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Defense Science and Technology: Foundation of the Future
Anita K. Jones

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Defense Science and Technology: Foundation of the Future

Anita K. Jones

Since June 1993, Anita K. Jones has been director of Defense Research and Engineering, responsible for managing the Defense Department's (DOD's) science and technology program and overseeing DOD laboratories, university research initiatives, and the Defense Advanced Research Projects Agency. She is the principal staff assistant and advisor to the Under Secretary of Defense for Acquisition and Technology for defense-related scientific and technical matters, basic and applied research, and advanced technology development. In this capacity, she develops and approves strategies and supporting plans to exploit and advance technologies that meet war-fighting needs and maintain a military advantage for U.S. forces throughout the battlespace. Dr. Jones has served on several government advisory boards and scientific panels, such as the Defense Science Board and the Air Force Scientific Advisory Board, and on boards and panels for the National Aeronautics and Space Administration, National Research Council, and National Science Foundation. Her private sector experience includes serving as professor and chair of the Department of Computer Science at the University of Virginia, and vice president and founder of Tartan Laboratories. She has published more than 35 technical articles and two books in the area of computer software and systems. Dr. Jones received her A.B. from Rice University in mathematics, an M.A. in literature from the University of Texas, and a Ph.D. in computer science from Carnegie Mellon University.

Oettinger: You have all had a look at her biography, so I will not waste her time or yours with more elaborate introductions, and I will turn the floor over to Dr. Anita Jones, director of Defense Research and Engineering. Welcome.

Jones: Thank you very much. I'm glad to be here. I actually have decided that I will leave the Pentagon and I am going back to the University of Virginia, where I was before I went to the Pentagon.[1] So I regard this as a practice run at getting back into the academic scheme of things.

I'd like to talk to you about the Department of Defense's support of the science and technology (S&T) of the United States, and then we can range into any area you'd like to discuss. I'd like to present a sequence of observations. In a number of cases, I will back up those observations with data. I won't describe in egregious detail what's on the slides, but they will often serve to illustrate a particular point.

I'll start with some real basics: what kind of science and technology? I assume most of you aren't scientists or engineers, so I'll give you some examples of specific efforts along the way.

Why does the federal government invest in S&T? And why does DOD invest in it? The rationale from the federal government's point of view is that there are national goals that industry can't meet, such as national security, and that it's appropriate for the federal government to invest for these purposes (figure 1). This is not a complete list, but health, the economy, national defense, education, and the environment are among these national goals.

In this chart (figure 2), the federal government's investment is contrasted with that of industry. The two invest in complementary ways. Basically, the government makes the longer-term, higher-risk investments where there is no immediate payoff—or even a clearly foreseeable application. In some cases, the government invests to (hopefully) find a breakthrough.

[1] Editor's note: Dr. Jones retired as DDR&E in May 1997 and has resumed her professorship at the University of Virginia.

- **Federal government invests to meet national goals, e.g.:**
  - National security and global stability
  - Economic strength
  - Health of citizenry
  - Education
- **Federal S&T invests for continued future success:**
  - Longer-term, higher-risk and breakthrough technologies
  - Generally no short-term commercial market or payback
  - May result in creation of new markets
  - Educate next generation of scientists and engineers

Figure 1
Why a Federal Investment in S&T?

The government doesn't look for commercial payback in the S&T program. It doesn't make many arrangements with business to pay it back if they're successful based on the results of the government's investment. It's investing against national goals.

As a byproduct, it educates the next generation, particularly the next generation of graduate scientists and engineers. How did this come about? The science and engineering community played a crucial role in World War II. Coming out of the war, a man named Vannevar Bush wrote a report called "Science: The Endless Frontier."[2] He proposed to Roosevelt, and later Truman, that the federal government invest in science and engineering. For example, radar and the use of radar, which was absolutely crucial in World War II, came out of the science community without much earlier investment by the federal government. He reasoned that the government should assure itself of such benefits in the future.

I'm going to go back and forth between the federal investment and the DOD component of that investment (figure 3). One of the marvelous things about the DOD is that it knows exactly what its mission is. If you know exactly what your mission is, you understand what your objectives are. They may change over time. For instance, the department is grappling with "new threats and new priorities." Instead of the threat that DOD had a decade and a half ago of a massive war of attrition with the Soviet Union, today's concern is with terrorists and with regional situations much smaller than all-out war with a superpower. So while the mission remains dear, aspects of it change, and that affects the technology program.

The technology program in the DOD only exists to serve the armed forces. That's the right way to think about it. The only reason I have a job—my job is oversight of the DOD S&T program—is to serve the military, and to develop what they may need in the future.

I want to return to federal investment, and to define two terms. The term "R&D" means research and development. On the left side of this chart (figure 2) is the total R&D investment by the nation, as measured about three years ago. Industry invests about $124 billion a year, and it changes slowly, up or down. Government invests about $75 billion, and about half of that comes from the DOD budget.

The term "technology base," means basic and applied research. When described in terms of budget accounts, basic research is called 6.1, and applied research is called 6.2. You're going to see those terms in my charts because most of the time when I'm briefing, it is to people who find those terms more convenient to use than the words.

The important message of this slide is that the long-term technology base investment is very small in industry. The ratio of federal-to-industry investment is about a factor of 5:1. The technology base is a component of R&D. Recall that R&D is both the long-term investment, which is the

[2] U.S. Office of Scientific Research and Development, "Science: The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research," by Vannevar Bush. Washington, DC: U.S. Government Printing Office, 1945; also New York: Arno Press, 1980.

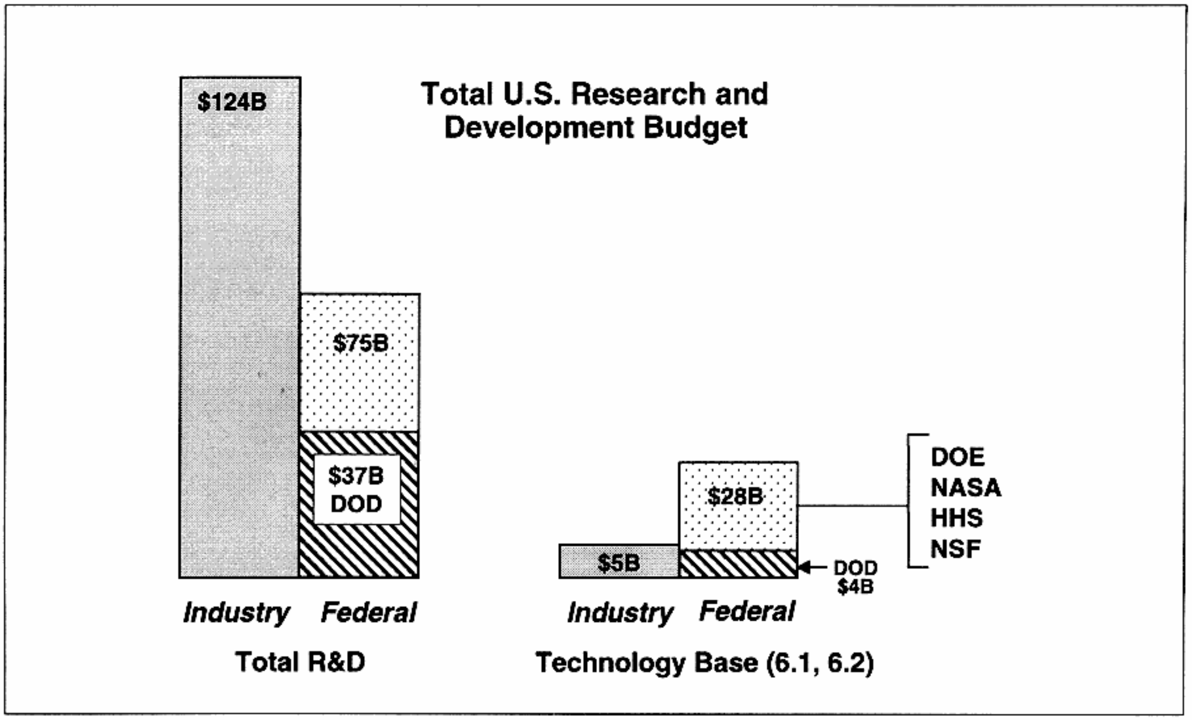


Figure 2
Industry Invests for the Short Term – Mostly

technology base plus the short-term, near-term investment, such as building a new microelectronics fabrication plant every three years, or designing and constructing the next-generation automobile. The bulk of R&D is very near-term manufacturing, assembly, and fabrication capabilities and next-generation products. This balance of government investment in the long-term technology base, and industry investment in the near-term product capability represents a partnership between the federal government and industry.

Before we leave this subject, I'm going to break down the DOD budget. As you can see (figure 4), $4 billion out of this $36 billion is basic and applied research. The majority of the rest of it is the DOD counterpart to industry's next-generation automobile: it's the next-generation attack submarine; it's the next-generation aircraft.

Let me remind you of a trend in this country where large corporations that heretofore had fielded large, long-term research facilities or laboratories are reducing the size of them 20 to 35 percent on the average (figure 5). These are very large, mainline, blue chip kinds of companies.

- **In support of national goals, Defense invests in S&T to maintain overwhelming qualitative military advantage on the battlefield:**
  - Based on threats and priorities
  - Basis for readiness, acquisition and modernization
  - Need to invest broadly in order to integrate many new revolutionary and evolutionary components and technologies into leading edge systems
  - Provide options to future warfighters and planners
  - Ensure against future technological surprise
  - Invest where there is military need and commercial capability does not exist

Figure 3
Defense Investment in S&T?

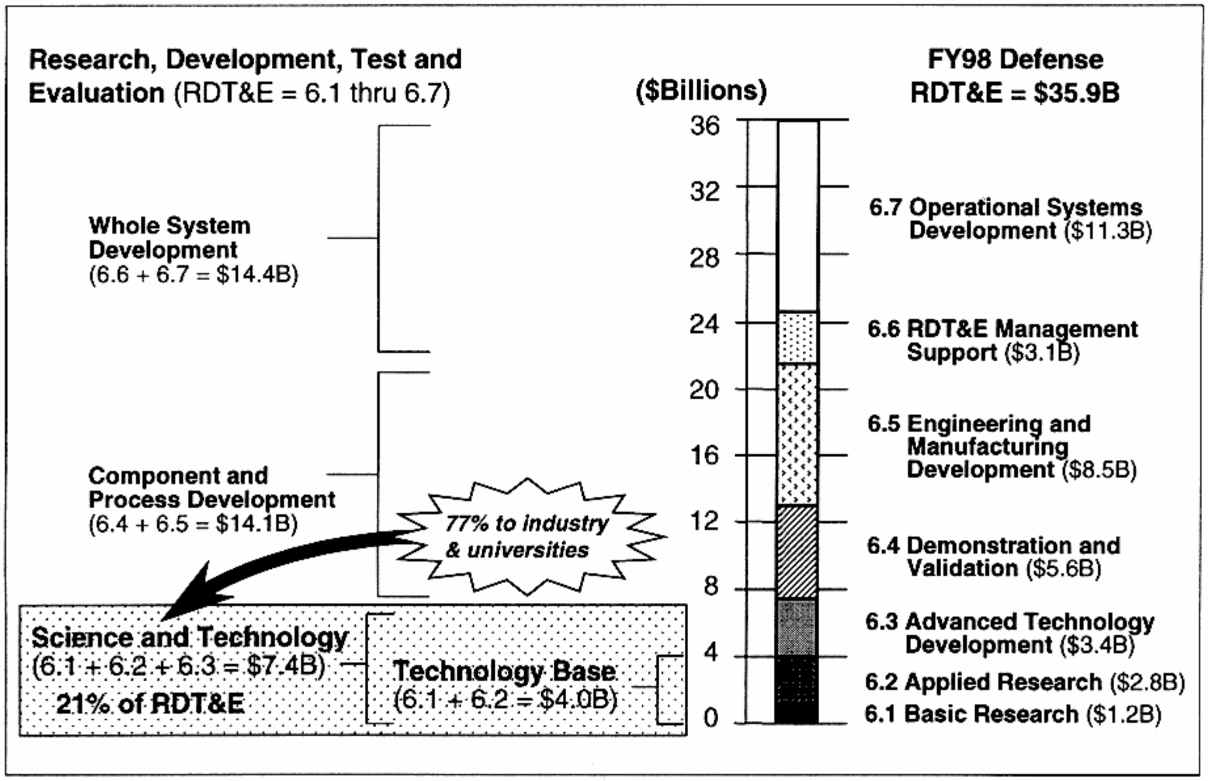
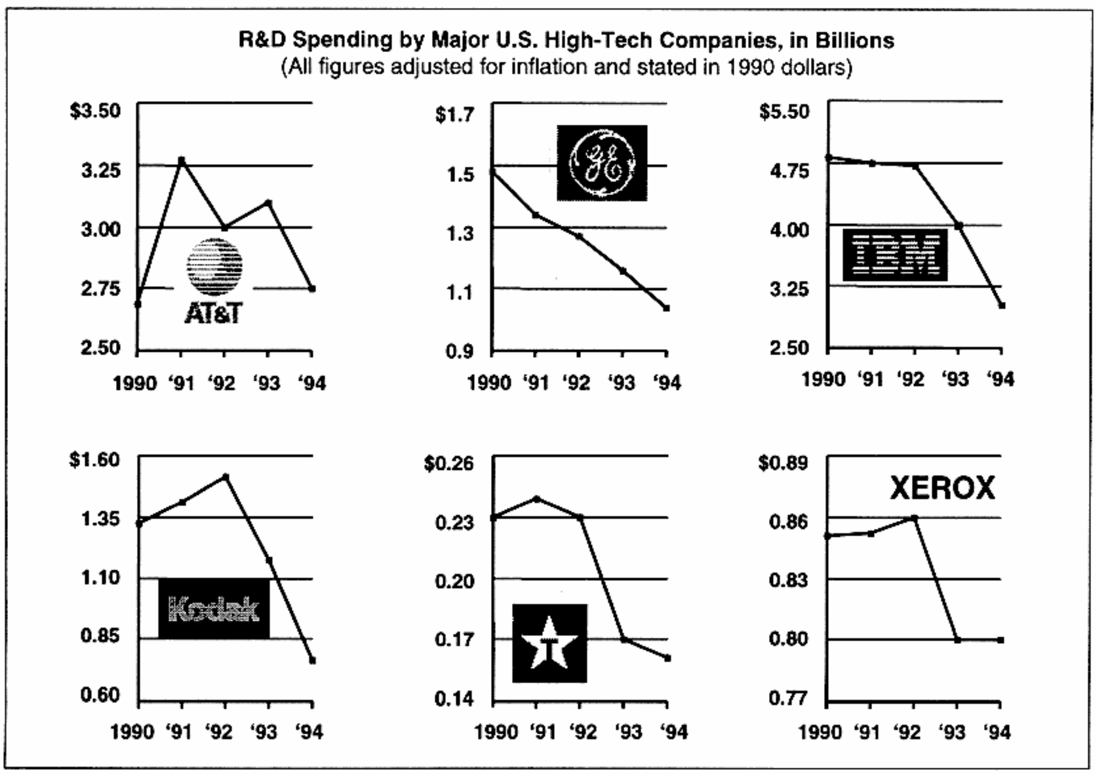


Figure 4
Science and Technology–The Foundation of Research, Development, Test and Evaluation (RDT&E)



Source: *The Wall Street Journal*, May 22, 1995, p. B-1 (Schonfeld & Associates).

Figure 5
Industrial R&D is Down and Focused on Short-Term Payback

This means that the industrial investment in R&D is becoming even more short term.

Let's look at government R&D to see how the different agencies complement each other (figure 6). The total federal budget in R&D is about $75 billion. This chart shows the amount in each of the agencies. For science and engineering, five agencies are the main players, so you're going to see them represented on the next several slides. At the R&D level, both short-term, next-generation products, and S&T, DOD is the source of half of the federal investment. The other big players in R&D are Health and Human Services (HHS), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and the National Science Foundation (NSF).

Oettinger: Is HHS mostly NIH (National Institutes of Health)?

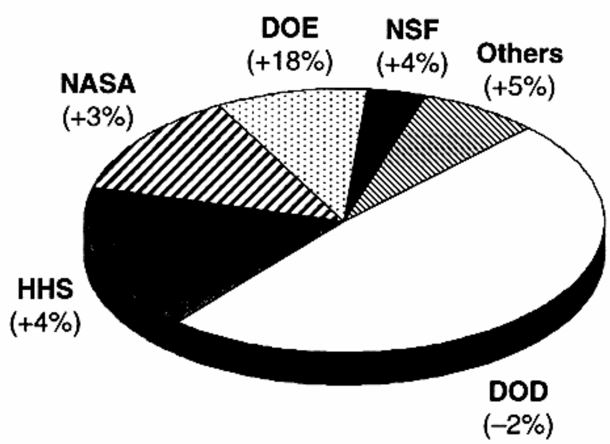
Jones: Yes.

I told you there are these things called the "6" accounts. The technology base, the $4 billion a year that I told you about earlier, is part of the S&T program, which is $7+ billion (figure 4). By the way, most of the S&T program is executed outside DOD in the universities and in industry. If you want to look at the health of the technology-based portions of our country, you don't look at the broad category of R&D. You consider the S&T piece, which is half of that $75 billion. For the remainder of my talk, I will focus on the S&T portion of R&D.

One can use the requested budget to take the pulse of the nation's federal investment in S&T—the thing that will produce fruit for a decade or more (figure 7). Again, you see the same players. Now DOD is a minority player. It provides 16 percent of the total federal S&T investment, or about $7 billion. HHS (or NIH) accounts for about a third of the federal investment. NASA, DOE, NSF, and other key agencies account for the rest.

S&T is a small portion of the DOD budget. This chart (figure 8) starts in 1978 and graphs S&T in the context of the full procurement budget out past the end of the century. The vertical line marks the end of

1998 Total Federal R&D: $75.5B (+2%)



DOD: Defense ($36.8B)
HHS: Health ($13.5B)
NASA: Space ($9.6B)
DOE: Energy ($7.3B)*
NSF: General Science ($2.6B)
All Others: ($5.7B)
[R&D = 4.4% of federal budget]

*Includes +$1B to fully fund new DOE facilities

Source: Federal Funds for R&D, NSF Draft Report on FY98 Budget, Table 4-1.

Figure 6

Fiscal Year 1998 Proposed Federal Research and Development by Activity (6.1 through 6.7 Funding) with Percent Change FY97 to FY98 (Constant 1998 Dollars)

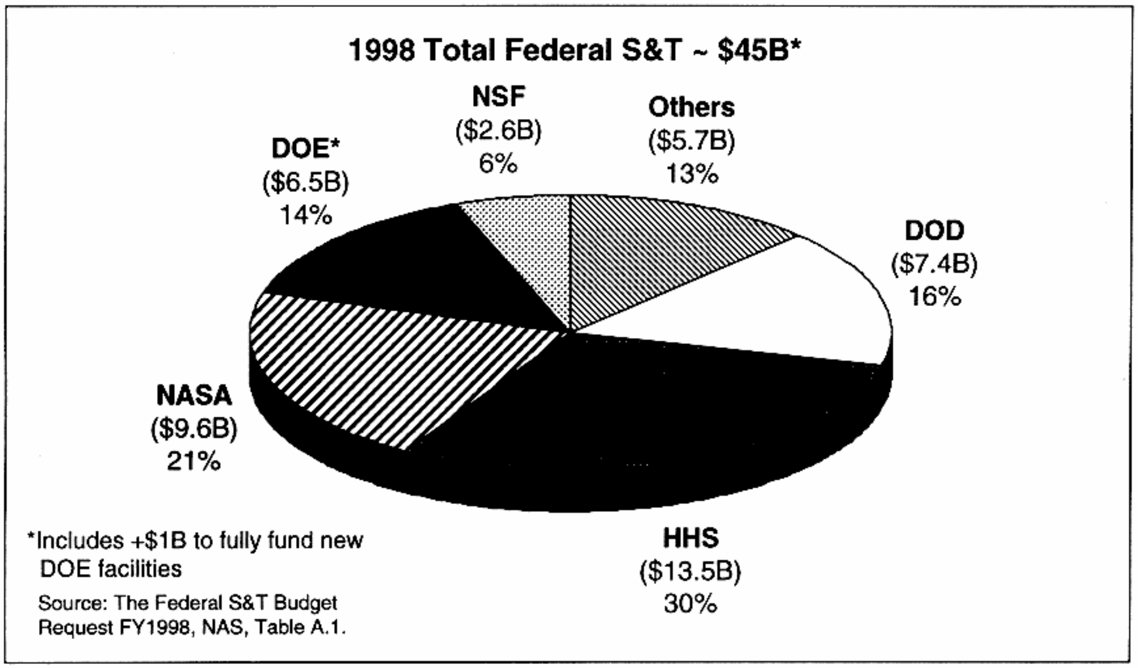


Figure 7
Fiscal Year 1998 Requested Federal Science and Technology by Activity
(6.1 + 6.2 + 6.3 Constant FY98 funding)

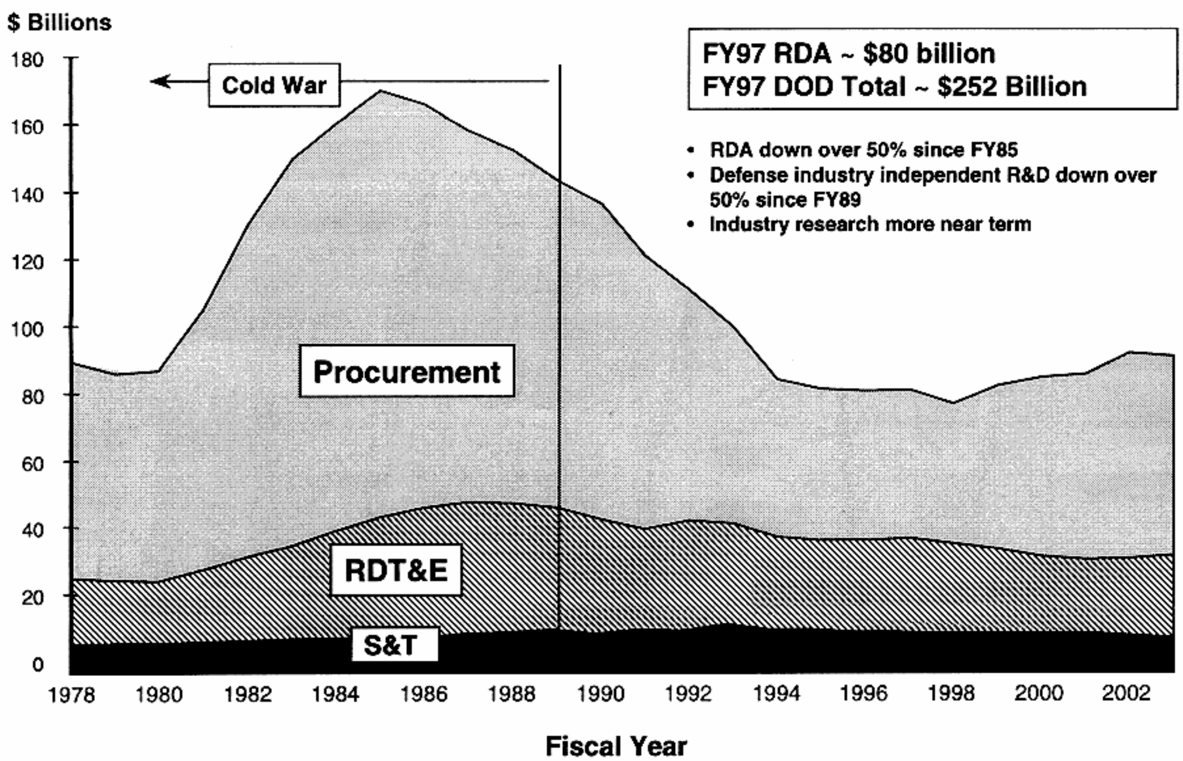


Figure 8
Research, Development, and Acquisition (RDA): Constant FY97 Dollars

the Cold War. The DOD has taken a 40 percent reduction in its budget over the last decade. DOD continues to be healthy, and the forces continue to be ready to go wherever the President sends them. That's a pretty amazing feat! If you think about reducing your budget by 40 percent, it is a shocking event in the life of any organization. The dramatic budget reductions have been in procurement, personnel, and operations. S&T is so small in this chart that its fluctuation is not evident. Budget numbers beyond FY98 are estimates, of course.

This slide shows the technology base budget (figure 9) of the $45 billion in S&T funded by the federal government. The DOD budget is decreasing, and NSF and HHS budgets are increasing.

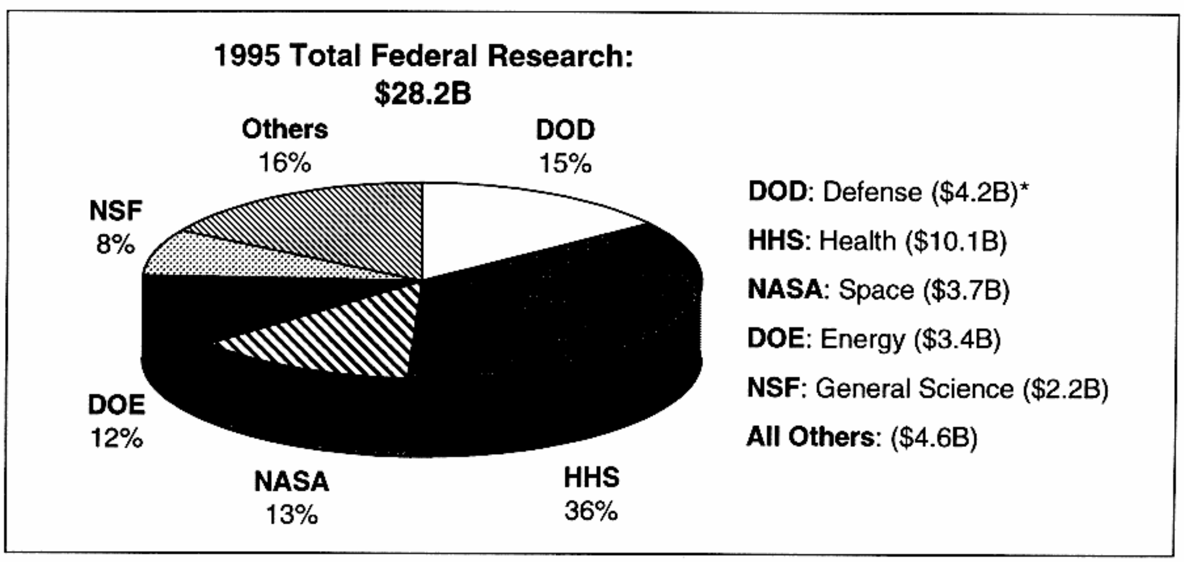
Basic research constitutes $14 billion of the $45 billion for S&T (figure 10). This is the part of the budget that funds the universities. They perform 60 percent of the 6.1 work for DOD; I don't know the percentage for other agencies. DOD is a small player. HHS is very large; it's almost half. NASA, DOE, and NSF are the main investors in science and engineering. DOD is half the size of any one of them.

What's been happening recently in terms of budget (figure 11)? I regret to tell you that DOD is decreasing. HHS is dramatically up. NASA and DOE are down, and NSF is up 5 percent. This chart depicts "constant dollars": it indicates comparative buying power across time. So, DOD is down 18 percent in buying power, and some of that is because of inflation.

Now I want to turn to why the DOD invests. If you consider the DOD S&T program across the past three-plus decades (figure 12), measured in constant dollars (i.e., buying power), the technology base (basic and applied research) has been more or less sustained. A later chart will show that it is being reduced.

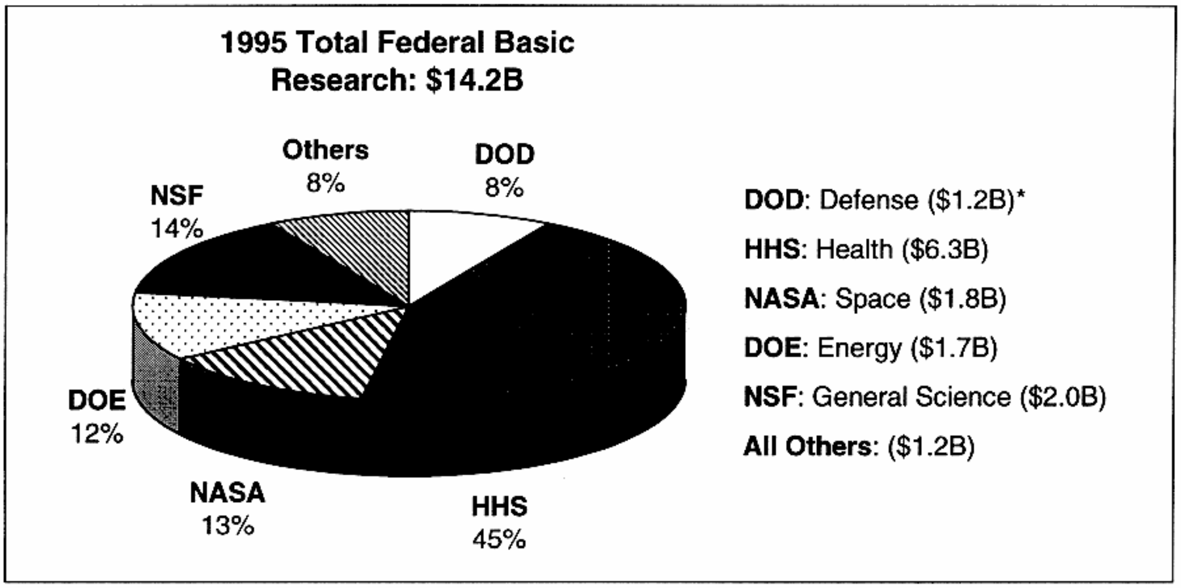
Back in the late 1970s, the advanced technology development account (6.3) was started. A great deal of that portion of the budget went into an agency called the Defense Advanced Research Projects Agency (DARPA), which works for me. Ignore the jagged behavior of this upper line. To the first order, these bumps represent earmarks—basically, where Congress was increasing budgets for specific programs or reducing them.

Another point made on this slide is that it takes decades to develop the kind of technologies that matter to the armed forces. I'm going to show you some examples later. As a rule of thumb, a major advance in military capability that is enabled by technology requires a decade of research, followed by a decade of technology



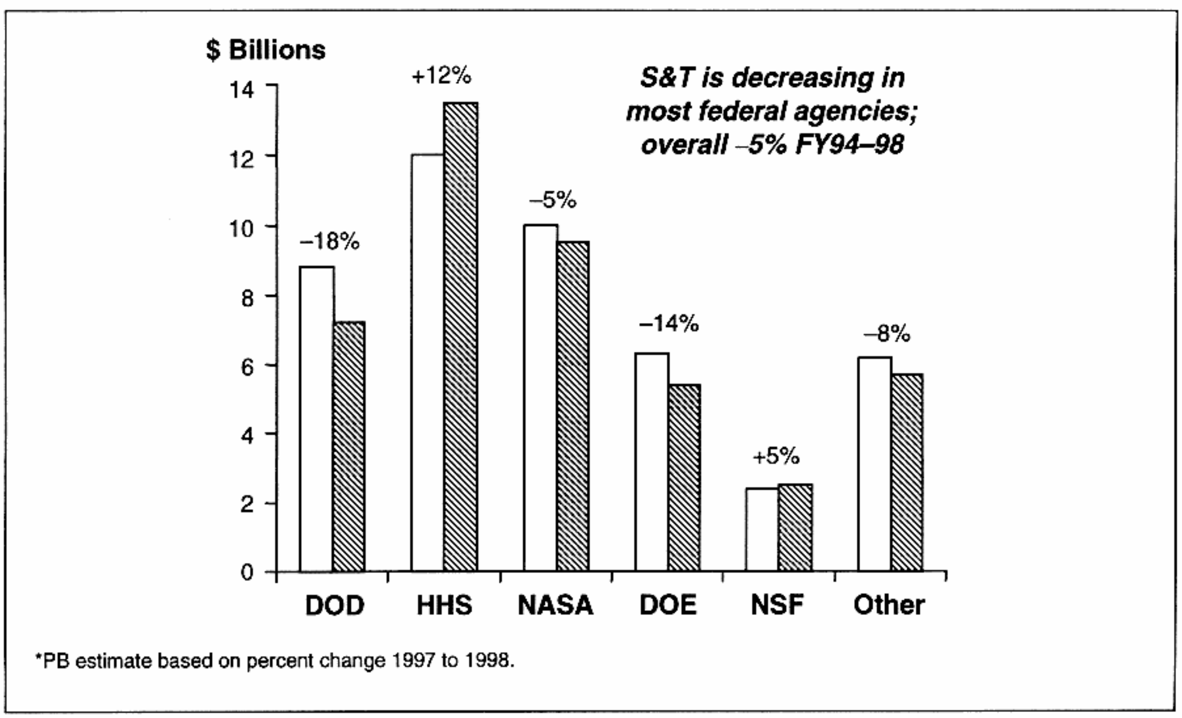
Source: Federal Funds for R&D NSF Report #95-334 *(exception: DOD).

Figure 9
1995 Total Federal Research by Activity—(6.1 + 6.2 Funding)



Source: Federal Funds for R&D NSF Report #95-334 *(exception: DOD).

Figure 10
1995 Federal Basic Research—(6.1 Funding)



Source: The Federal S&T Budget FY1997, NAS, Table A.1.

Figure 11
Federal S&T Investment by Activity* (FY94–98—Constant FY97 Dollars)

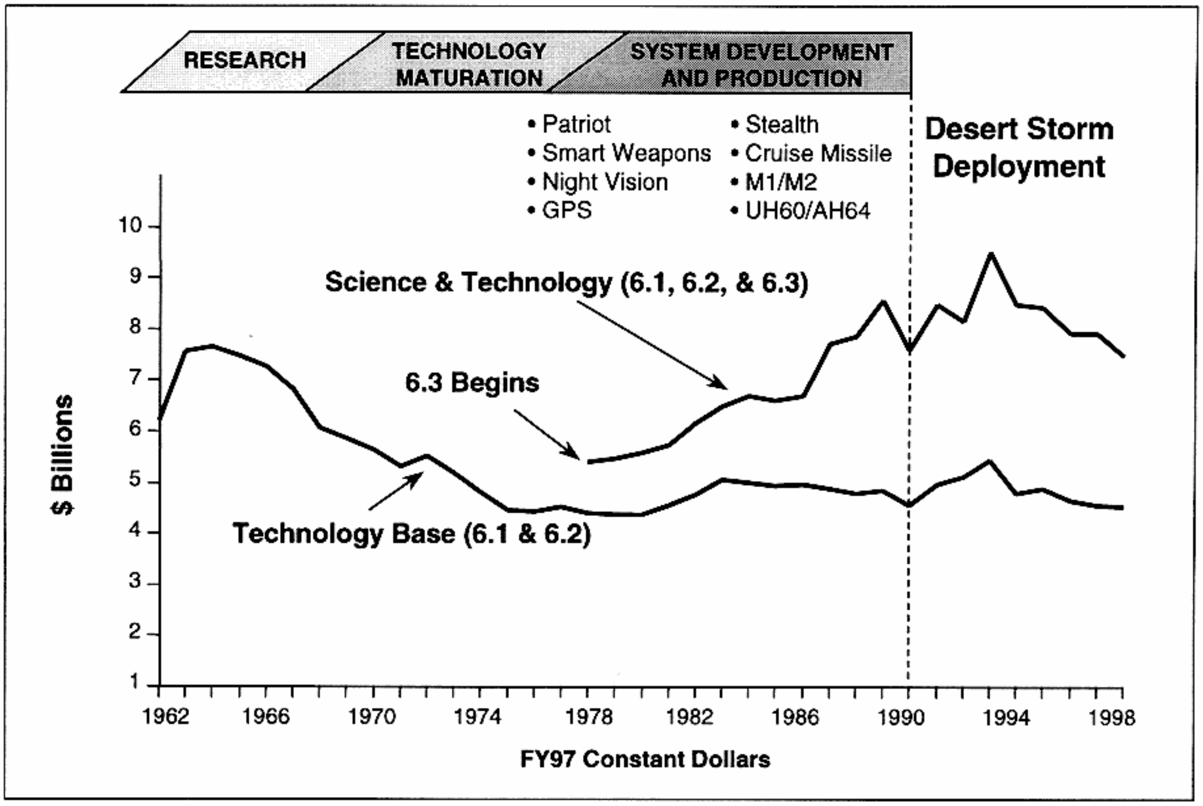


Figure 12
Defense Science and Technology

maturation, followed by a decade to build a system.

Stealth, as used in Desert Storm with such great skill, provides one example (figure 13). Relevant research began in the 1960s. To put it into the hands of the war-fighter required the advancement of many different technologies. There was not just one magic breakthrough. Technologies included radar-absorbing materials, test ranges to determine the aircraft's signature, and the mathematical design tools. If you've ever seen the F-117, you might have noticed that its surface is planar. The simplistic reason is that DOD did not have the mathematical codes to build a continuous surface design. Those tools exist today, and the B-2 has a continuous surface. Further needed technologies included laser designators to designate the targets and suitable wind tunnels.

In the second generation of development, a prototype called "Have Blue" was built. That took more years.

I want to emphasize again that technology that yields a real advancement in military capability typically relies on advances, even breakthroughs, in multiple areas. The Army is buying the Comanche helicopter (figure 14). The slides list areas of advancement that enabled the Comanche design and performance characteristics.

- **Digital fly-by-wire controls**
- **Radar cross section mathematical tools**
- **Radar cross section test ranges**
- **Computational fluid dynamics codes and wind tunnels for inlets and airframe**
- **Forward-looking infrared**
- **Target tracker**
- **Laser designator**

Have Blue Tech Demo ⇨ ***F-117 Stealth Fighter***

Figure 13
Stealth

DOD has a very proud legacy of major changes in the technology of the nation, not just the military (figure 15). Things often start as military applications and go into commercial applications. Most technology is not military unique. Almost all of it has applications in broader areas. The Internet, as you know it today, started in the late 1960s as a packet-switched radio networking experiment that DARPA (then ARPA) sponsored. Almost all early computers were built by the military; they computed ballistics tables.

Oettinger: That goes back to Mark I and the ENIAC.

Jones: Yes, that's true. Night vision was developed by the military. It has become less expensive and is now in use for law enforcement.

Turbine engines provide another good example. All the commercial turbine aircraft engines have ancestors that were fighter aircraft turbine engines. Technology development, paid for by a combination of DOD and industry, is performed in the context of fighter aircraft high-performance engines. Over time, the advancements migrate into commercial engines, which are often built by the same companies that build military engines.

Now, let me look more toward the future. The military is grappling with new threats (figure 16). From my point of view, when the Cold War ended, the technology competition heated up. Yes, there is not a threat of a war of attrition, but now the technology that we develop in the United States for military purposes has to go against the best of the technologies that a potential adversary can buy in the global arms market. That means adversaries buy Italian mines (the Italians build very good mines) and they buy French missiles. They buy Russian whatever. Before, we were wholly focused on the Russians. They were the technology competitors, because they were the dominant military competitor. Today, the technology competition, which is the way I look at the world, is with the best that arms industries provide across the globe, not simply one nation's technology.

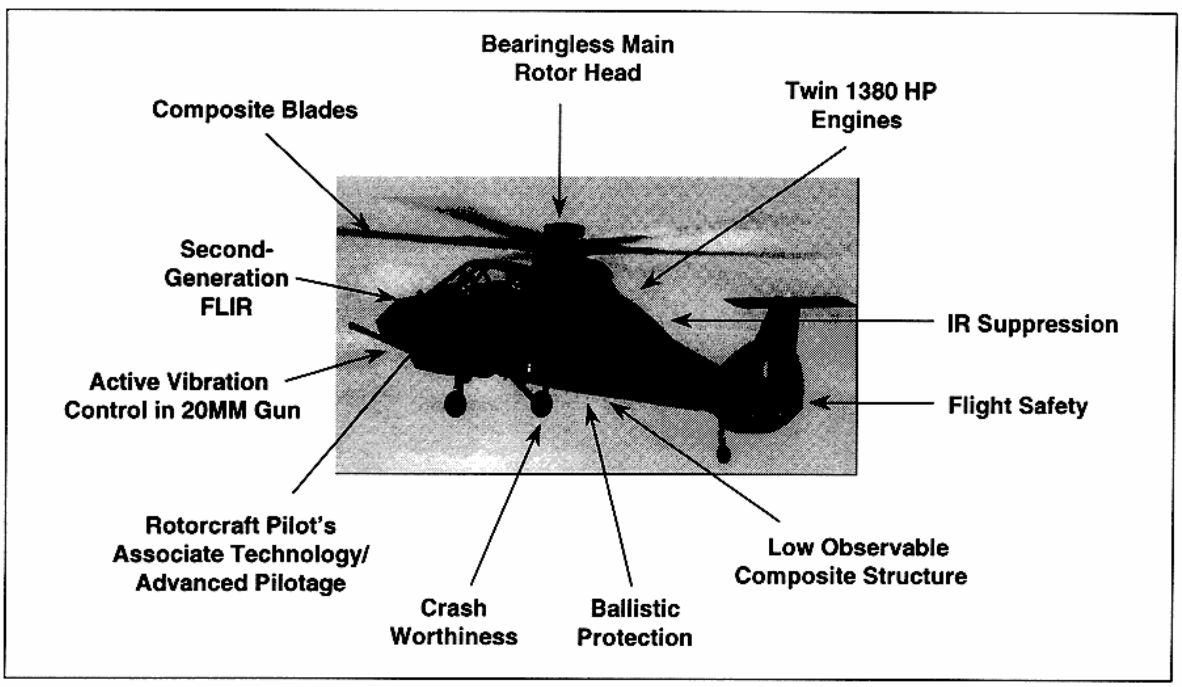


Figure 14
S&T Contributions to Comanche

ARPANET	→ Internet
ENIAC	→ computer
GPS	→ Desert Storm, navigation, mapping, SAR
SIMNET	→ distributed interactive simulation
Aircraft Propulsion	→ F-117, UH-60, AH-64, B-777
Night Vision	→ "Own the Night"
Infectious Diseases	→ HIV screening, Hanta virus
Composites	→ Stealth, F-22, JSF, V-22, Comanche, civil transport, body armor

Research is the foundation of acquisition and modernization.

Figure 15

DOD Research Legacy—Examples

- **Today's competitor is the global arms market.**
- **Increased transnational threats/ scenarios from:**
  - Ethnic rivalries
  - Genocide
  - Drug trafficking
  - Religious extremism
  - Rogue regimes
  - Terrorist cells
  - Proliferation of arms
  - Global information infrastructure

Figure 16

Post Cold War: New Threats of a New Era

New threats bring new technology emphases. The threat of biological agents looms larger than it did in the past. DOD is in the process of building up a program for detecting and counteracting biological agents, after the agent gets into the human system. One exciting approach is to use the body's disposal system (it has a very efficient disposal system in the kidneys and the circulatory systems). The challenge is: Can the biological agent be forced to be flushed out of the system? There is some experimental evidence that appears to say "yes."

Student: I don't mean to interrupt the flow of the discussion. You made a number of fascinating comments already, but one of the more recent ones is this idea of the global competition in arms development. You mentioned that within the context of its being a threat or challenge that requires additional enhancements in the American technology development area. I'm wondering if, in fact, one could look at it conversely. At a time in which we no longer have a tight bipolar system, but much more of an integrated global system, could this global technology development and global arms market production be seen as sort of an asset from which one could draw either technology or products relatively cheaply? Specifically, instead of following the standard formula of the United States developing technology and then developing the actual weapon system and paying for it through U.S. funds, does it seem viable, given the tremendous changes that we have in the international system, to have the Pentagon in fact procure the needed technology and weapon systems, buying from the Italians or the Russians or the Germans or the Japanese or whoever else is developing it, instead of feeling like we have to develop a parallel technology and a better technology as competitors?

Jones: The answer is yes, but with a slight twist. DOD continues to develop technology. Comparatively better technology can yield comparatively better military technology. However, there is good technology elsewhere. In selected situations, DOD already buys foreign-made materiel. There is an increasing number of partnerships with allies to build prototypes and to co-produce systems. For example, we have a cooperative project with the Japanese in the aircraft area. We have a cooperative program with the Brits, French, and Germans in different combinations on several different kinds of ground and surveillance systems. Such arrangements are carefully thought out because funds spent abroad are not spent with U.S. industry. Indigenous industrial capability remains important.

Student: Understood, but there still seems to be built into the procurement and technology development systems this sort of concept that arose in another era, which is: "We must be the best; we must have state-of-the-art technology. If anyone's going to develop a new technology, it must be within the controls of the U.S. military." It's very understandable from the bipolar world view. What I'm asking, or trying to get to, is that if the Swedes have developed a new radar technology that we never thought about, instead of seeing the world as a sort of threat structure in that way and saying, "We've got to rush and spend $100 million on this," we say, "Hey, great! We can buy this from them, instead of having to do all this sort of development."

Jones: DOD does act just as you describe. The best aircraft ejection seat in the world, in my estimation, is the K-36. It comes from the Russians. We're just grappling with how we buy that. In my view, we definitely should just go buy it, and not develop our own.

Student: Being on the pointy end of the spear myself, it would seem to me that it would be very natural, although we obviously can go out and acquire systems from other countries, that it then becomes incumbent upon our R&D and S&T to be able to counter those systems, or some of those systems.

Jones: Absolutely.

Student: For self-protection purposes, if for nothing else, we need to know who's making the best and what can beat it.

Jones: Yes. DOD has a foreign materiel exploitation program. When something good is found, DOD will sometimes just go buy it. For example, the Navy is buying from the Australians the cradle in which you put a SEAL (Navy Sea-Air-Land unit) boat. These are small, very high-powered boats with which the SEALs go into a (typically) denied area. This cradle goes around the boat. It can then be dropped from a cargo plane. The U.S. does not have a comparable cradle, so the Navy will buy it.

Student: You said earlier that the DOD knows exactly what its mission is. What is the DOD's mission, exactly?

Jones: To defend and protect the United States of America.

Student: Your point about the world changing at the end of the Cold War and its effect on procurement then leads to the next question: What does it now take to protect and defend? If that's changed, then should the budget reflect it? In other words, do we need to continue to develop main battle tanks every 20 years, or should that money go into countermine warfare, which is a more likely threat on the low-intensity end of the spectrum?

Jones: I believe that you are correct. The nation has decided that it can invest less in national security than in the past. So the DOD budget is reduced by 40 percent (figure 8). I happen to think that's just right. What is developed and what is bought should be guided by current and future demands on the military as illustrated here (figure 17). For example, the Marines are saying, "We need some nonlethal weapons, because we're being put in situations where that's what we should have." The technology program should develop those, or should already have developed them. Or they should be bought from wherever they are available.

Countering terrorism is a real challenge. The technology investment in demining has increased. I highlight this area because I believe that it is idea limited, not money limited. In fact, over the last two years, I've awarded three contracts to universities asking them for fundamentally new ideas.

What you are asking for requires a culture change. The Army may not want to give up a new main battle tank every 20 years. Serious debate is under way. There is such an evaluation in progress now and

- **Broader mission requirements with less resources:**
  - Counterproliferation of weapons of mass destruction
  - Peacekeeping and operations other than war
  - Small unit operations and military operations in urban terrain
  - Counterterrorism
  - Protection of critical infrastructure
  - Countermine and humanitarian demining
  - Nonlethal weapons
  - Biological agent detection/ neutralization
  - Environment, force and population protection

Increased pressure on Defense S&T program to maintain technology advantage with reduced budget

Figure 17
Post Cold War: New Demands on Defense

this group might like to talk about it. It is called the Quadrennial Defense Review (QDR), and will be turned in to the Secretary of Defense in May. With the Revolution in Military Affairs, which I expect you all talked about, the Secretary, or the leadership, is basically going to have to decide between the current investment plans and a new approach. Do you stick with the long-standing investment plans, where these large platforms, like a battle tank, take 17 years? Or, in fact, do you want to say, "No. We're in a revolution. I want to emphasize information technologies, and I want to change my procurement investment portfolio dramatically" (figure 18).

The technology program has already shifted (figure 19). There is increased investment in chemical and biological research, less in materials, less in electronics, and much more in information systems.

After the QDR is completed, a set of policy decisions will be made. They must address just the question you ask. It will be very interesting to see how it turns out.

Student: I really raised what seemed like an overly simplistic question because, having been in the military for quite some time, it was never clear, in the last 10 years, what our mission was—because of that conflict between conventional warfare and the evolution towards less conventional means. While I understood the charter, which was to take steps required to defend the nation, our mission seemed to be going through rather dramatic changes on a quarterly basis. So, when you said that the Defense Department knew exactly, my heart leapt for joy, because I think that's important. Nothing good can happen until it does. But, at least at the policy level, it seems that there are still some significant decisions to be made.

Jones: I agree, there are significant policy decisions to be made.

Student: One more simple question. How long does it take for you to shift gears: to rein in the momentum of either a thematic set of programs or a particular program if

SecDef Cohen to decide shortly what course Defense will take:

- **Alternatives range from:**
  - Current investment plans, which emphasize readiness and call for a moderate rate of weapon system modernization
  - Full RMA involving major investment and integration of modern information technologies into many aspects of command and control, warfighting and support
    - e.g., Army's Force XXI Advanced Warfighting Experiment
  - Somewhere in between
- **Ongoing Quadrennial Defense Review looking at:**
  - Strategy, force structure, modernization, infrastructure and readiness needs to meet future mission requirements
  - Due to SecDef in May 1997

Figure 18
Revolution in Military Affairs (RMA)

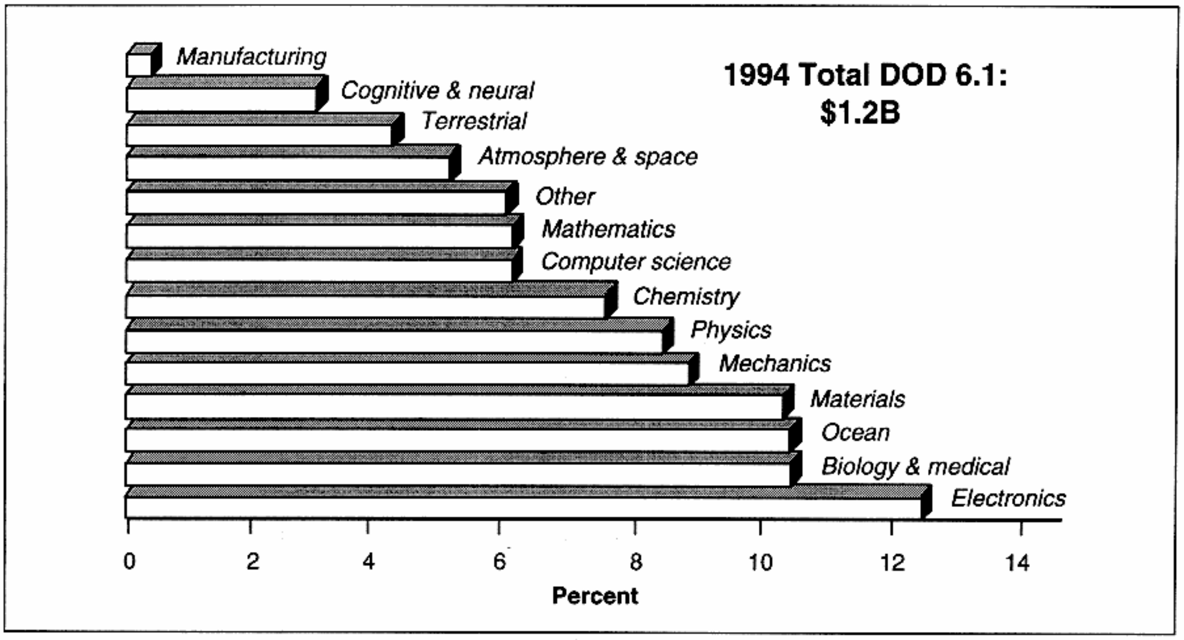


Figure 19
1994 Defense Basic Research by Discipline

the need for that program goes away? I'll just use nuclear weapons as an example. I don't know if DOD is still making major investments in nuclear weapons or whether that was DOD or DOE.

Jones: That's DOE.

Student: There are still the platforms for them and all that kind of thing. At what point in time after a decision is made can that program really be stopped?

Jones: The answer is a week to a decade. It sort of depends on what the program is. Let me give you two examples. These are proactive.

Two years ago, I put funds into DARPA and said, "I want a program in defensive information warfare—defending the information systems, the information grid." The program is really just getting defined. It's taken a long time.

I told you we were building up a large program in bioagent detection and in counteracting bioagents in human beings. A very aggressive program is in the early lifting stages, and it's taken about six months to initiate.

A program can get shut off in a day. You've got to deal with what you have to do to break a contract, if that's what's necessary. But DOD does that too.

Let me give you one of the most difficult examples of a real cultural change. I've taken on an initiative to try to change the culture in the services, particularly in the laboratories, so that affordability of something is on par with performance. A decade ago, the priorities were performance, performance and performance—make it go faster, shoot further, see further, whatever. Today, cost is equally important because of the budget downturn. To balance performance and cost requires a huge cultural change. Some people still don't get it. We have a number of programs whose first or leading priority is to build a more affordable system. But the culture change is slow. I think it takes a decade.

Now let me tell you more about what we invest in. This chart (figure 19) shows basic research only. Avoiding technological surprise is an objective of the DOD S&T programs. DOD invests broadly in basic chemistry, basic biology, basic physics, and basic mathematics. There is quite a bit of size difference in budgets for different areas. The horizontal axis is percentage.

The next slide shows investment areas for applied research and advanced technology (figure 20). The largest areas of investment are electronics, the sensors built on them, information technology, software, and software applications.

Comparing agency investments, they differ, and choices reflect agency missions (figure 21). DOD invests a couple of hundred million dollars in aerospace and related things, but NASA invests much more because of launch needs. NASA is the largest federal investor in aerospace. In an area like mathematics, multiple agencies invest. For computers, materials, and electrical engineering, DOD is the major investor.

This next chart (figure 22) illustrates something that greatly concerns me. DOD provides about 16 percent of all federal funding in the technology base. However, DOD alone accounts for 75 percent of the federal funds for basic and applied research in electrical engineering, 50 percent of such funding for computer science, and slightly under 40 percent of such funding for engineering. If this one agency ever changed its investment in these areas materially, this would destabilize research in these areas.

Oettinger: This is always a percentage of the federal technology base number, right? Because I was going to say that these are the growth areas that I think would be important for industry as well. But this is within the federal government.

Jones: This is only the basic and applied research, where industry does not invest heavily. But you are absolutely right: these areas are key to the health of some industrial sectors.

This is one of the fragilities, in my view, of the federal way of investing. A diverse set of agencies invest, but, in any given area, one agency may be dominant. If the agency management ever changed its investment materially, it could have large ripple effects.

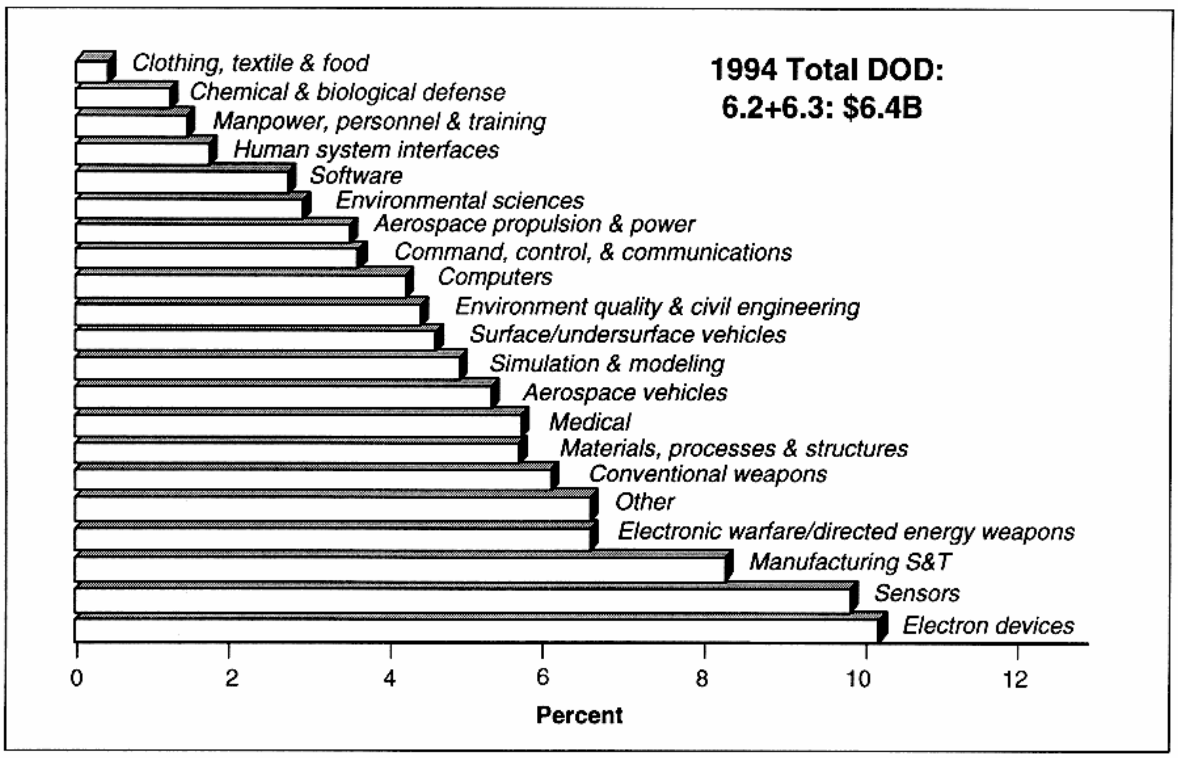
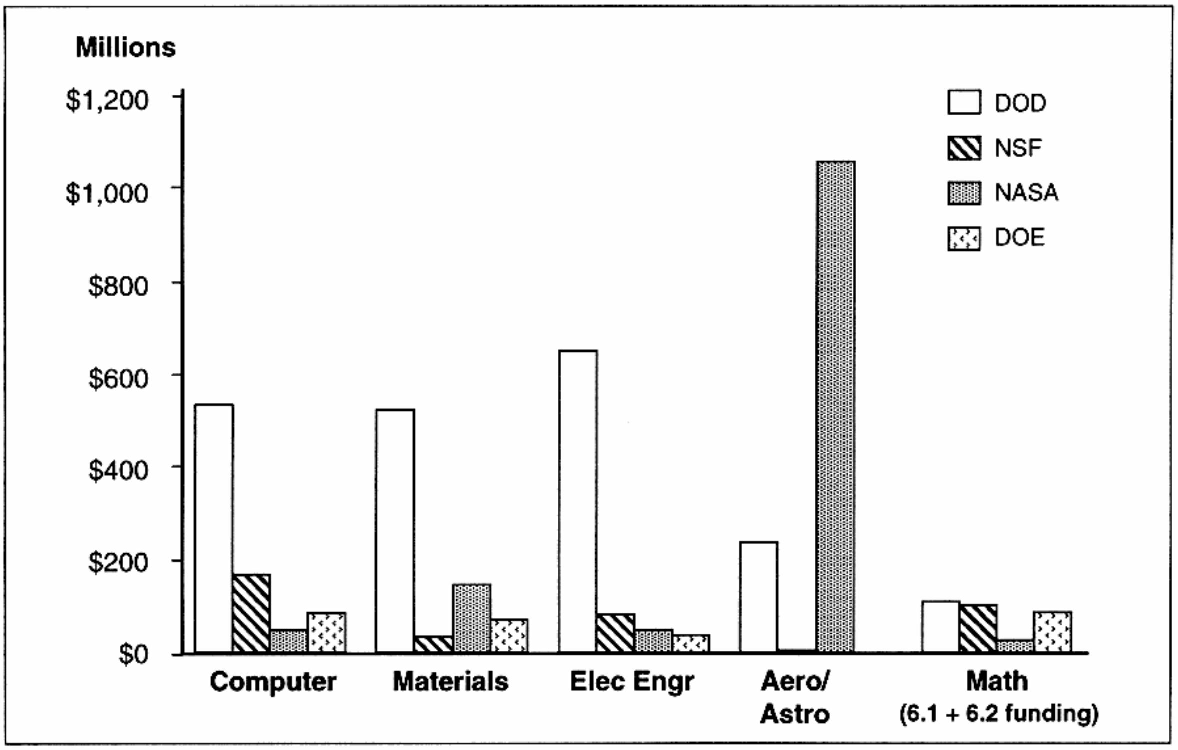


Figure 20
1994 Defense 6.2 + 6.3 by Technology Area



Source: Federal Funds for R&D NSF Report #94-328

Figure 21
1994 Federal Research in Selected Disciplines

	DOD Percentage of Federal Technology Base
Electrical engineering	75%
Metallurgy and materials	62%
Mechanical engineering	59%
Computer science	56%
Civil engineering	45%
All engineering	37%
Mathematics	28%
All funding	**16%**

Source: NSF Federal Funding Report 94-328.
Note: 6.1 and 6.2 funding only.

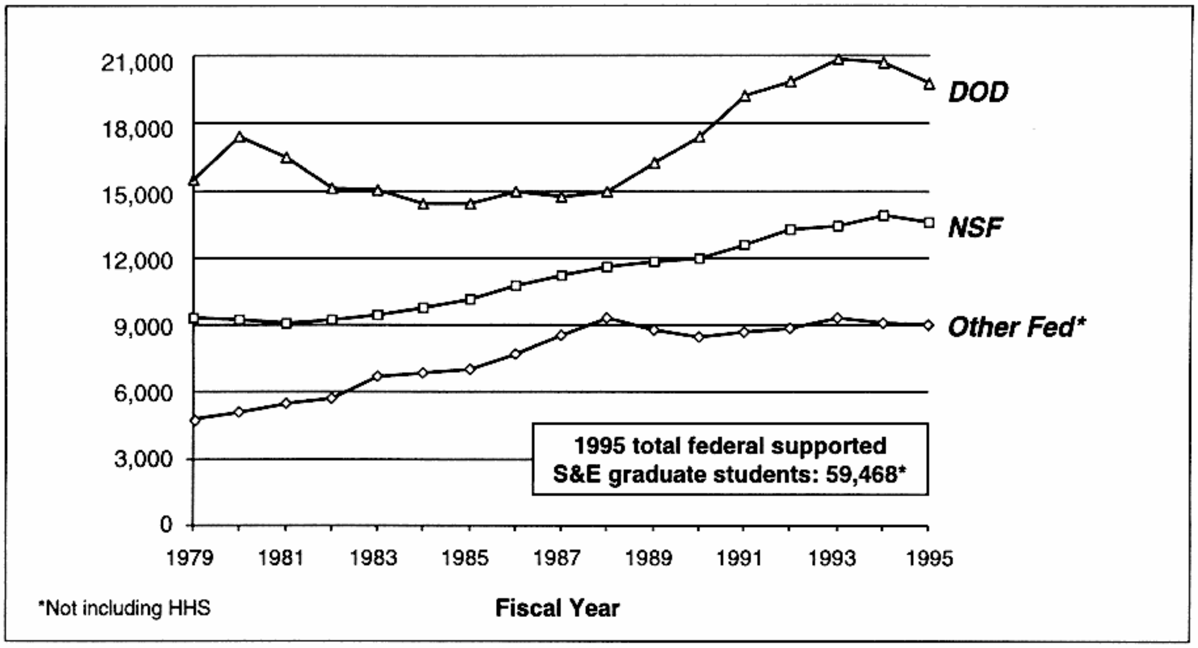
Figure 22
DOD is the Dominant Investor in Critical Fields in the Technology Base ($ FY94)

The investment in S&T also supports the education of scientists and engineers (figure 23). Roughly, the federal government pays for about 60,000 students per year. If research in an area is stopped, funding to support graduate education in that area is stopped or reduced. That would also affect industry in the long run.

Student: In those numbers, is there a requirement that a certain number be U.S. citizens, or is this investment just in talent?

Jones: I can only speak for DOD. I think the rules are slacker elsewhere. DOD has some fellowship programs, which is a very small portion of them, that are U.S. only. Almost all the support of students is in the context of a research project. Faculty determine which students to support. They may or may not be citizens of the United States.

Let me reinforce the point that it takes a long time to make a breakthrough and then build a business and deliver products—military or civilian (figure 24). This slide depicts breakthroughs in information technology that have spawned a more than billion-dollar business. The horizontal axis starts in 1965 and goes through 1995. It charts government and industry investment



Source: NSF Division of Science Resources Studies

Figure 23
Supported S&E Grad Students (1979–1995)

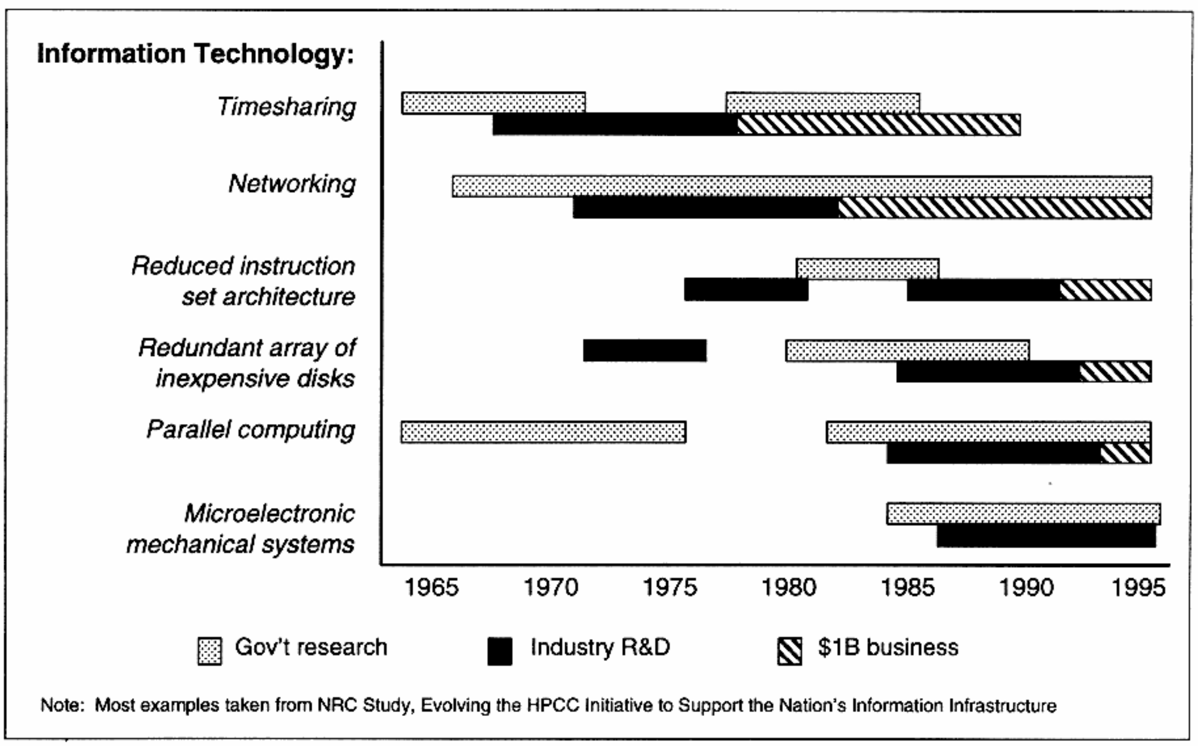


Figure 24
Long-Term Investments Have Payoff

in research and development over that period of time. The amount of investment is not shown. This chart was derived from material in a National Research Council study chaired by Fred Brooks and Ivan Sutherland.

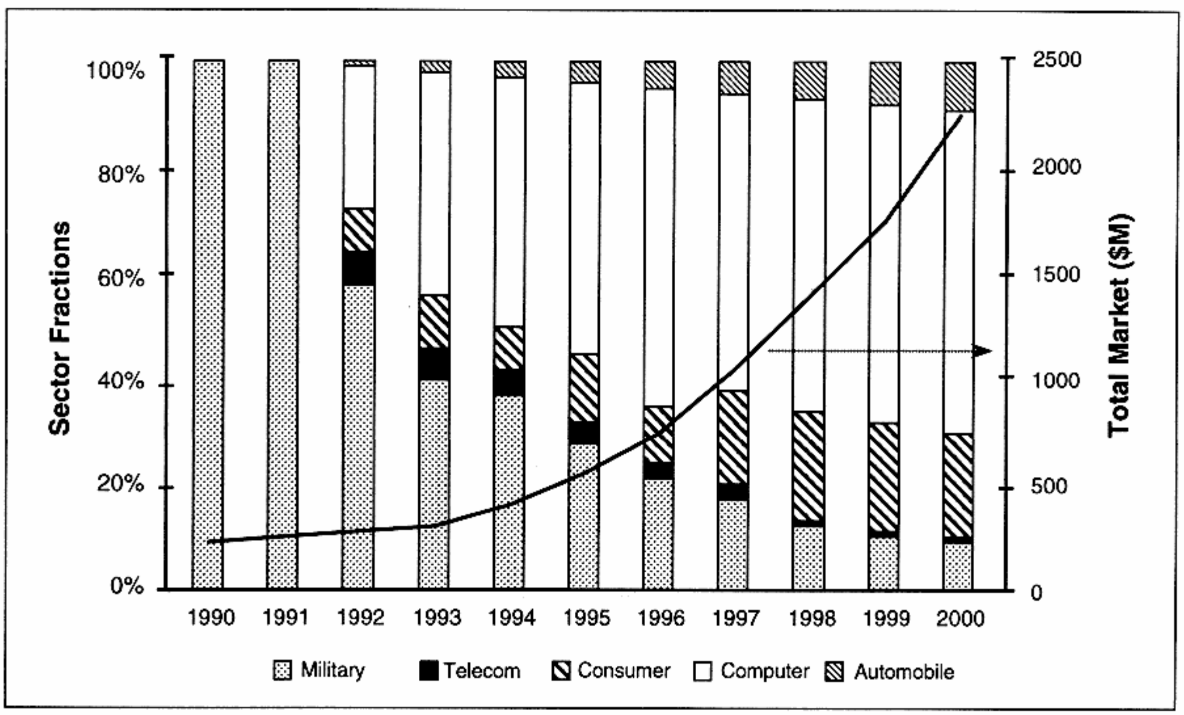
For example, timesharing was invented down the road at MIT. It was funded by DOD. There was industry involvement early on. Timesharing was picked up by industry; products were developed and interactive computing became a reality. But it took a decade.

I want to illustrate long-term technology maturation with a second example, multichip modules. A multichip module is an alternative to a printed circuit board. Printed circuit boards involve soldering packaged chips together to perform some complex function. Soldering leads to fragile joints, slower circuits (than on-chip) and higher heat dissipation.

Someone made a sage observation, "Forget the packaging of chips. Glue them onto a bigger chip or wafer that forms the communications substrate." That is a multichip module. No packaging and no soldering are required. Multichip modules can run at a higher clock rate because they don't have the solder and the wires. They generate less heat, and there are no solder joints to break. Multichip modules appeared to be very attractive, especially for applications in which electronics must endure high gravity forces and extreme buffeting.

Multichip modules were an interesting idea in the late 1980s, but the technology was not developed, so they could not be manufactured reliably and cost effectively.

This complex chart (figure 25) covers the decade from 1990 to the year 2000. The left vertical axis is fractions of 100 percent of a market sector that bought multichip modules. Back in 1990, the military was 100 percent of the market. The right-hand vertical axis is the size of the market measured in dollars. The market was essentially zero back in 1990. The DOD had it all, because nobody else cared: the chips were too expensive, and they could not be built reliably. But the technology really looked promising.



Source: from TechSearch International, ICE Status 1997, includes captive market data.

Figure 25
Multichip Module (MCM) Worldwide Merchant Market by Sector

The line across the bars is the size of what's called the merchant market—the chips that are available for open sale. What's not in the merchant market are multichip modules that are built by a company and consumed by that company and are never available for sale. The merchant market is above $1 billion today. By the way, multichip modules are much cheaper than they were because of large manufacturing economies of scale.

The DOD is now a minority buyer in the market. The computer industry and the consumer electronics industry are dominant purchasers.

Well, how was multichip module technology developed? A companion slide (figure 26) shows a decade-long government investment in developing multichip module technology. (This chart also shows a decade.) Early on investment was made in next-generation technologies. For example, DOD funded three different kinds of glue by which you could bond the naked die (chips) to the communications substrate. Experiments were performed with three competitive bonding materials. It doesn't matter which one is the best, and it doesn't matter whether it turns out that one bonding material is better for some circumstances and another is better for other circumstances. The objective is to build a stable multichip manufacturing capability.

As the base technology improved, DOD invested in what's called flexible access. This permitted small companies and universities to get their designs fabricated and to test early modules. Experimentation was broader than only the corporations that were developing multichip module manufacturing capability.

By the mid 1990s, investment in next-generation technologies had ceased, and the investment in flexible access has peaked and will decline. The focus is on maturing manufacturing processes, tooling, and applications. This illustrates a decade long S&T program, which sought (successfully) to develop a technology that had military and commercial application.

The next subject that I would like to talk about is information technology in particular, and some related DOD activities. Do you want me to go on?

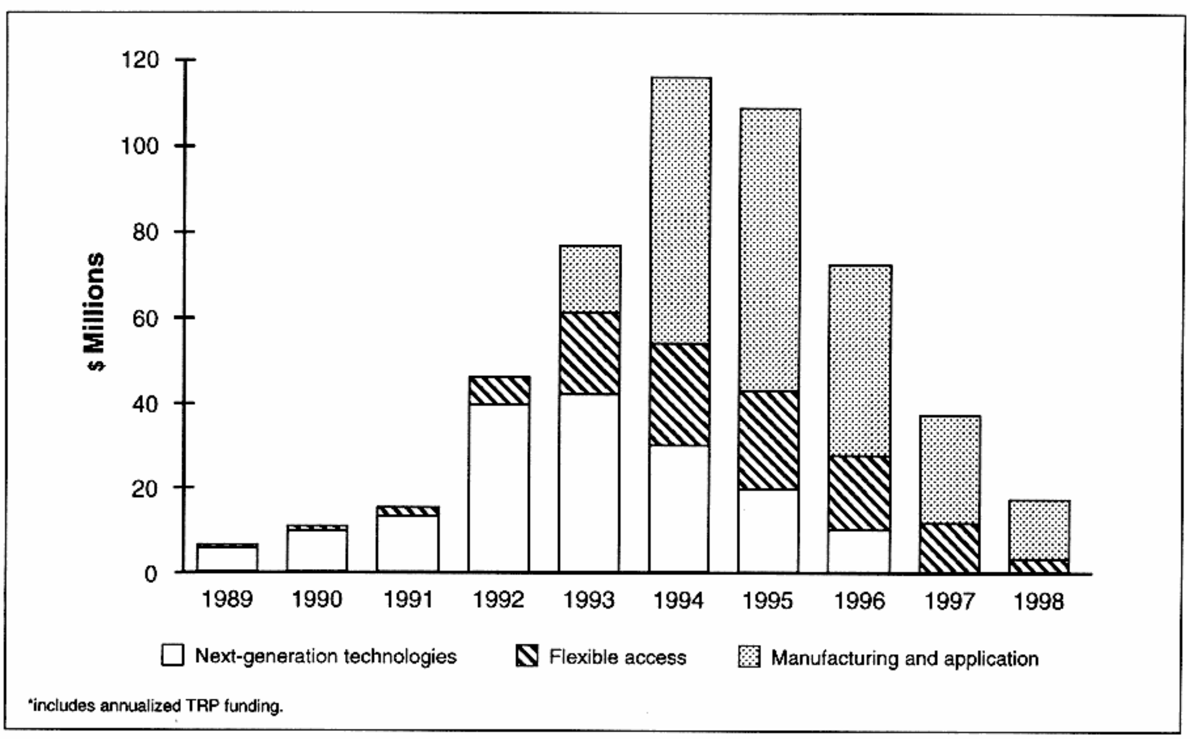


Figure 26
DARPA Investment in MCM

Oettinger: Please do. Are you game? You have our undivided attention. Nobody's asleep.

Jones: Let's plow ahead.

For the past five years, and for the next five years, information technology, broadly writ, is in my view the most important technology area for the DOD. More than $2.3 billion of the $7 billion in the S&T budget is directed at electronics and information technology.

This slide (figure 27) lists some generic issues. These are basic research problems to be solved; for example, exploitation of images, and assuring that the capability of a network will be used for high-priority needs.

Before I leave this topic, let me tell you about a multiple agency effort, the Next-Generation Internet (figure 28). The President announced this as an initiative last December. Its purpose is to let a portion of the research community catapult themselves (you can only afford it for a small number of them) into the future, where you have organizations operating end to end—from workstation to the telescope they're controlling, or to another scientist on another workstation across the country—100 times faster than they do now. For a very few organizations, it will be 1,000 times what they now have. The bottom line metric is to develop whole new paradigms that enable people to solve problems, particularly science and engineering problems, with these very high-speed communications.

- **Image exploitation**
- **Terrain depictions and analysis**
- **Distilled data—maximum relevant knowledge**
- **Global transaction services**
- **Human-computer system interaction**
- **Integrated models and simulations**
- **Assurance of services**

Figure 27

Technology Priority: Information Technology

Objectives:

- **Goal 1: connect research universities and federal research institutions with high-performance networks:**
  - 1.1: At least 100 organizations at speeds of 100 times today's Internet
  - 1.2: At least 10 organizations at speeds of 1,000 times today's Internet
- **Goal 2: promote experimentation with the next generation of networking technologies.**
- **Goal 3: demonstrate new applications that meet important national goals and missions.**
- **Funding: ($100M FY98)**

DOD (DARPA) = $40M	NIST = $5M
DOE = $35M	NSF = $10M
NASA = $10M	

NIST = National Institute of Standards and Technology

Figure 28

Next-Generation Internet

Student: Is that Bill Gates's initiative, the one he's trying to push? The satellites?

Jones: He has nothing to do with this. This is a federal initiative.

Oettinger: This is a Clinton-Gore effort.

Jones: Yes.

There are additional technology priorities beyond information technology. The next slide (figure 29) lists some. I have already mentioned biological defense and the supporting of small units.

There's also a lot of excitement about unpiloted vehicles. The Air Force has finally decided that these may be useful. The white scarves stiffed that idea for a long time, but they really have embraced this technology and are exploring how and where unpiloted air vehicles might be useful. The Navy is looking at unpiloted submarines. Possible applications are quite exciting.

Another area that is quite exciting is miniature systems. I can imagine building

- **Microelectronics (MCM, MEMs, lithography)**
- **Simulation for acquisition, training, operations**
- **Chemical-biological defense**
- **Small unit operations**
- **Uninhabited systems—manually guided and autonomous**
- **Miniature systems—swarm of systems**
- **Cruise missile defense**
- **High-density, lightweight energy storage**
- **Kill hard targets**
- **Service priorities**
  - Rocket propulsion—high cycle fatigue
  - Littoral area dominance
  - Extended capability combatant
- **Wholly new concepts to mitigate new threats**
  - Demining, counterterrorism, intelligence, surveillance, reconnaissance, counterproliferation

Figure 29
Other Technology Priorities

an air vehicle that I could hold in the palm of my hand. You can buy an off-the-shelf camera that weighs ounces, and put it in the nose of such a vehicle. It's easy to launch. But there are research issues. The aerodynamics of really small things are quite different from large things. They're cheap. You might send out a swarm of them. But how do they communicate? Or how do you figure out what they collectively know and see as opposed to what one knows and sees? The whole notion of swarms of systems, and how you understand what they can detect, is an interesting question.

Today, the Navy is much more concerned with shallow, muddier water; the littoral area. For a long time, they have been almost wholly focused on the deep blue ocean, about which they understand a great deal. So this is an area of considerable investment in terms of acoustics, images, and mine detection in sediment-laden water.

There are some wholly new concepts like quantum and DNA computing.

Let me close. In my view, the S&T budget of the federal government is going to decline through the turn of the century (figure 30). The exceptions are NSF, which is going up (but they have a very small budget), and Health and Human Services. Faced with that, agencies will use their mission as guidelines for what they invest in. I can assure you that the Department of Defense will do that.

The military decides what the impact of this Revolution in Military Affairs is. You will see a proliferation of information system prototypes.

I talked to you about the Next-Generation Internet. In addition, there is a program in my office that is putting large, high-performance computers in the military service laboratories. DOE has a program that is doing a similar kind of thing in support of nuclear stockpile stewardship, where they have to compute because they can't test.

- **Science and technology budget will decline substantially by the next century, except for health sciences and NSF.**
- **Agencies will protect mission-unique and mission priority investments.**
- **Multidisciplinary projects will increase.**
- **Mission information system prototypes, experiments, and technology will flourish:**
  - Many mission application systems
  - Next-generation Internet
  - DOE Nuclear Stockpile Stewardship Advanced Supercomputing Initiative (teraop computers and simulation)
  - DOD high-performance computing modernization
  - DOE collaboratory initiative
- **University consortia will increase, partly to reduce facility costs.**
- **University/industry consortia will increase.**
  - Encouraged by federal programs
  - Desired by industry
- **Industry sponsorship of research may increase.**

Figure 30
Trends: Federal

I expect multidisciplinary projects with government labs and industry, with a consortium of universities, and with universities and industry will continue to flourish. There will be more of them.

DOD has entered into a partnership with the semiconductor industries. We signed an MOU (memorandum of understanding) a month and a half ago whereby the DOD and the Semiconductor Industries Association are going to co-fund basic research in the universities, not in industry. That's a very promising partnership.

Oettinger: Is that a self-conscious thing on their part to make up for the cuts in their internal R&D? What's the motivation at a time when they're cutting?

Jones: I can only assume that it is a business decision, made in the face of growing global competition.

Oettinger: Your drop-in-spending chart (figure 5) was for old-line companies like GE. But this is a new approach for these folks.

Jones: That's right. I believe the only reason they do it is because they believe it's in the interest of the industrial sector's long-term health. Remember when we were losing share of the microelectronics market to the Japanese? In 1986 Norm Augustine[3] chaired the Augustine Panel. They reported, "This is a national crisis, and certainly it is a national security crisis. The military depends on electronic systems advantage." And so SEMATECH was created. Since then, DOD has funded SEMATECH at about the level of $100 million a year. Industry put in money. SEMATECH took action to reverse market erosion. Two years ago, they said, "Thank you very much. 1997 is the last year that we need federal money." Industry alone sustains SEMATECH now.[4]

I think I have already underscored that we in the technology program have shifted investments to address new threats and to explore this Revolution in Military Affairs (figure 31).

I have not said much specifically about the services. Each of the military departments does have a basic research program that is tailored to that service's needs. For example, the Army funds research in composite or ballistic materials for tanks. They are the users of parafoils for the delivery of materiel to ground forces. Such parafoils can convey materiel 25 miles and put it down precisely where desired.

- **Investments shifted to address new threats**
- **Emphasis on information technology—the basis for a "Revolution in Military Affairs"**
  - Many application systems
  - Expanding use of modeling and simulation
  - Information warfare—especially defensive
- **Services invest in mission-unique S&T**
- **Affordability and dual-use technologies**
- **New definition of the "offset strategy"**
- **Hard problems still attract investment**
  - Chemical/biological agent detection and protection
  - Unpiloted vehicles—small to medium size
  - High-density energy storage
  - Counterproliferation and hard target defeat
- **Space remains a frontier**

Figure 31
Trends: DOD

[3] In 1986, Norman R. Augustine was president of Martin Marietta Corporation; he recently retired as chairman and chief executive officer of Lockheed Martin Corporation.

[4] For background on consortia such as SEMATECH, see Norman S. Zimbel, "Cooperation Meets Competition: The Impact of Consortia for Precompetitive R&D in the Computer Industry, 1982–92." Cambridge, MA: Program on Information Resources Policy, Harvard University, Center for Information Policy Research, 1992.

Long-term cultural trends in DOD include an emphasis on affordability. I already highlighted that, and the cultural change it represents. DOD does exploit dual-use technology. Sometimes DOD develops what comes to be commercial technology. The Internet and multichip modules are two examples.

In the Cold War, there was something called the "offset strategy." It was: "Use technology to offset larger forces." I think that today there's a new definition of the offset strategy, which is: "Use technology to minimize or completely eliminate casualties and to limit collateral, unintended damage," so that an attack on a building will not destroy the hospital next door. Precision control of munitions targeting is a military capability enabled by technology.

My last slide (figure 32) provides pointers to key documents that will tell you where DOD is going. The Chairman of the Joint Chiefs of Staff, General Shalikashvili, last year built a document called *Joint Vision 2010*.[5] The area that he highlighted was information superiority.

- **Joint Vision 2010**
- **Advanced Battlespace Information System Task Force Report**
- **Quadrennial Defense Review (when completed)**
- **1997 Defense Science and Technology Plans**
  - S&T Strategy
  - Basic Research Plan
  - Joint Warfighting S&T Plan
  - Defense Technology Area Plan
  - Defense Technology Objectives

Available through DDR&E, DTIC, or off Internet at:

http://www.dtic.mil/ddre (or)
http://www.dtic.mil/dstp/DSTP

Figure 32
Sources for Further Details

Oettinger: They'll see it. I'll be handing that out next week.

Jones: My office builds annually, a set of DOD-wide technology plans. This is an activity that I started in the past couple of years. We have just released these plans. You can find them on the Web at the addresses on this slide.

At the highest level is the S&T strategy. It asserts DOD-wide strategic goals such as "making affordability as important as performance." Several more detailed documents complement the S&T strategy. The first outlines long-term research objectives and plans. The second is the Joint Warfighter S&T Plan. Every year I go to the Joint Requirements Oversight Council, which is the vice chairman of the Joint Chiefs of Staff sitting with the vice chiefs of the four services. I ask them what their most important needs are. Last year they gave me 12. This year it was 10. These are not requirements. There's only a one-paragraph description of each. We look at technologic possibilities for meeting these needs. And for each one, the Joint Warfighter S&T Plan exhibits a roadmap; it discusses what is being done to develop technology to help meet that need.

Oettinger: If you need more detail on that whole process, you'll find it in the presentation by Admiral Owens.[6]

Jones: The last plan is the Technology Area Plan and its complementary document, Defense Technology Objectives. The last plan is divided by technology areas. There are 10 of them. For each one, we document the corporate plans for the Department of Defense on how much money

[5] Chairman of the Joint Chiefs of Staff, *Joint Vision 2010*. Washington, DC: Joint Chiefs of Staff, 1996.

[6] William A. Owens, "The Three Revolutions in Military Affairs," in *Seminar on Intelligence, Command and Control, Guest Presentations, Spring 1995*. Cambridge, MA: Program on Information Resources Policy, Harvard University, January 1996.

we're investing in that area, what we expect to achieve, and metrics of success.

Sitting behind these plans is a set of about 286 technical objectives. That's in a separate book, and it's coded so you see how it relates to a technology area or a chapter in the Joint Warfighter S&T Plan or both. Each technology objective is quantitative. It has milestones and dates. It describes programs DOD-wide. These plans span about 60 percent of the Defense S&T program. I don't seek to cover everything. I don't seek to cover the single military department-unique programs.

So with that I'll conclude, but I'll be glad to discuss whatever you'd like to.

Oettinger: Thank you. Further questions, ladies and gentlemen?

Student: Is there a continued development of virtual environments, keeping up with the times and the dual-use technology? I know that virtual environments are very popular in commercial areas and that there was development of virtual depictions. Is that still being pursued?

Jones: It is still being pursued along some dimensions. However, where industry is developing the technology, DOD has stepped back. For example, in an area such as head-mounted displays, except for developing a helmet for helicopter pilots (particularly for the Apache) or for a particular fighter aircraft system, generic investment has been curtailed.

Oettinger: That's sort of interesting, because you mentioned Ivan Sutherland in passing before, and when he was head of ARPA/DARPA IPT (information processing technology office), he started the head-mounted research there. So we're talking about a 30-year span from idea to this statement that it's sort of getting routine.

Jones: That is correct. Yet challenges remain. DOD has some investment in how you give somebody a three-dimensional experience inexpensively. For head-mounted displays, I see lots of immediate applications, such as maintenance.

Student: Surgeons could use them.

Jones: Yes, indeed.

Student: I remember we had several pilot training simulators, and it wasn't even a full-dome simulator. It was just wrap-around for the front of the aircraft. I think the software alone for the visual, and this was in 1988, cost $7 million per simulator. So, this is pretty expensive. I'm not sure how much cheaper it's gotten since 1988.

Jones: I know they're expensive. But costs have come down somewhat.

Student: How early on does the political side of the issues come into play, and how do you ensure appropriations in Congress? Is there a special staff at your office concerned with that matter, and do you consider it from the very early stages on, or do you just leave that to other people?

Jones: You never ignore the people who sign the checks and pay the bills! During authorization and appropriation, Congress makes a choice on what to spend on science and technology. The four committees receive the President's budget in January. As of a couple of years ago, they also have the S&T plans that lay out the objectives and roadmaps for many technical areas. The congressional staff studies the budget line items and our documents. I review the program with the staff. My office provides further data and answers to their questions. Each year I testify on topics of Congress's choosing.

DOD has a Legislative Affairs office whose only job is to work with members of Congress and with congressional issues. Interaction on S&T matters is managed out of my office. We work with members and staff year around. We try to be immediately and effectively responsive to Congress.

Oettinger: Thank you so much for sharing your thoughts with us. We have a very small token of our very large appreciation.

Jones: Thank you very much.

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