dependency on "information, not iron" as a means of protecting the force. The strategic use of forces will require long-range satellite communications to support dispersed command groups and provide "reach-back capability" for decision-support tools and logistics. The Army's air and space IST requirements for its aviation and intelligence components are similar to those of the Air Force and the Navy (DSTAG, 2000b).

An analysis of joint-service and individual-service visions by the DoD Project Reliance IST technology area panel derived a list of key requirements that IST S&T must address (see Box 4-2).

CURRENT AND PLANNED PROGRAM

The purpose of DoD's current information systems program for air and space operations is to provide global awareness, intelligence, targeting information, communications, weather information (both space and atmospheric), navigation support, and decision-support tools. In addition, information systems are being developed to support training, analysis, and system acquisition. Major elements and associated goals are listed below (DSTAG, 2000a):

Box 4-2
Key Requirements Driving Future Information Systems S&T

Key requirements for meeting visions for U.S. military capability in the 21st century include, but are not limited to:

- accurate, consistent, assured, global information access
- assured availability of a large-bandwidth, secure, global information grid
- protection, detection, and response to attacks against computers and networks
- distributed, interactive C2 simulation and visualization
- interoperability across coalition C2 information systems
- rapid reconfigurability to support dynamic C2 requirements
- rapid course-of-action generation and assessment
- ability to build and maintain dynamic air (and space) execution orders
- integrated management and exploitation of ISR assets
- integrated information systems to support ground, air, and space assets
- ability to find, fix, track, and engage mobile targets
- high-resolution, high-accuracy sensors with active, all-weather, foliage-penetration capability
- ability to support training, analysis, and system acquisition
- multilevel security

SOURCES: DSTAG 2000a, 2000b, 2000c; Lupo, 2000.

1. Global awareness—to provide consistent, integrated battlespace information on demand and tailored to the needs of individual warfighters.
   - information obtained through fusion of data from high-resolution, all-weather sensors
   - automated information-exploitation tools with visualization of uncertainty
   - fusion of information into a single, consistent operating picture that provides situational awareness
   - an affordable, integrated, global information base that supports real-time exploitation and fusion
2. Dynamic planning and execution—to enable commanders to shape, visualize, and control the pace and phasing of engagements by exploiting global awareness and global information-exchange capabilities.
   - capability for predictive planning, integrated force management, and mission execution
   - capability for real-time sensor-to-shooter operations
   - collaborative, distributed, real-time mission planning, training, and rehearsal (battlespace simulation)
3. Global information exchange—to ensure that information is available anywhere, anytime for a mission through adaptable, scalable, fault-tolerant information systems.
   - seamless collaborative workspaces
   - 1,000-fold increase in capability for global communications to aircraft capability
   - continuous 24-hour per day, 7-day per week, in-transit visibility
   - worldwide information on demand
   - information warfare capability to protect, detect, and react
   - reliable, survivable networking

IMPACT OF COMMERCIAL TECHNOLOGIES

Commercial investments in non-DoD-related information technology in the United States amount to about a trillion dollars per year. The DoD IST budget is significantly less, about a billion dollars per year. DoD should leverage this large commercial resource, where appropriate, by adopting, adapting, and/or reengineering new technologies and determine the shortcomings of commercial technologies that warrant investing in DoD-unique S&T.

Leveraging commercial information technologies is difficult, however, because industry rapidly changes direction to meet rapidly changing customer demands and because the time to market must be as short as possible. Fierce competition dictates limited, short research and development cycles and near-term investment strategies. Very little funding is being invested in basic research, which is usually outsourced to academia (NRC, 1999). Industry's short-term needs cannot support the longer-range visions of the services. Although commercial technologies show promise in providing significant near-term capabilities, leveraging them could require much effort (and significant resources) to adopt, adapt, or reengineer them. The services need to continue to be intelligent users that can recognize and exploit the military worth of commercial technologies.

Another caveat about using commercial information systems is that they are becoming available to all nations and interest groups. If the services depend on commercial technologies for advancing the state of the art in their information systems, potential enemies may come close to achieving parity (or even asymmetrical superiority) with U.S. forces. The services can try to maintain an advantage with better systems engineering, but that advantage may be temporary. Therefore, the services, and the rest of DoD, should protect and maintain a strong systems-engineering capability that can transform the commercial advances available to many nations into very powerful C4ISR systems.

Because of the global availability of advanced commercial technologies, DoD needs to expand its basic research to explore the frontiers of science in search of new technological approaches for maintaining military superiority. Figure 4-2 shows that, for a particular technology, the combination of commercial development that approaches DoD's capabilities and the flattening of the capability S-curve as perceived technical or physical limits are reached will significantly limit DoD's advantage. In this example, continued DoD investment would probably not increase its warfighting capability advantage. Therefore, DoD needs to either raise the "perceived" technical or physical limit or move to a totally new technology that provides a much greater warfighting capability. Either (or both) would require high-risk, large-payoff, basic research. The committee believes that DoD should continue to explore the frontiers of science and that basic research has never been more important to DoD.

Identifying gaps in commercial technology development is often difficult because most commercial

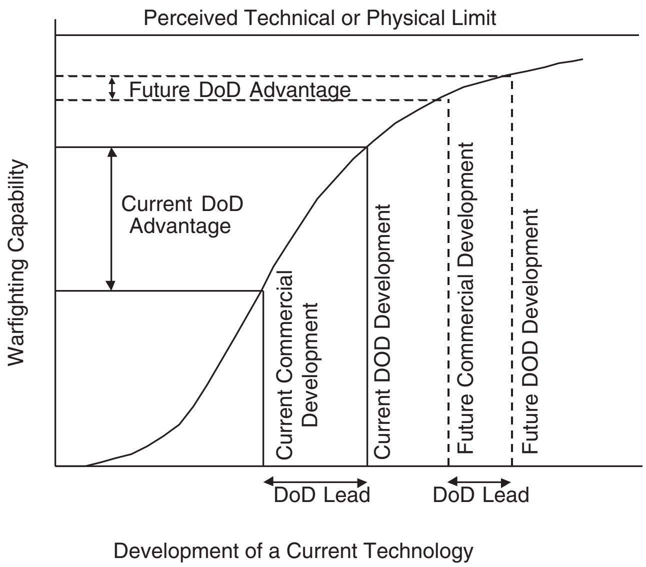

FIGURE 4-2 Notional S-curve depicting shrinking military warfighting advantage as technology matures and commercial development catches up to DoD development. SOURCE: Lupo, 2000.

work is proprietary. However, trends drawn from professional journals, trade shows, market analyses, and similar sources can provide good indicators. For discussion of commercial advances in communications, information assurance, computing and software, decision-making tools, and modeling and simulation and a description of commercial shortcomings in satisfying DoD needs, see Appendix F.

In summary, many advances in the commercial sector could be leveraged by DoD by making more rugged hardware, building top-layer applications for software, and adapting human-computer interfaces. However, many shortcomings of commercial technologies challenge the assumption that commercial information technology development can satisfy DoD needs. Many DoD-unique needs cannot be satisfied by the commercial sector.

CURRENT DOD EFFORTS

The IST that will support the air and space systems of the 2010 to 2020 time frame will depend on basic research (6.1), applied research (6.2), and advanced technology development (6.3), in that order. Most of the basic research will come to fruition in the 2010 to 2020 time frame, applied research will support information systems in the 2005 to 2015 time frame, and the results of technology development will probably be supportive of information systems in the 2000 to 2010 time frame.

Basic Research

DoD's basic research program has been very successful in supporting warfighter needs. Products have become enablers across a wide range of systems. The objective of basic research supported by DoD is to maximize the value of its investment by producing enabling technologies for realizing the operational concepts and mission goals of *Joint Vision 2010* and *Joint Vision 2020* (JCS, 1999; JCS, 2000). The technologies that result from basic research will be the cornerstones for satisfying air, space, and supporting IST needs in the 2020 time frame.

DoD's timely investments in past basic research have resulted in many value-added capabilities and systems, including the Internet, night-vision technology, precision guidance for missiles, airborne lasers, the Global Positioning System, and mine countermeasures (DDR&E, 1999a). Some DoD basic research projects are conducted in DoD laboratories and research centers or in industry laboratories, but the major portion are conducted by academia.

Each service emphasizes basic research areas that support its long-term needs. For example, the Army emphasizes information technologies (mathematics), computer science (intelligent systems, software, and architecture), electronics for digitizing the battlefield, materials science for armor and for soldier protection, optical sciences for target recognition, chemistry and biological sciences for chemical and biological agent defense, and geosciences for terrain-related knowledge relevant to battlefield mobility. The Navy has a full-spectrum program that emphasizes a wide range of ocean-science activities, including predicting weather and currents, mapping the ocean floor, using acoustics to detect objects in the ocean, and conducting biotechnological research, such as understanding and mimicking communications between mammals. Air Force research is concentrated on aerospace sciences, materials, physics, electronics, chemistry, life sciences, and mathematics for application to air vehicles, space systems, and communications, command, control, computers, and intelligence (C4I) (DDR&E, 1999a). The service laboratories also conduct and manage basic research for DARPA, the Ballistic Missile Defense Organization, and other defense research agencies.

Considering the Air Force's requirement for IST to support future air and space operations, it should be emphasizing information technologies. Yet the Defense Basic Research Plan reveals many weaknesses. For example, the Air Force has very limited efforts in the area of information electronics research to develop technologies for wireless communications, decision-making tools, advanced modeling and simulation, and image/target analysis and recognition. Similarly, Air Force research does not focus on atmospheric and space atmospheric sciences, meteorology, or remote sensing (DDR&E, 1999a). Unless the Air Force expands its basic research program in support of IST, it may not be able to satisfy the requirements of its future air and space operations.

Applied Research and Technology Development

A review of the DoD IST TARA shows that overall DoD support for IST in applied research (6.2) and technology development (6.3) is commensurate with service visions. However, realizing DoD visions will depend on funding and, in many cases, DARPA initiatives. This dependence on DARPA may be risky because DARPA's approach to S&T is different from the approach of the services. DARPA frequently uses the briefing chart shown at Figure 4-3 to highlight what it believes are the differences between its approach to S&T and the services' approaches. According to DARPA, it focuses on radical innovations, while the services support requirements-based R&D.[1]

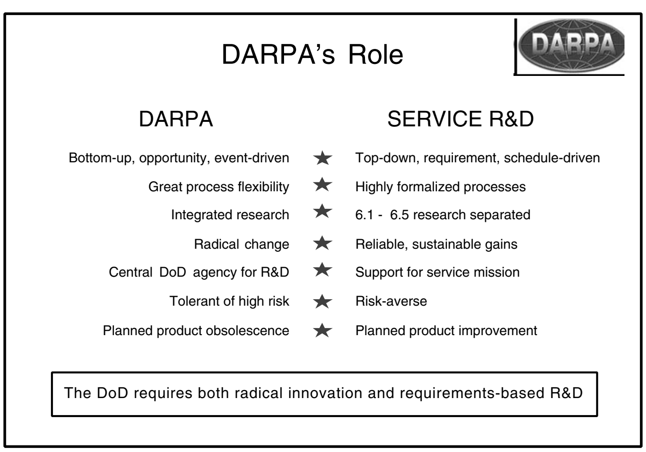

FIGURE 4-3 Defense Advanced Research Projects Agency (DARPA) briefing chart contrasting DARPA's approach to R&D with its view of the approach taken by the services. SOURCE: Fernandez, 2000.

Based on the differences between DARPA's approach and the services' approaches, DoD could develop an S&T program that provides both market pull (requirements-based innovation) and technology push (radical innovation). However, reductions in service funding, particularly Air Force funding, in IST have made the services more and more dependent on DARPA. A combined market-pull/technology-push approach would require that DARPA closely coordinate its investment strategy with the services and continue working in technology areas long after "radical innovations" had been developed to support technology development and transition to the services. However, DARPA has not traditionally supported projects past the radical innovation phase through the transition into actual systems, which are much more costly to develop.

To exploit DARPA's successes, the services need to have the proper people and resources ready to take over a DARPA technology and continue its development until it is ready for transition to a service or joint information system. This approach appears to be far more acceptable than changing DARPA's focus. However, service funding is often insufficient for the services to accept a DARPA technology, develop it, and transition it to an information system. The services do not have the flexibility to shift discretionary funding (or any other funding) to take advantage of a DARPA (or even commercial) radical innovation. Under the present system, service funding has to be programmed years in advance.

The Need for Investment Priority

The services need to deliberately place a priority on their IST S&T investments. The services uniformly recognize IST as being central to their visions; however, the details of the required IST S&T programs are complex and arcane. This can lead to IST S&T investment effectively receiving a lower priority than high-visibility, more easily understood investments in sys-

[1]It should be noted that the services do not necessarily agree with DARPA's characterization of the service R&D programs, especially the implications in the chart reproduced as Figure 4-3 that the services do not pursue opportunity-driven research, are not innovative, and/or do not tolerate high-risk/potential high-payoff research. In particular, the service basic research programs are, by definition, high risk in that they seek to discover the unknown.

tems such as faster, longer-range air and space platforms that can carry heavier payloads. Advanced systems are still needed; however, IST investments are just as necessary. In after-action reports on Kosovo, it is often mentioned that warplanes could not complete bombing missions (hit the appropriate targets) because of poor weather conditions and inadequate information (DoD, 2000; Graniero, 2000). Pilots were unable to "see" through thick clouds because of the lack of high-resolution, all-weather sensors and information systems (Lupo, 2000). Other problems were inadequate tracking or loss of targets from the time they were detected, which indicates a need for smarter, global, time-independent information systems. As the services make their investment decisions, trade-off analyses based on simulation-based experiments and technical features of the air, space, and supporting information systems can help provide insight into the value of their investment in IST.

ADEQUACY OF FUNDING

Air Force funding for IST basic research (6.1), applied research (6.2), and technology development (6.3) does not appear to be adequate to support future air and space needs. Recent trends indicate that future funding may be even less adequate. Because the Air Force is focused primarily on air and space operations, Air Force funding is used as a benchmark in this section.

Basic Research (6.1) Funding

DoD funding for basic research in information systems has increased slightly since FY97 (see Figure 4-4). As discussed in the previous section, there are weaknesses in the Air Force IST-related basic research program, and industry has very little interest in basic research. Therefore, funding in basic research may not be adequate to support air- and space-related IST needs for the 2010 to 2020 time frame. The committee believes that the Air Force basic research program is too small to match its IST visions and compensate for the limited availability of commercial research.

In addition, as Figure 4-5 shows, there is proportionally little in-house funding for basic research in AFRL's Information Directorate (AFRL/IF) budget (only $2.5 million of the total S&T budget of $555.4 million), not nearly enough to maintain in-house IST expertise. As shown in Figure 4-4, the Air Force invests a total of about $30 million per year in IST-related basic research. About $27 million of that supports outsourced research in academia and industry.

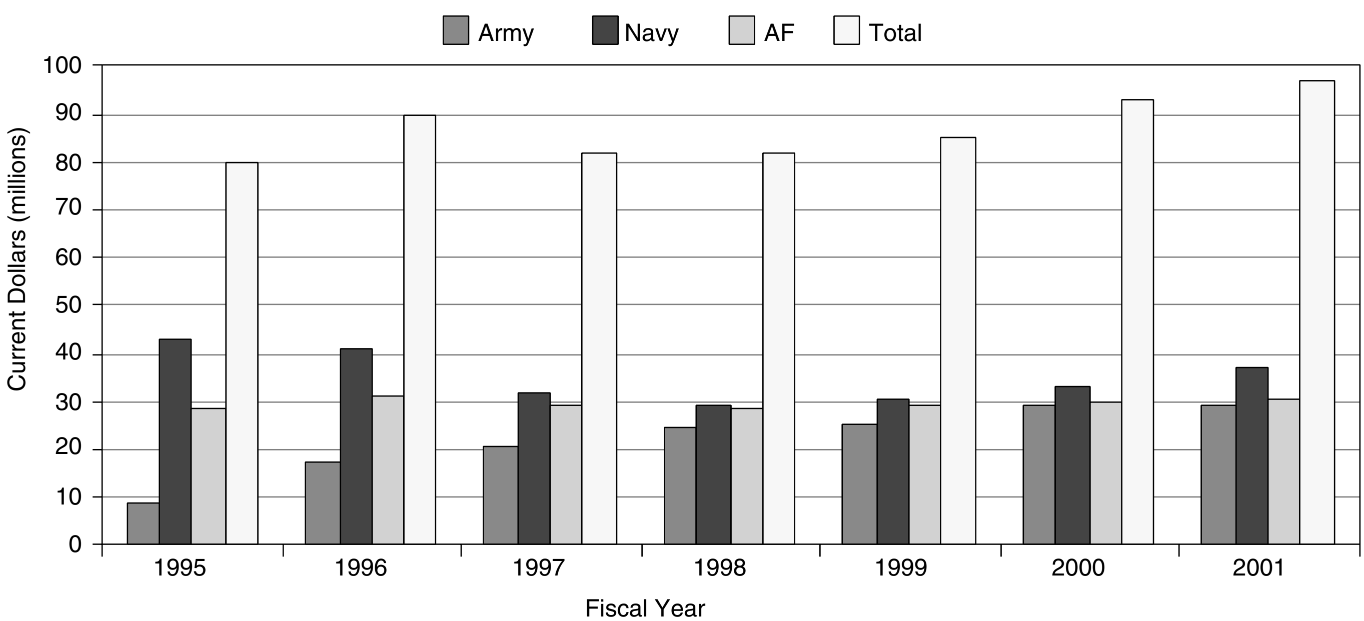

FIGURE 4-4 Service funding for information systems technology-related basic research, FY95 to FY01. SOURCE: DSTAG, 2000d.

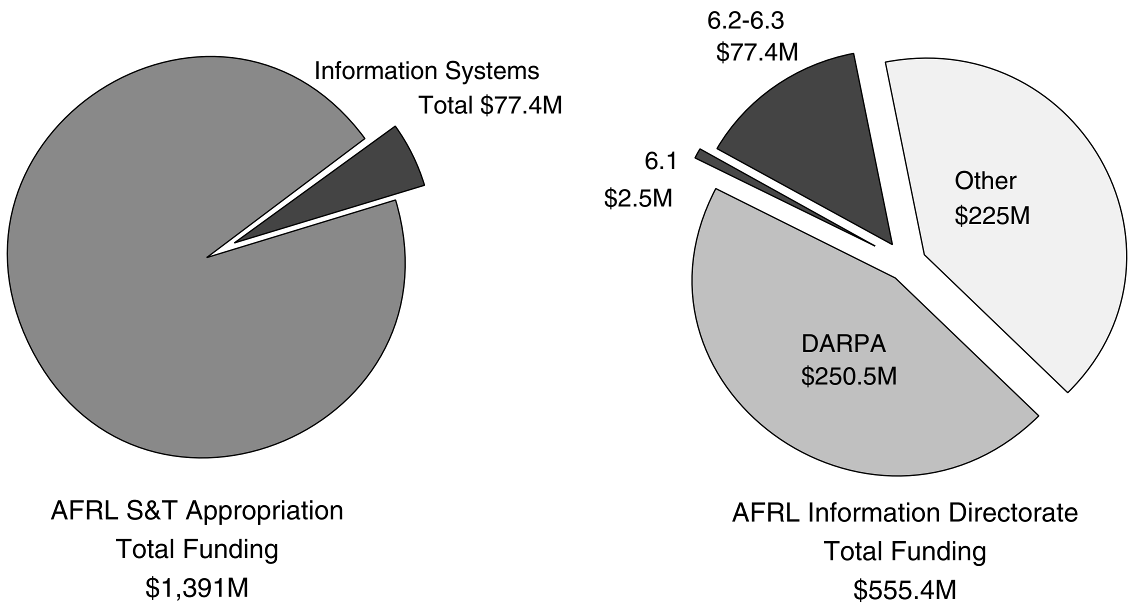

FIGURE 4-5 FY00 budget for Air Force Research Laboratory Information Systems Directorate (AFRL/IF). SOURCE: DSTAG, 2000a.

Applied Research (6.2) and Technology Development (6.3) Funding

Figure 4-5 shows that the amount of FY00 Air Force funding in IST applied research and technology development ($77.4 million) is only about 5 percent of the total amount of AFRL S&T funding ($1.391 billion), much less than the committee believes is required to meet Air Force needs. Figure 4-5 also shows that the Air Force is using DARPA and other funding to offset the shortfall. However, Air Force core funding for 6.2 and 6.3 ($77.4 million) is not enough to maintain a service capability in IST and still continue the development and transition of technologies shown to be promising by DARPA and other DoD sources (DSTAG, 2000a). Air Force 6.2 funding can barely pay the operating costs of the AFRL/IF laboratory including in-house salaries. Unless salaries can be covered by non-Air Force customer funding, thereby freeing up some IF 6.2 funding, no money will be left for external research and development (e.g., by industry and universities) (personal communication, Dr. Northrup Fowler, AFRL/IF, February 7, 2001).

As Figure 4-1 shows, IST funding has not been steady. Each year since FY96, the Air Force has established a funding program for the AFRL/IF that appeared to be stable or to increase for the next five years. And in each subsequent year, the predicted level of funding did not materialize. Even if the FY01 budget is realized, the amount will still be inadequate. Even the very optimistic funding for the out years in the President's budget request falls short of FY96 and FY97 levels. These decreases have occurred at the same time that Air Force operational visions have become more dependent on information systems and supporting non-DoD commercial efforts (especially long-term basic research) have continued to fall short of expectations.

HIGH-LEVEL ADVOCACY

As would the other areas of Air Force S&T, the Air Force IST S&T program would benefit from S&T-focused representation and advocacy at the corporate policy and decision-making level of the Air Force. A trusted, authoritative Air Force champion at that level could help ensure that the Air Force IST investment better matches its warfighting visions.

CONCLUSIONS

Funding Incommensurate with Vision

Conclusion 4-1. The Air Force visions for air and space operations have become increasingly dependent on information systems, yet the Air Force has reduced its IST S&T budgets each year. Although projections for Air Force IST S&T funding show increases through FY05, the trend has been to disregard the investment plan, reduce funding, and then propose increased funding for the future. The committee believes that budgets for 6.1, 6.2, and 6.3 S&T are much too small to support Air Force IST visions.

Need for Joint-Agency Development

Conclusion 4-2. Service visions are not truly joint visions. They do not address the issues of interoperability with, and leveraging of, air and space technology developments by NASA, the National Reconnaissance Office, the Ballistic Missile Defense Organization, and other government organizations.

Taking Advantage of Commercial IST

Conclusion 4-3. Although about $1 trillion is invested in non-DoD commercial IST development in the United States every year, leveraging the results has been difficult because commercial technologies are not focused on military needs, they satisfy only some needs for IST, they provide mostly near-term solutions, they do not benefit from stable investments in research and development (and there is very little investment in long-range basic research), and they may not be able to provide long-term support. DoD technologies should leverage commercial technology where appropriate and use advanced systems-engineering techniques to provide a differential capability. For DoD to invest its limited resources wisely to maintain its capability advantage, budgeting processes need to be flexible enough to take advantage of commercial advances as they become available.

Dependence on DARPA

Conclusion 4-4. The Air Force is becoming increasingly dependent on DARPA to support its S&T needs. However, inadequate Air Force funding, differences in DARPA's and the Air Force's S&T roles, and differences in investment planning and execution processes have made it difficult for the Air Force to exploit and transition DARPA successes.

Need for IST Advocate

Conclusion 4-5. The Air Force (and other services) would benefit greatly from a high-level advocate for S&T programs during internal budgetary decision making.

RECOMMENDATIONS

IST Budget

Recommendation 4-1. The committee believes that the Air Force should increase its science and technology (S&T) budget for information systems technology (IST). The basic research (6.1) program should support long-term air and space IST needs, surpass previous-year levels, support a strong in-house program (with appropriate researchers), and compensate for limited long-term commercial investment.

DoD Joint Vision

Recommendation 4-2. The U.S. Department of Defense (DoD) should develop a better DoD-wide joint vision for information systems technology (IST) science and technology (S&T) that takes into consideration work by the National Aeronautics and Space Administration, the National Reconnaissance Office, the Ballistic Missile Defense Organization, and other government agencies. The services should develop closer working relationships with other DoD and non-DoD organizations.

Commercial Leveraging

Recommendation 4-3. The U.S. Department of Defense (DoD) should make as much use of non-DoD commercial developments in information systems technology (IST) as possible to reduce or offset the impact of recent reductions in IST science and technology (S&T) programs. S&T programs and flexible budgeting processes would enable the services to leverage the best commercial technologies and still maintain a strong military advantage.

Investment Strategy

Recommendation 4-4. The Air Force (and other services) should develop an investment strategy for applied research (6.2) and technology development (6.3) that takes advantage of Defense Advanced Research Projects Agency successes, but is not dependent on them.

IST Advocate

Recommendation 4-5. Each service should designate a high-level advocate who has an understanding of the state of the art of information systems and can formulate service S&T budgets, participate in corporate policy and decision-making activities, and work closely with other DoD and non-DoD organizations.

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5

Science and Technology Workforce

In the last 40 years, at least 20 studies have examined the health of government S&T laboratories. All of these studies agree in general with a conclusion of one of the earliest studies that "no matter how heavily the government relies on private contracting, it should never lose a strong internal competence in research and development" (McNamara et al., 1962). Most of the studies identified similar problems and offered similar solutions, but few changes were effected in the long term. Recent studies have again raised the alarm about the quality and retention of technical personnel and have recommended remedial actions to address the problem (e.g., CSAF, 1999; DSB, 1998). The recommendations in the present report support these efforts.

DECLINING NUMBER OF DoD S&T PERSONNEL

The number of government S&T personnel in the service laboratories has decreased over the last several years (see Figure 5-1).[1] Whether the data are based on "S&T" personnel, "science and engineering" personnel, or "RDT&E" personnel, the trends are similar. The declines are partly a result of the deliberate post-Cold War DoD downsizing; however, the decrease in Air Force S&T personnel has been greater than that attributable to downsizing alone. Figure 5-2 shows that, from 1996 to 2000, the percentage decrease in AFRL personnel was twice that of the DoD or the Air Force as a whole. The decrease at all laboratories has been highest for personnel with advanced degrees. Attrition results mainly from the retirement of senior, experienced personnel and from the departure of younger, highly motivated S&T workers seeking new challenges in a better, more stable work environment.

In addition to attrition and deliberate downsizing, other factors have contributed to staffing deficiencies in DoD's S&T workforce. They include low morale, a result of reductions, uncertainties, and year-to-year variability in S&T program funding. High-quality scientists and engineers leave jobs when research and engineering challenges and opportunities are eliminated, when their work may not be applied or appreciated, or when uncertainties and instabilities increase to the point that their welfare or the welfare of their families is threatened.

Another reason for staffing deficiencies is the attraction of higher salaries and other compensation in the private sector. Incentives to leave are intensified when challenges and opportunities are plentiful in a growing, high-technology economy (such as the economy that the United States experienced during the 1990s). Figure 5-3 shows a gap of 25 to 30 percent ($10,000 to $20,000 per year) in starting salaries for personnel in industrial versus DoD laboratories as of 1998.

Civil Service rules governing the recruiting and management of government personnel also add to the difficulty of hiring and retaining the highest-quality DoD S&T personnel. Hiring ceilings during

[1]Since the statement of task asked the committee to examine the in-house (government) S&T workforce only, the committee was not provided data on on-base support contractor personnel, who complement the in-house workforce. The committee notes, however, that the reductions in DoD S&T funding also put downward pressure on the support contractor workforce.

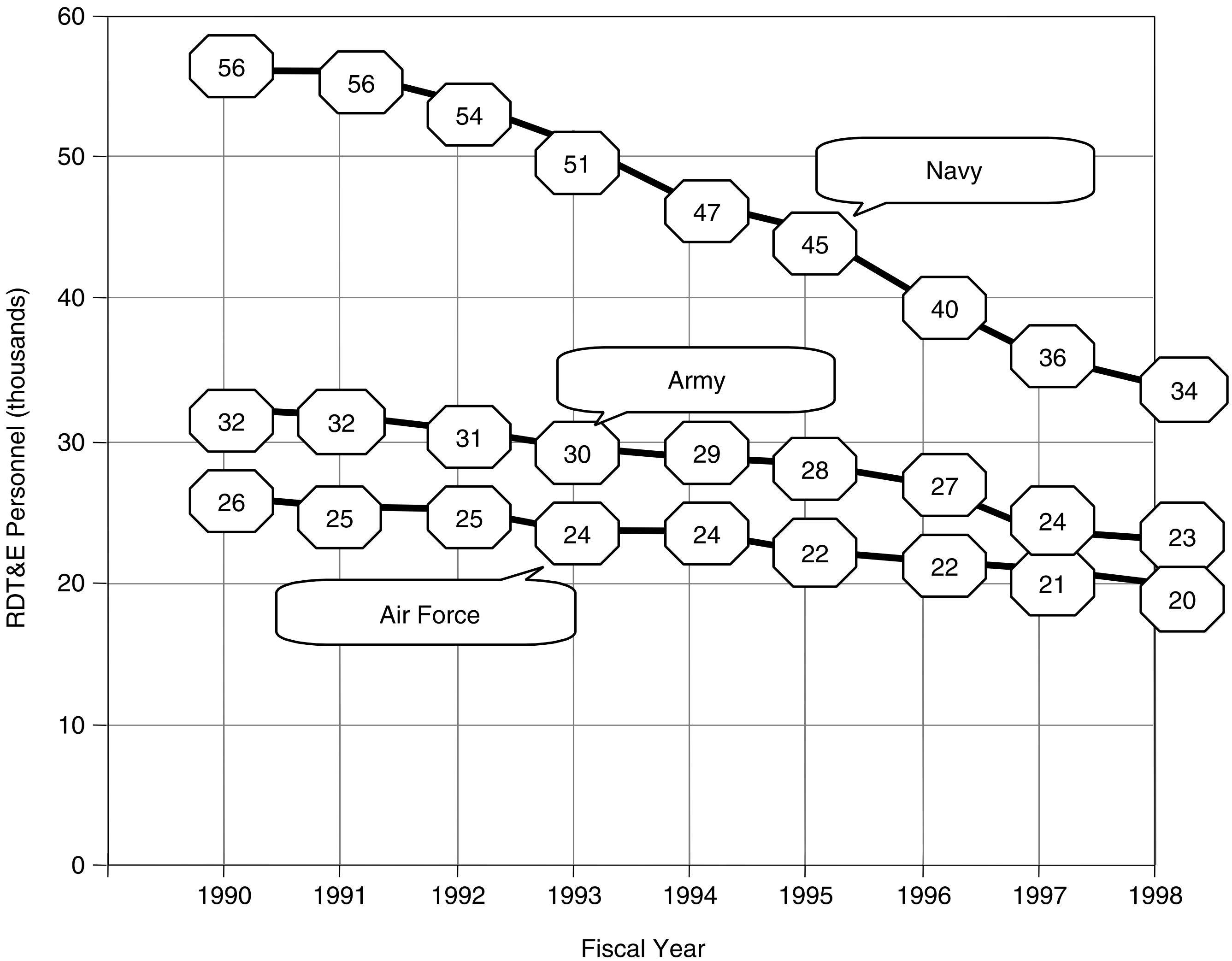

FIGURE 5-1 Number (in thousands) of service in-house RDT&E personnel, FY90 to FY98. SOURCE: Tangney, 2000.

downsizing, coupled with time-consuming Civil Service hiring and approval processes for new personnel, make recruiting new scientists and engineers difficult. During downsizing, reductions in force (RIFs) affect mainly younger personnel, who often have fewer years of service than some older workers who may be marginally productive but who have attained Civil Service career status and are difficult to remove under Civil Service rules. Civil Service attrition and RIF processes tend to result in a workforce populated with older workers not yet eligible to retire who are not being offered opportunities elsewhere.

The dearth of new personnel caused by downsizing-driven attrition, RIFs, and hiring restrictions is especially detrimental to S&T programs. New personnel not only are a primary source of new ideas and new knowledge but also represent a means of ensuring the continuity of a strong internal competence in S&T. The older workforce has a higher average number of years of service and so will be eligible for retirement sooner. This situation leaves S&T programs vulnerable to a mass exodus of workers at one time. AFRL could lose 25 to 30 percent of its science and engineering personnel to retirements in the next five years (CSAF, 1999).

DECLINING AIR FORCE MILITARY S&T PERSONNEL

For decades, DoD's policy has been to assign uniformed personnel to S&T activities, both in laborato-

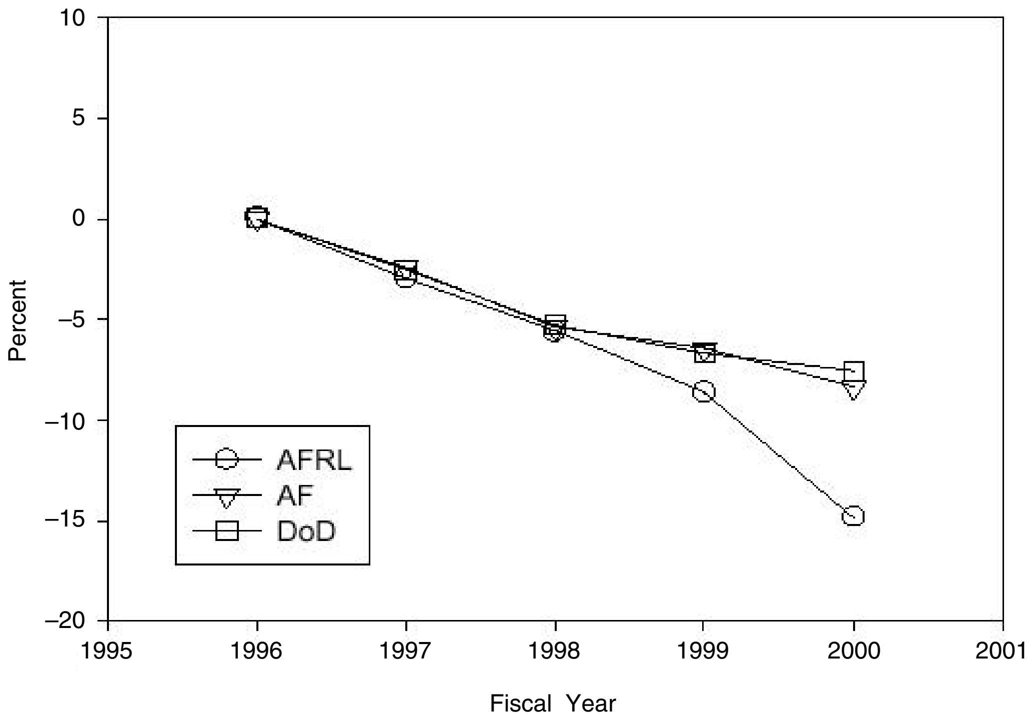

FIGURE 5-2 Percentage change in total Department of Defense, Air Force, and Air Force Research Laboratory personnel from FY96 to FY00 (AFRL data do not include Brooks Air Force Base and minor installations for which complete data were not available). SOURCE: Gessel, 2000.

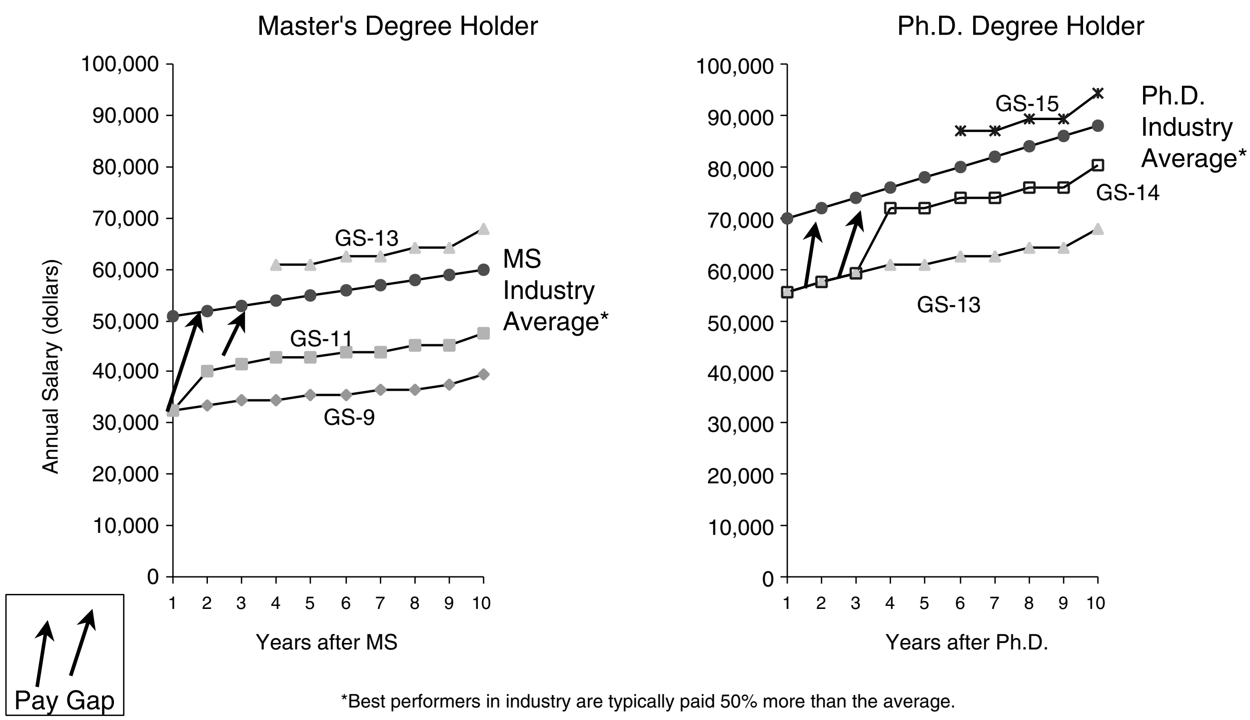

FIGURE 5-3 Cash compensation for Department of Defense RDT&E personnel versus industry RDT&E personnel as of 1998. SOURCE: DSB, 1998.

ries and in technical oversight positions, with the obvious benefits of providing knowledge and insight on technological capabilities to service officers and providing operational perspective to researchers. Many technically trained officers are also assigned to the acquisition branch.

A significant source of Air Force officers with advanced technical degrees is the Air Force Institute of Technology (AFIT), located at Wright-Patterson AFB. AFIT is the Air Force's accredited, in-house, resident graduate school awarding Air Force officers master's and doctor of philosophy degrees in several science and engineering areas. Since AFIT first granted resident degrees in 1956, it has awarded 920 bachelor of science, 13,406 master of science, and 333 doctor of philosophy degrees (AFIT, 2000). In addition to its in-house students, AFIT also oversees students who are sent to civilian educational institutions for advanced technical degrees.

During the 1990s, the Air Force contemplated closing the in-house school at Wright-Patterson. A key factor was cost. Congressional concern arose that was reinforced by the declining size of the Air Force S&T workforce. The Air Force decided not to close AFIT; however, AFIT remains a congressional interest item, and it has congressional support.

This military S&T workforce has been experiencing problems similar to those experienced by the civilian workforce. Young, highly motivated officers with advanced scientific and engineering degrees are affected by the same factors that affect civilian S&T workers, including low morale and plentiful challenges and opportunities outside the military. In addition, there appears to be a perception among some military officers that S&T assignments provide limited career opportunities, or are even detrimental to their careers. For example, only nine current Air Force general officers have ever served a tour in an Air Force laboratory (CSAF, 1999). As a result, the number of officers seeking such assignments has dwindled. In 1999, only half of the allocated positions for uniformed personnel at AFRL were filled (CSAF, 1999).

RESULTS OF TWO RECENT REPORTS

Two recent reports focused sharply on these problems related to the decrease in DoD and Air Force S&T personnel (CSAF, 1999; DSB, 1998). In a report issued in 1998, the Defense Science Board concluded, "The Department [of Defense] has commissioned several dozen studies of this problem extending over several decades. All these studies have reached the same conclusion, namely that there are severe difficulties in maintaining technical staff quality in the Service laboratories under the present Civil Service system" (DSB, 1998). Both recommended making modifications to the Civil Service system. Both examined technical staffing alternatives, including government-owned, contractor-operated (GOCO) arrangements; government leadership, private-sector staffing arrangements (DSB report); and government-owned, collaborator-assisted (GOCA) arrangements (Air Force report). Both reports discussed making use of private-sector personnel on a rotating basis through Intergovernmental Personnel Act (IPA) agreements or on a contract basis.

The DSB report strongly recommended that OSD and the services "staff a majority of their S&T management and execution technical positions with individuals provided from the private sector under the Interagency and Personnel Act [sic] and a reinstated Public Law 313 (1947)." (Public Law 313 permitted the services to establish certain positions for important DoD R&D functions, make such appointments without competitive examination, and pay market rates for these positions. Public Law 313 was superseded by the Civil Service Reform Act of 1978 (P.L. 95-454).) The DSB report identified the high quality of DARPA's technical managers as being among the key reasons for DARPA's enjoying the greatest S&T management success in DoD, and it noted that more than 50 percent of DARPA's managers are engaged for limited terms from outside the Civil Service system. The DSB report compared private-sector S&T personnel practices to Civil Service practices to show that the Civil Service practices were biased, relatively speaking, toward achieving a lower-quality workforce. Therefore, IPA assignments and similar arrangements that rotate high-quality, private-sector S&T personnel through DoD laboratories improve the quality of the DoD S&T workforce and, thereby, the quality of the DoD S&T program.

The Air Force report recommended moving AFRL toward a GOCA model: "The key idea is to have a significant core group of excellent civil servants who bring continuity coupled in an integrated team with excellent collaborators who bring agility and fresh ideas" (CSAF, 1999). The non-Civil Service collaborators would be in the AFRL workforce for a shorter term than the core civilian workers and would include postdoctoral associates, term-appointment and temporary-appointment personnel, personnel on IPA assignment, military officers, and employees of private-sector S&T organizations. Like the DSB report, the Air Force report viewed the outside collaborators as bringing with them their home organizations' standards of excellence.

The Air Force report also observed that Civil Service rules work against DoD S&T workforce quality and agreed with the DSB recommendation that 50 percent of AFRL's workforce should be provided by rotating outside Civil Service sources. The Air Force report also stated, however, that personnel mix alone is not the answer to strengthening the AFRL workforce. It noted that although AFRL has already evolved to a personnel mix in which approximately 50 percent of the in-house S&T workforce are non-Civil Service employees, deficiencies in AFRL performance and user impact still exist. To ensure success in a transformation to excellence, AFRL leadership needs to be given the authority to make the changes needed to transform the workforce, including the authority to modify Civil Service practices that limit the quality of the S&T workforce. The foundation for the GOCA model is a core group of excellent civil servants. Many current Civil Service rules work against achieving that excellence.

SECTION 246

DoD has undertaken several initiatives intended to maintain or improve the quality and efficiency of the S&T workforce. Section 246 of the 1999 National Defense Authorization Act (P.L. 105-261) provides for a three-year pilot program for revitalizing the service laboratories and centers through innovative, more business-like operations and encouragement of working relationships with academia and private entities. DoD has also selected pilot laboratories to set goals for achieving "world-class" status. The directors have the authority to waive restrictions not required by law and have been asked to identify other restrictions that might be candidates for change through legislation or regulation.

A central feature of the program is temporary appointments of industry personnel to management positions in the laboratories and an increase in the number of technical experts that can be hired on temporary IPA-like arrangements. Industrial-level salaries and benefits have also reduced the barriers to recruitment. Many restrictions on workforce retention and shaping, the use of experts and consultants, and hiring have been waived (Tangney, 2000).

CONCLUSIONS

Factors Inhibiting Hiring

Conclusion 5-1. Downsizing, noncompetitive salaries, cumbersome hiring and downsizing practices, and other factors have reduced the effectiveness of the air and space S&T workforce. DoD (as well as the Air Force) has begun to take measures to revitalize the S&T workforce, which should help the situation in the near term. In the long term, changes to the Civil Service system may be necessary.

Analyses Undertaken

Conclusion 5-2. The Defense Science Board and the Chief of Staff of the Air Force have undertaken comprehensive analyses of the situation and have recommended ways to solve the problem.

RECOMMENDATIONS

Take Opportunities to Strengthen S&T Staff Under the Law

Recommendation 5-1. The U.S. Department of Defense should seize the opportunity offered in Section 246 of the National Defense Authorization Act (P.L. 105-261) to strengthen its science and technology staff and other technical personnel.

Change Civil Service Regulations

Recommendation 5-2. The U.S. Department of Defense (DoD) should formulate reasonable changes to Civil Service regulations that would mitigate staffing problems in the long term and should promote them to Congress and the Office of Personnel Management. DoD's report to Congress on the status of its Section 246 initiatives could be a vehicle for promoting these changes.

Extend Section 246, P.L. 105-261

Recommendation 5-3. The U.S. Department of Defense should request that Congress extend the Section

246 initiatives beyond their three-year limit by another three years to allow adequate time to implement and evaluate the effects of the modified procedures.

Make World-Class Research the Goal

Recommendation 5-4. The U.S. Department of Defense should continue to pursue world-class status for the service laboratories (including developing criteria or measures to assess such status), not only to obtain the highest-quality results from its research, but also to attract superior scientific and engineering personnel who want to work where the best research is done.

Encourage Career Opportunities Through R&D

Recommendation 5-5. Career Air Force officers with the requisite backgrounds should be encouraged to serve tours of duty at the Air Force Research Laboratory or other laboratories and to pursue advanced technical degrees. Assignments to a research laboratory should be considered a positive step in consideration for promotion to general officer rank.

Promote S&T Career Officers

Recommendation 5-6. As a further inducement to career officers, the Air Force should provide organizational billets for these officers at the highest level of the Air Force.

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6

Overarching Conclusions and Recommendations

Focusing on specific areas, Chapters 2 through 5 provide conclusions and recommendations relevant to those areas. This chapter offers conclusions and recommendations that reflect the common themes of the study as a whole.

Although the reductions in DoD (and Air Force) S&T funding since the end of the Cold War may have seemed reasonable at the time they were made, they did not take into account new threats that would have to be addressed through S&T. Many nations and groups have taken advantage of advanced off-the-shelf information systems, foreign military equipment sales, and the relative ease of developing or acquiring weapons of mass destruction and now present new threats worldwide. Current U.S. forces and systems were not designed specifically to meet these highly unpredictable, asymmetrical threats.

The Cold War impetus driving the development of some systems has diminished; however, continued S&T investment to support advanced systems is still necessary. The United States still relies on technological superiority to provide a military advantage to ensure military success with minimal casualties. In addition, many DoD and Air Force systems are decades old and are expected to last many more years until new systems are ready. All of the services recognize that S&T programs will be necessary to extend the lifetimes of these systems. Finally, new operational concepts, such as the Air Force's Expeditionary Aerospace Force, will require S&T investment. The Air Force has challenged its S&T community to improve the operational parameters of the Expeditionary Aerospace Force by an order of magnitude. For all of these reasons, DoD still needs a strong, broad-based S&T program.

Post-Cold War reductions to DoD and Air Force S&T in air, space, and related information systems have been particularly harmful. S&T for air systems is necessary to support aging systems, systems currently in development, new operational concepts, and new systems, such as unmanned air vehicles, unmanned combat air vehicles, and guided weapons. Funding for Air Force S&T for air systems is less than half of what it was 10 years ago.

The new DoD space policy highlights the strategic significance of space as a vital defense arena and will certainly require expanded research in space technologies. However, DoD's current investment in space S&T is only 3 percent of its overall S&T program, not nearly enough to support an aggressive space technology initiative. The Air Force has increased its emphasis on S&T for space systems; however, to pay for the increase within a fixed total for S&T, funding has had to be shifted from already-underfunded air systems S&T programs.

Battlespace information systems are pervasive throughout the services and DoD agencies. All of the services need information systems technology to support air and space operations. The Air Force's *Vision 2020* identifies information superiority as one of the Air Force's core competencies and states that information superiority will be necessary to ensure decision dominance over adversaries. Although Air Force visions for air and space operations are becoming increasingly dependent on information systems, Air

Force S&T budgets for information systems have continued to decline each year. In FY00, only 6 percent of the funding appropriated for Air Force S&T was budgeted for the AFRL's directorate responsible for information systems S&T.

AIR FORCE INVESTMENT IN S&T

Conclusion 1. The committee believes that the reductions made by the Air Force to its S&T investment since the end of the Cold War did not take into account the changing nature of the global threat and the S&T challenges it presents. While the need for the Air Force S&T investment oriented to the Soviet threat was diminished at the end of the Cold War, the need for overall Air Force investment in S&T was not. The committee believes that the Air Force's current (FY01) investments in air, space, and information systems S&T are too low to meet the challenges being presented by new and emerging threats.

Recommendation 1. The Secretary of Defense and the Secretary of the Air Force should continue to increase the Air Force investment in science and technology (S&T) to reach one-and-a-half to two times its current (FY01) level. Investments in S&T for air, space, and information systems should all be increased. Increasing one by decreasing the others will not satisfy current S&T program shortcomings and may create new ones.

In recommending that S&T investment levels be increased, the committee recognizes that DoD and the Air Force need to maintain the S&T base required to ensure technological superiority over potential adversaries with advanced systems. However, they should also reorient their S&T programs to discover and develop technologies to address evolving threats, support aging systems, and enable new operational concepts. This reorientation has already begun and should be continued. S&T programs will have to be broad-based, flexible, and stable to deal with the uncertainties presented by future threats.

S&T REPRESENTATION AND ADVOCACY WITHIN THE AIR FORCE

Conclusion 2. The committee strongly believes that the Air Force needs authoritative, S&T-focused and -dedicated representation and advocacy at the corporate policy and decision-making level of the Air Force to help make informed trade-offs and budget decisions. Without corporate-level understanding and consideration of the effects its S&T investment can have on the Air Force's future, the committee believes that the Air Force faces undue risk that its S&T investment will not provide the technologies and systems needed to meet future threats. The committee is encouraged by the actions that the Air Force has recently taken to increase the level of S&T advocacy in the Air Force and believes these actions can result in a stronger S&T program. Additional actions could make Air Force S&T even stronger.

Recommendation 2. In addition to the actions they have already taken, the Secretary and the Chief of Staff of the Air Force should continue to look for ways and take actions to further strengthen S&T representation and advocacy at the corporate policy and decision-making level of the Air Force. There are a number of options they can consider, including (1) formally designating the Air Force science and technology (S&T) program as a corporate program, (2) having the current AFRL commander/TEO position report directly to the Chief of Staff or be a member of the Air Force Council, and (3) establishing an Air Force Council member position (normally an assistant secretary or a 3-star deputy chief of staff) to be filled by a person in the Pentagon who is focused on, dedicated to, responsible for, and authorized to represent and advocate S&T within the Air Force, formulate Air Force S&T budgets, and participate in Air Force corporate policy and decision-making activities. The Air Force can also benefit from carefully examining the special roles accorded the Chief of Naval Research and the Office of Naval Research in the Department of the Navy to consider how these roles could be adapted to the AFRL commander/TEO and AFRL to strengthen Air Force S&T. These options or others the Air Force identifies can address remaining weaknesses in Air Force S&T representation and advocacy and build upon the recent successes of the Air Force.

S&T WORKFORCE

Conclusion 3a. The reductions in the Air Force's S&T workforce since the end of the Cold War and the rules governing the hiring, firing, and management of S&T workers have helped to undermine the quality and health of the Air Force's S&T program. They threaten the S&T program's ability to deliver the technologies, enable the strategies, and satisfy the visions of the future military.

Conclusion 3b. Personnel management rules threaten the quality of the Air Force's S&T program.

Conclusion 3c. The talents of DoD's technically educated officer corps are not being fully exploited, the benefits of locating uniformed personnel with their warfighter perspectives close to DoD S&T performers and S&T investment decision makers are being lost, and the number of officers throughout DoD who understand the importance of S&T to U.S. military superiority is decreasing.

Recommendation 3a. The Secretary of Defense should request that Congress extend the three-year pilot program for revitalizing the service laboratories (under Section 246 of the 1999 National Defense Authorization Act [P.L. 105-261]) by at least three years to allow laboratory programs to implement changes and evaluate the results. The Secretary of Defense, service secretaries, and service chiefs of staff should seize the opportunity that Congress created with Section 246 to improve the quality and health of their science and technology (S&T) workforces as much as possible. The services should take maximum advantage of the flexibility offered by Section 246 to try innovative approaches to managing their S&T workforces.

Recommendation 3b. The Secretary of Defense, service secretaries, and service chiefs of staff should work aggressively to improve the development and use of their military science and technology (S&T) workforce. Officers should be encouraged to carry out S&T assignments, which should be viewed positively during consideration for promotions. High-grade career advancement opportunities for S&T officers should be made visible.

Recommendation 3c. The Secretary of Defense, service secretaries, and service chiefs of staff should implement the remedial actions proposed by previous reports. These include establishing personnel demonstration projects, increasing the presence of leading national (perhaps also international) non-Department of Defense (DoD) scientists and engineers in DoD laboratories through Intergovernmental Personnel Act assignments, and using alternative laboratory management and staffing approaches, such as government-owned, collaborator-assisted arrangements.

Recommendation 3d. The Secretary of Defense, service secretaries, and service chiefs of staff should work with Congress and with other agencies to enact targeted modifications to Civil Service rules that directly affect the quality and health of the science and technology workforce.

Appendixes

Appendix A

Strom Thurmond National Defense Authorization Act for Fiscal Year 1999 Public Law 105-261—Oct. 17, 1998

SEC. 214. SENSE OF CONGRESS ON THE DEFENSE SCIENCE AND TECHNOLOGY PROGRAM.

(a) FUNDING REQUIREMENTS FOR THE DEFENSE SCIENCE AND TECHNOLOGY PROGRAM BUDGET.—It is the sense of Congress that, for each of the fiscal years 2000 through 2008, it should be an objective of the Secretary of Defense to increase the budget for the Defense Science and Technology Program for the fiscal year over the budget for that program for the preceding fiscal year by a percent that is at least two percent above the rate of inflation as determined by the Office of Management and Budget.

(b) GUIDELINES FOR THE DEFENSE SCIENCE AND TECHNOLOGY PROGRAM.—

(1) RELATIONSHIP OF DEFENSE SCIENCE AND TECHNOLOGY PROGRAM TO UNIVERSITY RESEARCH.—It is the sense of Congress that the following should be key objectives of the Defense Science and Technology Program:

(A) The sustainment of research capabilities in scientific and engineering disciplines critical to the Department of Defense.

(B) The education and training of the next generation of scientists and engineers in disciplines that are relevant to future defense systems, particularly through the conduct of basic research.

(C) The continued support of the Defense Experimental Program to Stimulate Competitive Research and research programs at historically black colleges and universities and minority institutions.

(2) RELATIONSHIP OF THE DEFENSE SCIENCE AND TECHNOLOGY PROGRAM TO COMMERCIAL RESEARCH AND TECHNOLOGY.

(A) It is the sense of Congress that, in supporting projects within the Defense Science and Technology Program, the Secretary of Defense should attempt to leverage commercial research, technology, products, and processes for the benefit of the Department of Defense.

(B) It is the sense of Congress that funds made available for projects and programs of the Defense Science and Technology Program should be used only for the benefit of the Department of Defense, which includes—

(i) the development of technology that has only military applications;

(ii) the development of militarily useful, commercially viable technology; and

(iii) the adaptation of commercial technology, products, or processes for military purposes.

(3) SYNERGISTIC MANAGEMENT OF RESEARCH AND DEVELOPMENT.—It is the sense of Congress that the Secretary of Defense should have the flexibility to allocate a combination of funds available for the Department of Defense for basic and applied research and for advanced development to support any individual project or program within the Defense Science and Technology Pro-

gram, but such flexibility should not change the allocation of funds in any fiscal year among basic and applied research and advanced development.

(4) MANAGEMENT OF SCIENCE AND TECHNOLOGY.—It is the sense of Congress that—

(A) management and funding for the Defense Science and Technology Program for each military department should receive a level of priority and leadership attention equal to the level received by program acquisition, and the Secretary of each military department should ensure that a senior official in the department holds the appropriate title and responsibility to ensure effective oversight and emphasis on science and technology;

(B) to ensure an appropriate long-term focus for investments, a sufficient percentage of science and technology funds should be directed toward new technology areas, and annual reviews should be conducted for ongoing research areas to ensure that those funded initiatives are either integrated into acquisition programs or discontinued when appropriate;

(C) the Secretary of each military department should take appropriate steps to ensure that sufficient numbers of officers and civilian employees in the department hold advanced degrees in technical fields; and

(D) of particular concern, the Secretary of the Air Force should take appropriate measures to ensure that sufficient numbers of scientists and engineers are maintained to address the technological challenges faced in the areas of air, space, and information technology.

(c) STUDY.—

(1) REQUIREMENT.—The Secretary of Defense, in cooperation with the National Research Council of the National Academy of Sciences, shall conduct a study on the technology base of the Department of Defense.

(2) MATTERS COVERED.—The study shall—

(A) result in recommendations on the minimum requirements for maintaining a technology base that is sufficient, based on both historical developments and future projections, to project superiority in air and space weapons systems and in information technology;

(B) address the effects on national defense and civilian aerospace industries and information technology of reducing funding below the goal described in subsection (a); and

(C) result in recommendations on the appropriate levels of staff with baccalaureate, masters, and doctorate degrees, and the optimal ratio of civilian and military staff holding such degrees, to ensure that science and technology functions of the Department of Defense remain vital.

(3) REPORT.—Not later than 120 days after the date on which the study required under paragraph (1) is completed, the Secretary shall submit to Congress a report on the results of the study.

(d) DEFINITIONS.—In this section:

(1) The term ''Defense Science and Technology Program'' means basic and applied research and advanced development.

(2) The term ''basic and applied research'' means work funded in program elements for defense research and development under Department of Defense category 6.1 or 6.2.

(3) The term ''advanced development'' means work funded in program elements for defense research and development under Department of Defense category 6.3.

Appendix B

Biographical Sketches of Committee Members

Eugene E. Covert, chair, is a member of the National Academy of Engineering (NAE) and the T. Wilson Professor of Aeronautics (emeritus) at the Massachusetts Institute of Technology (MIT). He has served as the chief scientist of the U.S. Air Force, member and chairman of the Air Force Scientific Advisory Board, and consultant to the Defense Science Board. He served on the Presidential Commission on Space Shuttle Challenger and was chair of the National Research Council (NRC) committee on National Aeronautics and Space Administration (NASA) program changes. He is director of the Wright Brothers Laboratory and has been a consultant for the Lincoln Laboratory, Sverdrup Technology, Inc., Boeing Company, CACI, and the United Technology Corporation. Dr. Covert is also a past chair of the NRC Aeronautics and Space Engineering Board. He received a B.A.E. and M.S. from the University of Minnesota and an Sc.D. degree from MIT.

Aaron Cohen, a member of NAE, is currently Zachry Professor of Engineering at Texas A&M University. He is a graduate of Texas A&M University and Stevens Institute of Technology. Prior to his position at Texas A&M, Dr. Cohen was acting deputy administrator for NASA. In 1983 he was director of research and engineering at the Johnson Space Center and in 1986 he became director of the Johnson Space Center.

Robert S. Cooper is president and chief executive officer (CEO) of Atlantic Aerospace Electronics Corporation. He served as director of the Defense Advanced Research Projects Agency (DARPA) before he was appointed Assistant Secretary of Defense for Research and Technology. Dr. Cooper was previously vice president for engineering, Satellite Business Systems, and director of the NASA Goddard Space Flight Center. He was assistant director of defense research and engineering for the Office of the Secretary of Defense and an assistant professor at MIT. He received his B.S. from the University of Iowa, his M.S. from Ohio State University, and his Sc.D. from MIT, all in electrical engineering.

Ruth M. Davis, a member of NAE, is currently president and CEO of Pymatuning Group, Inc., which specializes in technology management, and chairman of the board of trustees for Aerospace Corporation. Dr. Davis was Assistant Secretary of Energy for Resource Applications and Deputy Under Secretary of Defense for Research and Advanced Technology. She served as a member of the NRC's Commission on Engineering and Technical Systems and is a fellow of the National Academy of Public Administration.

Eliezer G. Gai is vice president of engineering for the Charles Stark Draper Laboratory (CSDL), Inc., in Cambridge, Massachusetts. Dr. Gai has held many positions at CSDL, including director, Decision and Control Systems; manager, IRD/CSR Programs; and head, Guidance Technology Center. Dr. Gai served on the NRC Committee on the Review of ONR's Air and Surface Weaponry Program and on the Defense Science Board Task Force on Joint Superiority for the 21st Century. He received his B.Sc. and M.Sc. in electrical engineering from Technion (Israel) and his Ph.D. in instrumentation and control from MIT. His areas of expertise include guidance, navigation and control systems, fault-tolerant systems, and information systems.

George J. Gleghorn, a member of the NAE, graduated from the California Institute of Technology with a Ph.D. in electrical engineering and mathematics. Dr. Gleghorn retired after 37 years at TRW as vice president and chief engineer of TRW's Space and Technology Group. He began his tenure there as manager of the attitude-control laboratory and held many positions in project management, systems engineering, and systems design. He has served on many NRC committees, both as chair and as committee member. Dr. Gleghorn is a fellow of the American Institute of Aeronautics and Astronautics and is a member of several NASA committees and review teams.

Darold Griffin is president and CEO of Engineering and Management Executives, Inc. Mr. Griffin is a former member of the federal Senior Executive Service and was senior civilian, U.S. Army Materiel Command, where he was responsible for research, development, and acquisition. During his last year of federal service, Mr. Griffin was the executive director of the U.S. Department of Defense Specifications and Standards Task Force, which developed the innovative "Blueprint for Change," a plan for reforming military specifications and standards. He is a recipient of the Presidential Rank Award of Distinguished Senior Executive, three Presidential Rank Awards of Meritorious Senior Executive, Vice Presidential Hammer Award, Secretary of Defense Award, and the Department of Army Distinguished Service Medal. Mr. Griffin has many years of experience in the management of DoD personnel and the Army's Scientist and Engineer Career Program.

Robert W. Lucky, a member of NAE, is the current corporate vice president for applied research at Telcordia Technologies. He has a B.S., M.S., and Ph.D. from Purdue University in electrical engineering. The majority of his distinguished career was spent at Bell Laboratories, where he was noted for his work in digital data transmission and data communications. Dr. Lucky is a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and a regular contributor to the *IEEE Spectrum* magazine.

Milton A. Margolis is a consultant for the Logistics Management Institute. He received a B.A. from Columbia University and did graduate work at Johns Hopkins University in economics and statistics. Mr. Margolis is an expert in the cost analysis of weapon systems and military programs. He served as the director of cost analysis and the Deputy Assistant Secretary of Defense (Resource Analysis) in the Office of the Assistant Secretary of Defense (Program Analysis and Evaluation). His extensive knowledge of the aircraft industry, the space program, and cost-benefit analysis is based on 20 years of service in the Office of the Secretary of Defense and 25 years in industry. He is a recipient of the Presidential Rank Award and the Meritorious and Distinguished Service Medals. Mr. Margolis previously served on the NRC Committee on Live Fire Testing of the F-22 Aircraft, as well as various Defense Science Board studies of weapon-system development programs.

Malcolm R. O'Neill is vice president of operations and best practices for the Space and Strategic Missiles Sector of the Lockheed Martin Corporation. During a distinguished 34-year career in the U.S. Army, Lt. Gen. O'Neill served as director of the DoD Ballistic Missile Defense Organization as well as director of the Army Acquisition Corps for the Assistant Secretary of the Army (Research, Development, and Acquisition). He was also the Commander of the Army Laboratory Command. Lt. Gen. O'Neill received his B.S. from DePaul University and his M.A. and Ph.D. in physics from Rice University.

Albert A. Sciarretta is president of CNS Technologies, Inc., consultants in research and development, modeling and simulation, management, and support of advanced information technologies and systems for the Defense Modeling and Simulation Office, the Office of the Deputy Under Secretary of Defense for Science and Technology (ODUSD (S&T)), and the Joint Personnel Recovery Agency. Previously, he was manager, Advanced Information Technologies, at Quantum Research International, Inc., and program area manager, Advanced Information Technologies, for the MITRE Corporation. While at MITRE, he managed all of MITRE's support to DARPA and his division's information systems independent research and development, and he worked on Army command, control, communications, computers, and intelligence (C4I) technologies. He has experience in developing technology plans for modeling and simulation, combating terrorism, personnel recovery, DUSD (S&T)'s Smart

Sensor Web Initiative, and advanced concept technology demonstrations. Mr. Sciarretta has a B.S. in general engineering from the U.S. Military Academy and an M.S. in mechanical engineering and an M.S. in operations research from Stanford University. He has worked on several NRC studies as a member of the NRC staff.

Appendix C

Guest Speakers

Steve Ansley, *Professional Staff Member*
House Armed Services Committee

Pamela Farrell, *Professional Staff Member*
Senate Armed Services Committee

Bob Tuohy, *Director of Plans and Programs*
Office of the Deputy Under Secretary of Defense for Science and Technology

Terry Neighbor, *Director of Plans and Programs*
Air Force Research Laboratory

Delores Etter, *Deputy Under Secretary of Defense for Science and Technology*
Office of the Director of Defense Research and Engineering

Bill Byrne, representing Christine Anderson, *Chair*
Space Platforms Technology Area Plan Panel

Bill Borger, *Chair*
Air Platforms Defense Technology Area Plan Panel

John Graniero, *Chair*
Information Systems Technology Defense Technology Area Plan Panel

Michael Gessel, *Executive Assistant to Congressman Tony Hall*
U.S. House of Representatives

John Tangney, *Special Assistant for Laboratory Management*
Office of the Deputy Under Secretary of Defense for Science and Technology

LTG John Costello, *Commanding General*
U.S. Army Space and Missile Defense Command

Colonel Mark Swinson, *Deputy Director of Information Technology Office*
Defense Advanced Research Projects Agency

Allen Adler, *Program Manager, Tactical Technology Office*
Defense Advanced Research Projects Agency

NOTE: Speakers are listed in the order of their appearance.

Appendix D

Milestones in the Management of DoD Science and Technology

Research on air science and technology, begun on a small scale prior to the establishment of the National Advisory Committee for Aeronautics in 1916, was increased dramatically just before and during World War II and the subsequent transition to jet propulsion in the 1950s. Space science and technology were predominant in the 1960s and 1970s. Information systems science and technology grew exponentially in the 1980s and 1990s.

Many of the outstanding issues concerning the management of U.S. Department of Defense science and technology programs are not new. Indeed, some issues have recurred over the past 50 years. The following chronological summary covers the most significant studies and actions that have affected DoD S&T since the end of World War II.

After the Manhattan Project's success in developing the atomic bomb during World War II, DoD was convinced of the value of investing in S&T. The subsequent development of aircraft, precision bombing, proximity fuzing, radar, and many other technologies has justified that belief in the great payoffs of S&T. Vannevar Bush, a leader of science and technology during the war, advocated continuing strong peacetime support of the S&T program by the federal government in his study, *Science, the Endless Frontier* (Bush, 1945). Another advocate was Theodore von Karman, a world expert in aerodynamics and an early developer of rocket propulsion. Under the direction of General Henry H. (Hap) Arnold, Commanding General of the Army Air Forces, von Karman formed a team of outstanding scientists that traveled wartorn Europe and Japan and gathered enough information to fill 32 volumes. The first volume, *Toward New Horizons*, was delivered in December 1945 (von Karman, 1945). The needs of a technologically superior military identified by von Karman are still applicable (Box D-1). Even though Congress consistently slashed budgets for S&T from 1945 to 1957, the studies by Bush and von Karman set an agenda for decades to come. An excellent discussion of von Karman and other significant Air Force S&T studies can be found in *Harnessing the Genie* (Gorn, 1988).

The launching of Sputnik on October 4, 1957, "the first artificial satellite in space," provided an impetus

Box D-1
Summary of von Karman's Recommendations

- S&T must permeate the entire command structure.
- Officers must be educated in S&T.
- Officers working in S&T must have the same promotional opportunities as line operational officers.
- Management of research and development must be separated from procurement.
- Military S&T must have its own facilities, staff, and funding.
- A scientific advisory group must be established and empowered at the highest level.

SOURCE: von Karman, 1945.

for an S&T program. Congress quickly reacted to the wake-up call by creating the Advanced Research Projects Agency (P.L. 85-325), later the Defense Advanced Research Projects Agency (DARPA), to manage U.S. space programs. Shortly thereafter, Congress realized that space operations should not be under the military and created the National Aeronautics and Space Administration (NASA), which incorporated existing facilities and research programs operated by the National Advisory Committee for Aeronautics. Defense against ballistic missiles, the detection of nuclear tests, the development of new sources of electric power, and the development of rocket propulsion were assigned to the Advanced Research Projects Agency.

When John F. Kennedy came into office in 1961, he placed a new emphasis on space S&T by setting a goal of landing a man on the moon "by the end of the decade." He also ordered a restructuring of military S&T programs. Charles Hitch, DoD comptroller, reorganized the research, development, test, and evaluation (RDT&E) budget and established the planning, programming, and budgeting system, which was the first time program elements were used as the basic budget building blocks. The so-called "Hitch Package" was based on a series of studies by Hitch at the RAND Corporation (Hitch and McKean, 1960). Budget categories, for 6.1 Research, 6.2 Exploratory Development, and 6.3 Advanced Development, were created. Various combinations of 6.1, 6.2, and 6.3 (and later 6.3A) and different names have been used over the years. The current RDT&E budget categories are defined in Box D-2.

Box D-2
Current S&T Budget Activities

Budget Activity 1, Basic Research. Basic research is defined as 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 (6.1).

Budget Activity 2, Applied Research. Applied research is defined as systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met (6.2).

Budget Activity 3, Advanced Technology Development. Includes all efforts that have moved into the development and integration of hardware for field experiments and tests (6.3).

SOURCE: OMB, 2000.

Based on studies and actions in the late 1960s and early 1970s, more controls were placed on S&T. *Project Hindsight*, a detailed study of the payoff of S&T, evaluated the contributions of 6.1 and 6.2 for the Bullpup, Honest John, Lance, Minuteman I, and Minuteman II missile systems, the C-141 cargo aircraft, and the Mark 56 and 57 naval mines. The study concluded that new technologies were often developed to meet specific detailed requirements. Although basic research was necessary to define potential technologies, oriented research was crucial to the development of useful systems (Isenson, 1967).

Congress and the services reacted quickly to the preliminary findings of *Project Hindsight* (which were available in 1965 and 1966). At the same time, Senator Mike Mansfield tacked on to the 1966 appropriations bill the so-called Mansfield Amendment requiring that all S&T proposals include a written statement of future military applications showing "direct" and "apparent" relevance. This requirement was particularly difficult to meet for 6.1 projects, basic research (Sullivan and Heaston, 1967).

To respond to Project Hindsight, the services created the Blue Ribbon Defense Panel, which made the following observation:

> There is no adequate mechanism to assure that funds appropriated for research and exploratory development are not diverted to advanced, or engineering development categories, or to operational systems developments. The overemphasis on mission justifications for research and development allocations and funding creates additional incentives for such diversions. (BRDP, 1970)

The services then transferred all 6.1 projects into single-program funding and 6.2 projects into single-program-element funding. At the same time, many projects were combined, priorities were changed, and laboratory directors were given more latitude to manage their programs. Combining programs, however, eventually made them more vulnerable to micromanagement by service headquarters, the Office of the Secretary of Defense, and Congress.

In response to the Blue Ribbon Defense Panel, Secretary of Defense Melvin Laird ordered a massive reorganization and increased the emphasis on prototypes to test new technologies (see Box D-3) (Foster, 1971).

Box D-3
Rationale for 1971 Prototype Initiative

My basic intention is to place the subject of prototyping in a proper perspective as a tool to be prudently applied.

1. We need to make maximum effective use of the smaller defense budget. To keep costs down, we must try things out before making heavy commitments of resources.
2. We need to find ways to improve reliability and reduce the anticipated maintainability costs of our defense systems before they are deployed.
3. We need to keep technological innovation moving ahead, recognizing there is a continuing threat to our country's technological leadership.
4. We need to keep some of our design teams together so we won't have to start over each time a new program is initiated.

SOURCE: Excerpted from Foster, 1971.

Although prototypes contributed greatly to the modernization of the services during the 1970s, the cost of hardware demonstrations put a great strain on the 6.3 advanced development budget; therefore, 6.3 was split into 6.3A nonsystems advanced development and 6.3B systems advanced development. Until this split, the S&T base (or technology base) was defined as 6.1 and 6.2. After the split, the technology base became 6.1, 6.2, and 6.3A. This structure worked very well throughout the 1970s and early 1980s, and many new weapon systems were fielded under the so-called modernization programs of the services.

In 1981, the Defense Science Board Panel on Technology Base was asked to conduct a study on three major aspects of DoD S&T: identifying critical technologies, working closely with users to accelerate the transition of new technologies, and maintaining high-quality in-house personnel and facilities. The following sections address these three themes.

CRITICAL TECHNOLOGIES

Numerous attempts have been made to establish priorities for the technologies that would meet DoD needs. The Defense Science Board report identified 17 so-called order-of-magnitude technologies for which funding should be increased by an order of magnitude. In 1983, the Strategic Defense Initiative was created, causing a major shuffle of S&T throughout DoD. Then came "Technologies for Competitive Strategies" in 1987. In 1988, Congress mandated that DoD submit an annual critical technologies plan (P.L. 100-456). The first plan, which listed 22 critical technologies, was submitted on March 15, 1989 (DoD, 1989). In response to Congress's request, another plan was submitted on March 15, 1990, with a list of 20 technologies (Box D-4; DoD 1990).

In the National Defense Authorization Act for Fiscal Year 1990 (FY90) and for FY91 (P.L. 101-189), Congress asked for a critical technologies plan with a national list of the DoD's and the U.S. Department of Energy's priorities (DoD, 1991). The final list included 22 technologies grouped into three categories: pervasive technologies, enabling technologies, and emerging technologies (NCTP, 1991).

Box D-4
1990 DoD Critical Technologies

Pervasive Technologies
- composite materials
- computational fluid dynamics
- data fusion
- passive sensors
- photonics
- semiconductor materials and microelectronic circuits
- signal processing
- software producibility

Enabling Technologies
- air-breathing propulsion
- machine intelligence and robotics
- parallel computer architectures
- sensitive radars
- signature control
- simulation and modeling
- weapon system environment

Emerging Technologies
- biotechnology materials and processes
- high-energy-density materials
- hypervelocity projectiles
- pulsed power
- superconductivity

SOURCE: DoD, 1990.

In 1992, DoD issued *Defense Science and Technology Strategy,* which announced seven S&T thrusts funded under 6.3A based on the "demands being placed on the S&T program by the users' most pressing *military and operational* requirements" (DDR&E, 1992a). The 6.2 program was addressed in the separate *DoD Key Technologies Plan* (DDR&E, 1992b).

In a parallel action, the Deputy Secretary of Defense asked the services to recommend a new approach to the management of S&T projects. The services began formal discussions on ways to strengthen interservice cooperation in their RDT&E programs and increase the use of each other's facilities. This project, called Tri-Service S&T Reliance, was the most comprehensive restructuring of the technology base in more than 40 years. As described in a white paper (JDL, 1992), the services agreed on a taxonomy of 28 technology areas, subareas, and sub-subareas, a total of 223 technology topics. Panels were appointed for basic research and 12 technology areas.

The Office of the Secretary of Defense evaluated the approach during 1993 and developed a technology area review and assessment (TARA) process in 1994. TARA established 10 DoD reliance panels and a research panel to evaluate the DoD S&T program (Box D-5), as well as an annual week-long TARA meeting, including nongovernment personnel, for comments on the DoD S&T program. The TARA process is still being used, along with a number of supporting plans: the *Basic Research Plan,* the *Defense Technology Area Plan*, the *Joint Warfighting Science and Technology Plan*, and the *Defense Technology Objectives* document (DUSD (S&T), 1999).

Box D-5
Current TARA Technology Areas

- air platforms
- chemical and biological defense
- information systems technology
- ground and sea vehicles
- materials/processes
- biomedical technologies
- sensors, electronics, and battlespace environment
- space platforms
- human systems
- weapons
- nuclear technology

The 1999 Defense Science Board Summer Study Task Force decided to take a strategic approach, focusing not on critical technologies but instead on three specific enablers: strategic agility, force protection, and information for decision superiority (DSB, 1999). The study approach was more parametric than usual and provided guidance that will have long-term value. This study may be a model for future evaluations of the technology base.

TECHNOLOGY TRANSITION

A prevailing theme in studies about the technology base is the question of how to transition the results of S&T projects into a military product. Despite the general desire to get new technology into the hands of the user as soon as possible, how to make the transition from a concept to a product seems to be little understood. In the case of DoD S&T, the budget is key to the process. In other words, improvements in the acquisition process, including the acquisition of S&T, must initially be implemented through the budgetary process.

Figure D-1 depicts the S&T research and budget categories 6.1 through 6.3 and two system development categories: 6.4 (demonstration/validation) and 6.5 (engineering and manufacturing development). To some extent, the figure suggests a linear process by which basic and applied research provide the foundation for the development and demonstration of advanced technologies, which, in turn, enable the development of new systems or system capabilities.

As a depiction of the development of any specific system, however, Figure D-1 is oversimplified. An air or space system application rarely, if ever, depends on only one 6.1 result, and basic research, sometimes done decades earlier, does not necessarily anticipate the defense systems it will enable. The process is not necessarily linear. Difficult problems may force a return from 6.3 to 6.2, and, if necessary, from 6.2 to 6.1. Other projects may jump ahead and skip stages. There may or may not be a distinguishable system-level prototype prior to the decision to enter full-scale system development. System operations may even need to call upon basic research products to solve operational problems. So, although Figure D-1 depicts a model of the relationship between the stages or categories of R&D, the actual transition of research results and technologies into systems can be much more complicated than the figure implies.

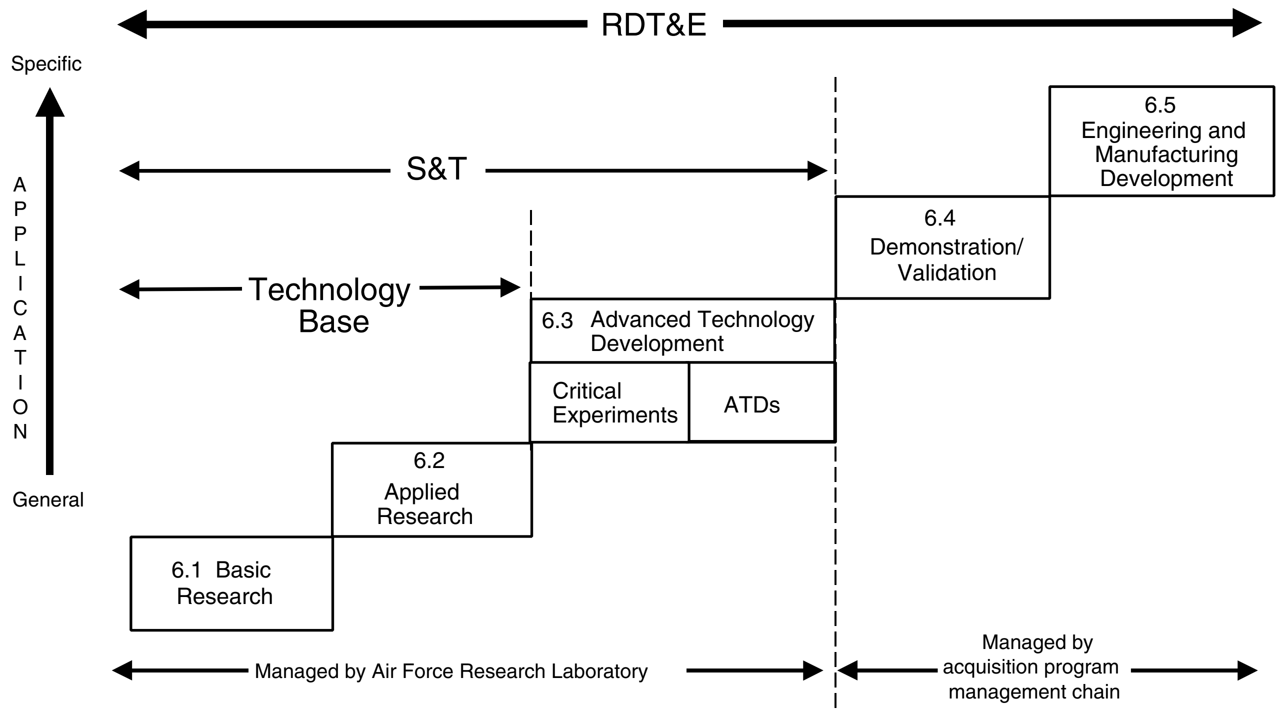

FIGURE D-1 RDT&E budget categories. SOURCE: Neighbor, 1999.

Project Hindsight, the prototyping initiative, and a Defense Science Board study (DSB, 1981) all recognized the value of a close coupling of 6.3, prototypes, and the user. A 1986 Blue Ribbon Commission on Defense Management reinforced the need for more investment in prototypes, particularly by DARPA (CDM, 1986). A Defense Science Board study in 1987 endorsed the use of technology demonstrations, which were called advanced technology transition demonstrations (ATTDs), and recommended that at least half of 6.3A funding should be used to support ATTDs (DSB, 1987). In response to these recommendations, DoD initiated advanced concept technology demonstrations (ACTDs), so-called system-of-systems demonstrations. The planning, intermediate testing, and full field testing of ACTDs were supported by active military personnel. After it was demonstrated, ACTD equipment was left with the troops to use.

In a short time, most of 6.3A was dedicated to ACTDs, and pressure was put on 6.2 to feed 6.3A. There was a trickle-down effect on 6.1, forcing most projects to adopt a short-term focus. The pressure to use commercial off-the-shelf components in developmental and fielded systems accelerated this trend (DSB, 1989). In 1998, DoD abolished the distinction between 6.3A and 6.3B and established 6.3 only. Some 6.3B programs moved into 6.4, demonstration and validation. It seems paradoxical that 6.3A and 6.3B were separated in 1972 in response to the DoD prototype initiative and that the reverse process then occurred in 1998 after the big push for ACTDs in the early 1990s.

PEOPLE AND FACILITIES

Many studies over the years have focused on how DoD is organized, how it manages its people, how it obtains and uses its facilities, and how it conducts the acquisition of weapons and materiel. Some of these studies and consequent changes have had a direct impact on the S&T program. All of them have had at least an indirect impact. The need for higher salaries for personnel in senior positions, adequate staffing of technical positions, technically trained military personnel in RDT&E positions, greater freedom for laboratory directors, and reorganization of the acquisition process were addressed in a report to the President in 1962 (U.S. Bureau of the Budget, 1962). The trend-setting 1981 Defense Science Board study recommended wider adoption of the approach used by the Naval Ocean Systems Center and the Naval Weapons Center (DSB, 1981). A report by the Under Secretary of Defense (Research and Engineering), a detailed overview of DoD laboratories, recommended the upgrading of personnel practices, streamlining of procurement practices, modest increases in the rate of modernization of facilities and equipment, and improvements in DoD/university relationships (USD (R&E), 1982). A report by the White House Science Council's Federal Laboratory Review Panel, which focused on conditions throughout the federal laboratory system, made the following recommendations: the missions of the laboratories must be clarified; laboratories must be held accountable for the quality and productivity of S&T projects; and constraints on laboratories must be relieved with regard to personnel administration (WHSC, 1983). This list of areas for improvement has not changed much over the years.

The Goldwater-Nichols Department of Defense Reorganization Act of 1986 (P.L. 99-433), as well as the President's Blue Ribbon Commission on Defense Management study of 1986, had a dramatic impact on the DoD acquisition process (CDM, 1986). This was only the third major legislative action since World War II involving the organization and mission of the DoD. At the time of the Goldwater-Nichols Act, DoD was experiencing extensive growth, particularly in RDT&E funding. Changes made at the time, such as changes in the acquisition executive and program executive officer chains of command, a dual chain-of-command arrangement, have imposed a substantial burden on the much-downsized system of today.

In 1988, the Office of Technology Assessment conducted a comprehensive study of the technology base over the previous 20 years (OTA, 1988). A DoD task force, working under the Institute for Defense Analyses, supported this study (IDA, 1988). Volume I of that report identified and summarized 22 other studies conducted between 1963 and 1988, especially the Defense Science Board studies of 1981 (an independent review of DoD laboratories) and 1987 (DSB, 1981, 1987). The Office of Technology Assessment report highlighted Congress's three major concerns: the apparently lengthening time of transferring laboratory advances into effective, dependable fielded systems (Box D-6); declining U.S. leadership in vital high-technology industries; and a downward trend in the proportion of the defense budget devoted to the technology base.

The Defense Science Board study of 1998 was a natural follow-on to the 1988 Office of Technology Assessment study. One conclusion of the Defense Science Board study—"DoD's technology base is threatened by an unstable budget and an inability to attract and retain

Box D-6
Transitioning Technology

Many experts believe that the long delays in getting new technology into the field arise not in the technology base, but in the subsequent programs that translate the products of the technology base into new systems. Full-scale development and production times are increasing, and the longer it takes to build a system, the older the technology will be when it finally reaches the field.

SOURCE: Excerpted from OTA, 1988, p. 6.

Box D-7
Selected Results of 1988 OTA Study

Personnel

Observers in government and industry believe that DoD is finding it increasingly difficult to attract and keep the skilled management personnel necessary to the functioning of its technology base programs. This appears to be, at least in part, a result of Civil Service salary structures and Congress' efforts to limit the movement of personnel between industry and DoD.

Stability of S&T Funding

Funding for technology base programs is particularly vulnerable during times of tight budgets. The rapid spend-out rates of technology base programs means that cuts in R&D go farther towards reducing deficits than similar size cuts in procurement programs. And the lack of obvious, tangible outputs from R&D projects makes the value of individual programs difficult to define. Technology base programs are particularly vulnerable to "raiding" to support programs in procurement or the later stages of development. Congress will have to determine what it thinks are proper levels of funding, which may entail acting as an advocate for technology base funding when DoD seeks to reduce it. The optimal level of funding is difficult, if not impossible, to gauge accurately. However, funding that fluctuates widely from year to year is inefficient and can be very disruptive. Congress faces the very difficult decision of whether it should be actively involved in the selection of technology base programs and the determination of specific funding levels, or whether instead it should give DoD managers wide latitude to construct programs within agreed overall funding levels.

SOURCE: Excerpted from OTA, 1988, p. 5.

Box D-8
Funding Level for S&T

No formula was discovered for establishing the optimum level of DoD investment in science and technology, but the most successful industries invest about 15 percent of sales in research and development with about 3.5 percent of sales invested in research (equivalent to DoD S&T program). This would imply that, currently, DoD should invest at least $8 billion in S&T.

SOURCE: Excerpted from DSB, 1998, p. 3.

high-quality scientists and engineers in laboratories and R&D centers"—echoed a conclusion of the Office of Technology Assessment report (Box D-7).

With the fall of the Berlin Wall in 1989 and the subsequent drawdown of military forces and programs, the findings, conclusions, and recommendations of these studies became critical for the DoD S&T base. In 1992, the Defense Conversion Commission described the impact of the drawdown on civilian and military operations (DCC, 1992). The Morrow Defense Science Board Task Force highlighted the challenges for the future of the S&T program in two primary recommendations: the DoD S&T program should be funded at $8 billion dollars a year (Box D-8), and the majority of DoD S&T management and executive technical positions should be staffed by individuals from the private sector under the Intergovernmental Personnel Act (P.L. 91-648) and the reinstated War and Navy Departments-Professional and Scientific Service Act (P.L. 313) (DSB, 1998). A broader approach to RDT&E staffing by DoD was described in a 1999 report on streamlining the entire RDT&E infrastructure (DoD, 1999).

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Appendix E

Air Force Evolutionary Concepts and Associated Information Systems Technologies

The evolutionary concepts of the Air Force are being driven by the demand for information. Indeed, information is becoming the "force multiplier" for the Air Force of the future. The increased emphasis on information and associated evolutionary trends can be found in many current and recent Air Force warfighting concepts; the time-critical targets (TCTs) problem; and modeling, simulation, and collaboration (MS&C). These warfighting concepts include:

1. dynamic aerospace command
2. joint battlespace infosphere
3. information operations
4. integrated aerospace operations
5. expeditionary aerospace force
6. effects-based operations

Very brief descriptions of these concepts, the TCT problem, MS&C, and their associated information systems technology drivers follow (DSTAG, 2000):

1. Dynamic aerospace command (distributed, configurable centers to support variable missions with joint, combined, and coalition forces)
   - capability to build and maintain dynamic air execution order
   - distributed, configurable centers, adaptable to mission, resources, guidance, and command style
   - minimal forward-deployed footprint
   - high-bandwidth, secure communications among units

2. Joint battlespace infosphere (integrated, current, consistent, globally accessible information)
   - core services of publish, subscribe, query, and control
   - development of information-centric client applications
   - exploitation of relevant commercial technologies

3. Information operations (comprehensive capability that incorporates both offensive and defensive information warfare)
   - integration of defensive and offensive information warfare
   - computer and network attack protection, detection, and response
   - secure, survivable networks for sensitive and classified traffic for joint/coalition operations
   - information assurance for embedded systems

4. Integrated aerospace operations (integrated planning and execution of air and space operations)
   - integration of C2 information systems that are fundamental enablers of an integrated aerospace force
   - control and integration of unmanned aerial vehicles and of uninhabited combat air vehicle, air, and space systems
   - aerospace experimentation
   - aerospace systems interoperability
   - global information services with assured availability and quality

5. Expeditionary aerospace force (rapid deployment of forces, small deployed footprint, connectivity to other deployed and in-garrison forces)
   - "reach-around" to distributed centers
   - coalition interoperability
   - information management, access, and distribution
   - in-transit visibility
   - affordable integration of military and commercial satellite communications (SATCOM)
   - antijam and differential Global Positioning System
   - improved chemical and biological detection

6. Effects-based operations (the right effect, on the right target, at the right time)
   - right information + right force + right timing = right effect
   - determining what effects best achieve commander in chief's goals
   - linking and integrating effects into theater-wide scheme of execution
   - directing execution through dynamic, real-time C2
   - creating effects concurrently at all levels of war and throughout the entire battlefield

7. Time-critical targets (dynamic battle control and dynamic targeting)
   - seamless near-real-time operations between sensors, decision makers, shooters, and weapons
   - exploitation of moving-target indicator data to find, fix, track, and engage mobile targets in "hide" mode and in motion
   - "no move" zones versus "no fly" zones
   - information architectures for real-time information into and out of the cockpit
   - robust terminal guidance

8. Modeling, simulation, and collaboration ("train like we fight," realistic mission rehearsal, and simulation-based acquisition)
   - distributed, interactive, C2 simulations and visualizations to enable expeditionary forces to plan and rehearse missions; making the synthetic battlespace part of the operational battlespace
   - courses of action assessment; real-time simulation generation for decision making
   - collaborative enterprises, not only for battlespace support, but also for training, analysis, and acquisition

The above concepts and their drivers indicate the strong dependency of future Air Force capabilities on information systems, and support the need for a rigorous information systems technology science and technology investment strategy.

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Appendix F

Leveraging Commercial Developments in Information Technologies

Commercial investments in nondefense-related information technologies in the United States amount to about $1 trillion per year. The U.S. Department of Defense (DoD) budget for information system technologies (IST) is significantly less, about $1 billion per year. Some of DoD's limited IST investments could be used for leveraging commercial developments, by adopting, adapting, and/or reengineering commercial successes; the remainder could be used to address DoD-unique needs not being addressed by commercial industry. A detailed discussion of some commercial capabilities and shortcomings follows.

The commercial sector has developed a very robust, static-fiber infrastructure (the opposite of the military's large-bandwidth, mobile computing). Military radio-frequency bands and other nonfiber communication methods will not receive commercial investment, although some commercial work is being done on lower-frequency VHF/UHF (e.g., Inmarsat) and higher-frequency capabilities (e.g., Direct TV on aircraft). DoD will have to develop small antennas for high-bandwidth capability, especially for aircraft. Although the commercial sector will address network technology challenges, these networks will be custom-built to connect a limited number of information systems. DoD will have to develop a common network-transport system for many legacy and new information systems (DSTAG, 2000a).

Information assurance (e.g., defensive information warfare, damage assessment/forensics, course-of-action assessment, automated recovery) is of great interest to both the commercial and military sectors. Ensuring the security (trustworthiness) of networked information systems is very difficult. Most commercial software packages are not hardened against attacks, and little is being done to enable detection of potential attacks. Instead, commercial software is modified after an attack. The commercial marketplace is willing to pay for new features but not for security, so the latter has received little attention.

In addition, the commercial sector appears to be doing little to detect "malicious code." The "Melissa" virus attack of 1999, the "I Love You" virus attack of 2000, and the denial-of-service attacks on Yahoo and similar sites in 2000 are all evidence of this weakness. Reliability, verification, and validation are not built into commercial software. Therefore, DoD will have to develop more rigorous protection systems against threats from enemies trained in information warfare. The impact of commercial attacks is measured in loss of dollars and, in some situations, loss of life. Military attacks, however, would result mostly in loss of life.

Commercial protection efforts are focused on components, rather than systems. Commercial protection is difficult to use, configure, and manage, and it does little to assess threat capabilities or forecast intrusions. Because most commercial protection is focused on commercial software, which is much less complex in design than defense software, commercial protection has not addressed the problem of detecting new and novel attacks. Commercial research and development are not focused on automated capabilities to assess damage, survive, or recover from attacks. Current forensic capabilities are limited to human experts and individual computers, which are not easily scalable to the network level (DSTAG, 2000b; NRC, 1999).

Many other DoD requirements cannot be satisfied by commercial technologies. DoD requires long-term software support, which is not common in the commercial sector. DoD is far ahead of the commercial sector in some technology areas, such as non-von Neumann architectures. Commercial industry is beginning to expand beyond low-cost, single-processor systems; DoD has had a long-standing need for scalable systems that increasingly mandate software portability standards. In the area of autonomous software, commercial activities have been focused on software agents primarily for the retrieval of noncritical information. Commercial software for robotic systems relies on synchronous remote-control and basic-control laws, whereas DoD requires real-time, dynamic information systems that rely on complex agents and models that can adapt and learn, and even reason, about system state.

In the area of intelligent information management and interaction, the commercial sector is making advances in E-commerce, and search engines are beginning to focus on foreign keywords and nontextual information. However, DoD needs knowledge-based authoring tools for nonartificial intelligence experts that can support the retrieval and analysis of information derived from multiple languages and presentation modes (e.g., text, graphics, images, and videos). Finally, in advanced software technology, DoD will have to leverage the very massive commercial capability to meet DoD-unique needs. For example, DoD requires dynamic assembly of software for system adaptability, dependability, and assurance; model-based integration of embedded software; and process models embedded in system descriptions (DSTAG, 2000c).

For decision making, some commercial work has been done on information fusion (e.g., in medicine, law enforcement, and the airline industry), cognitive understanding for decision making, and integrated assessment, planning, and execution. However, DoD requires a very robust fusion architecture to support very complex decision-support systems. DoD's needs include unique algorithms, georegistration of data, and object-oriented fusion databases. In the area of integrated assessment, planning, and execution, DoD requires highly automated plan-development tools that provide dynamic, optimal replanning in a rapidly changing environment. DoD also requires flexible, scalable, command and control architectures. Commercial technology, which is focused on in-system stability (e.g., manufacturing, traffic flow), bounded, well-defined environments (e.g., airline scheduling), and some process-based enterprise management (e.g., integrated workflow), will not satisfy these needs. Finally, the commercial sector is addressing perceptual, cognitive, and decision-making skills; consumer profiling; knowledge-management tools; Web-based human-computer interfaces; collaboration technologies; and information visualization. DoD will be able to leverage these capabilities to develop tools for monitoring human performance for managing workloads, developing more immersive human-computer interfaces (e.g., three-dimensional graphics, virtual and augmented reality, mobile/wearable devices, and speech and gesture recognition devices), and visualizing complex relationships (especially across space, time, and functional domains) (DSTAG, 2000d).

Few commercial attempts are being made to develop modeling and simulation technologies to support the interoperability and reuse of applications for the simulation-based design, analysis (i.e., system performance, tactical/doctrinal use, etc.), and acquisition of air and space systems (including information systems). The commercial sector has promoted the use of simulation-based design in the aviation and automotive industries and human-factors engineering. In addition, the entertainment industry has developed Web-based gaming and visually appealing graphics (especially for movies). However, DoD requires realistic, distributed, collaborative models and simulations that

- are representative of physics-based and behavior-based reality that can be verified, validated, and accredited by warfighters
- are real time (especially with graphics generation) and low latency
- represent human and organizational behavior
- use open-system linkages of disparate databases, models, and simulations
- have a capability for human immersion
- provide linkages to live C4ISR systems
- have reduced development/set-up costs.

Modeling and simulation in the entertainment industry have been focused on nonphysics-based fantasy worlds. Commercial simulations are market driven and often go to market when they are only 60 to 80 percent complete. There are only a few distributed simulations (some on the Internet), and those are not time sensitive. Graphics are often rendered (usually by artists), and real-time graphics are not at the fidelity/resolution levels required by the military. Human behavior is primarily based on stories and characters. Finally, linkages to other systems are usually custom set-ups using proprietary tools and systems.

Human immersion is a commercial art that should be leveraged by DoD. Commercial simulation-based design and development efforts should be leveraged for DoD's simulation-based acquisition endeavors. DoD should also be interested in commercial efforts to reduce development, set-up, and authoring costs. Basically, DoD currently has the lead in modeling and simulation research and development (DSTAG, 2000e).

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