AFA SPECIAL REPORT

SHORTCHANGING THE FUTURE

Air Force Research and Development Demands Investment

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Air Force Association

Science and Technology Committee

A Special Report by
The Air Force Association Science and Technology Committee

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The Air Force Association is an independent, non-profit, civilian aerospace organization whose objective is to promote greater understanding of the role aerospace power plays in national defense. AFA is a grass-roots organization with a membership of 150,000. The Air Force Association was incorporated in the District of Columbia on February 4, 1946.

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Why the Nation Needs Air Force Research

Victory in Desert Storm in early 1991 was not just the result of a punishing 38-day air campaign, followed by a 100-hour ground action. The seeds were sown years before in investments made in research and development. Desert Storm's dramatic military success owed much to systems like the E-3 Sentry Airborne Warning and Control System, E-8A Joint Surveillance Target Attack Radar System, Low-Altitude Navigation and Targeting Infrared for Night, AGM-65 Maverick TV-guided air-to-ground missile, AIM-120 Advanced Medium-Range Air-to-Air Missile and the F-117 stealth fighter. All of these systems were products of research and development in the 1960s, 1970s and 1980s:

- E-3, the Airborne Warning and Control System, based on a 1963 requirement, used radar and communications concepts tested in the mid-1960s. Over Iraq, AWACS was essential in establishing initial air superiority and coordinating precision air attacks.
- E-8A, the Joint Surveillance Target Attack Radar System, a prototype then being fielded provisionally, provided timely coordination of ground and air attacks on tactical surface targets. JSTARS originated from the PAVE MOVER studies of the 1970s.
- LANTIRN, the Low-Altitude Navigation and Targeting Infrared for Night system, carried as pods on F-15E Strike Eagle aircraft, had been fielded only in the late 1980s after a tough, technology-stretching development program beginning in the late 1970s. At times the program seemed destined to flop, but here at last it provided the ability to pound surprised Iraqi ground forces in bad weather and at night.
- The AGM-65 Maverick TV-guided air-to-ground missile was used to great effect by A-10s, F-4G Wild Weasels and F-16s. Based on early-1960s research and development, the Vietnam vintage Maverick had added infrared guidance in the mid-1980s and was a major factor in the A-10s' destruction of over 4,000 tanks, vehicles and artillery.
- The AIM-120 Advanced Medium-Range Air-to-Air Missile had been "touch and go" through several years of turbulent development and testing in the early 1980s. But here in its first combat, it claimed aerial kills that helped render the Iraqi Air Force ineffective.
- And most important of all perhaps was the F-117 stealth fighter-bomber, used to strike targets in Baghdad with deadly precision through dense Iraqi air defenses. And without a scratch. Its low-observable stealth technologies emerged from research first funded in 1974.

After their victorious use in Desert Storm, and their repeat performance in Operation Allied Force against Yugoslavia, these systems continue to provide reliable, effective service and will be around for the foreseeable future, but their technology is aging, and the threat to U.S. interests is becoming ever more complicated, leapfrogging into state-of-the-art technologies.

The Question. Desert Storm proved, and subsequent conflicts like Kosovo have confirmed, that technology provides a dependable way to counter high-risk threats. The question is whether, when they are needed, those technologies will be available in the future. Does the U.S. Air Force have the resources and resolve to create today the technological solutions that may be needed in another 20 or 30 years?

Troubling Trends

Since the end of the Cold War, funding for Science and Technology (S&T) has steadily declined. For instance, in constant Fiscal Year 2000 dollars, Air Force S&T funding has dropped from $1.77 billion in Fiscal Year 1990 to a projected level of $1.183 billion by FY 2000.

As a percentage of Air Force Total Obligational Authority (TOA), the S&T budget has been as high as 2.3% in FY 1993, but it will only be 1.81% for FY 2000, decreasing further to 1.65% by FY 2005 (the last year of the FY 2000 Future Years Defense Program [FYDP]).

The Air Force is not alone. The Department of Defense as a whole has also consciously reduced S&T funding in the mistaken belief that industry would fill in the gap. To make things even worse, both the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) are also stepping away from applied research.

Of all the services, the Air Force has a unique legacy of high technology vision and exploration. Army Air Forces General Henry H. "Hap" Arnold and Dr. Theodore Von Karman set the course at the end of World War II. Their challenge created structural changes in the Air Force Research and Development (R&D) community that gave impetus to exploring the technologies that led to ballistic missiles, launch vehicles, satellites, supersonic flight, night vision, stealth, precision weapons, the Airborne Warning and Control System (AWACS), the Joint Surveillance Target Attack Radar System (JSTARS), and the Airborne Laser.

Success in technology development can take up to 20 years. Without a robust Air Force R&D program today, there will be no way to catch up 20 years from now. What's in the pipeline now is what our airmen will have to depend on to face threats not yet imagined.

Unfortunately, in today's budget environment, it is clear that the institutional advocacy and planning required to produce a balanced R&D program are sorely lacking. The R&D community is no longer well positioned to prevail at the highest decision levels. Unfortunately, the planning and program development process does not support basic research and development at the critical funding junctures within the Air Force. And the logic of future payoff has not prevailed against near-term readiness and modernization priorities.

A critical capability and a real strength of the Air Force R&D community used to be development planning. This was a strong analytical function that looked at embryonic technologies and created compelling technology roadmaps tied to national security projections. These roadmaps provided a weapons systems acquisition rationale and brought technologies like AWACS and JSTARS to reality. The Air Force must recreate that development planning function as soon as possible.

Of equally critical importance is the need to educate and nurture a skilled cadre of Air Force officers in the R&D and the S&T community.[1] The evolution of Air Force leaders, from their entry into the service through graduation from the Air Force Institute of Technology, and then on to increasing S&T and R&D experience, including program management, is the crucial factor in rebuilding and maintaining Air Force R&D. The slowly diminishing number of highly qualified acquisition officers is of great concern.

To begin to reverse these trends, the Air Force should consider creating a high-level annual review of Air Force R&D pro-

[1] Note that the armed forces make a clear distinction between S&T, which involves basic research through to technology demonstration, and R&D, which goes all the way to preparation for operational service.

grams so that critical issues can be identified and debated at the highest levels during the decision-making process.

Among the findings of the Air Force Association Science and Technology Committee are the following:

1. Air Force funding of the R&D budget has declined too far over the past decade and is projected to decrease even more in real terms over the FY 2000 Future Years Defense Program. As Air Force investment shrinks, it will be more and more difficult to attract industry investment dollars.

2. S&T spending by agencies such as the Defense Advanced Research Projects Agency (DARPA) and the Ballistic Missile Defense Organization (BMDO) is no substitute for a robust Air Force S&T budget. To the extent the Air Force accepts outside funding, this should be done to complement its own spending on the Air Force's highest priority programs.

There has been a severe reduction in Air Force-initiated and research-oriented Advanced Technology Demonstration (ATD) projects. The FY 1999 budget has $130 million to cover 80 ATDs. With the creation of the more user-focused Advanced Concept Technology Demonstration (ACTD) process in DARPA, it is easy to argue that major ATDs should be proposed and funded by that agency. Although Air Force participation in S&T programs with the other services, as well as with DARPA and NASA, is vital to the overall health of the national aerospace technology base, the Air Force should also undertake some major ATDs on its own.

3. The Desert Storm Air Force systems (AWACS, JSTARS, Low-Altitude Navigation and Targeting Infrared for Night [LANTIRN], Infrared Maverick, Advanced Medium-Range Air-to-Air Missile [AMRAAM], and the F-117 stealth fighter) produced from 1960s' R&D projects were guided through annual congressional budget reviews with strong Air Force commitment and advocacy. Programs like the Global Positioning System (GPS) and improved space satellites had to be vigorously defended in the congressional arena.

4. Given a decade of declining S&T budgets, the most promising technologies, such as directed energy, miniaturized munitions, new electronics countermeasures (ECM) techniques, unmanned combat aerial vehicles (UCAV), and improved materials for space power, may not be ready to be incorporated into Air Force systems to be fielded through 2020.

5. In examining the technology base, particularly in times of scarce funding, the argument for "relevance" of the S&T budget has tended to couple S&T projects to emerging weapons system programs. This philosophy may weed out promising technologies not directly coupled to existing or emerging systems. Senior Air Force leaders need to reverse the S&T funding decline and invest in a stable, robust, balanced R&D base that is not necessarily tied to emerging weapon system programs but that does include long-term S&T investment.

Important technologies, such as hypersonics, have already been eliminated for lack of direct weapon system application. Hypersonics briefly flourished under the "National Aerospace Plane (NASP)" program, but was immediately dropped upon NASP cancellation. When the Air Force or DoD eliminates crucial technology like hypersonics, industry immediately does likewise. Such technology base funding focused on the future must be protected from arbitrary budget cuts.

6. In the last decade, the paucity of S&T funding has helped erode traditional Air Force technology strengths such as electronic warfare. Where once the Air Force was the leader in this area, the Air Force now depends on the other services.

7. Senior Air Force leadership must tolerate and even embrace failure as an integral part of the technology development process. Alongside the successes, like AWACS, JSTARS, LANTIRN, AMRAAM, IR Maverick, and F-117, that emerged from 1960s' R&D were many technology projects that failed. This is akin to the bid and proposal process, where 50% is a pretty good win rate.

8. The Air Force needs to strengthen institutionally the role of technology advocacy within the service. There are too many bureaucratic processes between the Air Force Research Laboratory (AFRL), the major commands (MAJCOMs), Air Force headquarters, the Office of the Secretary of Defense and Congress that continually dissect and ruminate on the Air Force S&T program submission.

9. The AFRL strategic plan must reflect a balance of MAJCOM interests, as well as promising exploratory technology and significant Advanced Technology Demonstrators (ATDs) not directly tied to current weapon systems. The strategic plan should also take into account foreign technology activities, particularly those of our allies.

The Future Threat

Repeated studies have confirmed that for America to mobilize all its military services swiftly in coordinated action against future threats — and to succeed in future high-priority missions with minimal casualties — depends on steady investment in science and technology.[2] So what is the future threat, and do we have technologies in development now to counter it? Perhaps this can best be determined by looking at three periods covering the next 25 years.

Near Term (2000-2010). The DoD's Quadrennial Defense Review (QDR) envisaged a threat from "robust regional adversaries" early in the 21st Century and from "heavily-armed theater-level 'peer' competitors or major powers" by about 2014. These potential adversaries are <u>now</u> acquiring threatening high technology in the areas of targeting, weapons of mass destruction (WMD), long-range delivery systems (theater ballistic missiles [TBMs] and cruise missiles), and airborne C^4ISR (meaning "command, control, communications, computers, intelligence, surveillance and reconnaissance").[3] It has been noted that "some 20 nations have or are seeking weapons of mass destruction, and many are also seeking the missiles to deliver them," while "a wide range of nations have significant conventional arsenals that could pose threats to regional security."[4]

To counter these threats through 2010, the Air Force will put into the field systems which are products of R&D from the 1970s through the 1990s:

- The Airborne Laser (ABL), to be operational in 2007, grew out of projects beginning in the 1970s, like Project DELTA, the Field Test Telescope, the Airborne Laser Laboratory, adaptive optics, the chemical oxygen-iodine laser (COIL), and jitter algorithms. COIL was funded as an internal Air Force Research Laboratory basic research project in 1976, but was not successful until 1979, when it was moved into development. Jitter algorithms that went into the ABL project grew from a basic Air Force Office of Scientific Research (AFOSR) project. Development work continues, but funding is now relatively stable, and this program is on schedule. Preliminary design review was completed in February 1999.

- The Space-Based Infrared System (SBIRS) comprises constellations of satellites in high and low orbits to provide theater forces with improved detection and warning of missile launches. Initial operational capability (IOC) for the high orbit system is 2003, and for the low orbit counterpart, 2006. SBIRS uses staring infrared (IR) detection technologies in development since the 1970s. Funding for this effort has been assured over the coming Future Years Defense Program, but other R&D has been decreased as a result.

- The F-22, to be deployed initially in 2005, depends on 1980s research into supercruise, supermaneuver, Advanced Fighter Technology Integration (including digital flight control) and "supercockpit" research. This next-generation fighter is now in the engineering-manufacturing development stage, with a funding cap imposed by Congress.

- The Joint Strike Fighter, with a projected initial operational capability in 2008, uses 1980s research in short takeoff and landing, materials and stealth. It is now in the concept definition phase.

[2] Committee for National Security of the National Science and Technology Council, <u>National Security Science and Technology Strategy</u>, Washington DC, 1995, p.ii.

[3] Daniel Goure (ed), <u>Air and Space Power in the New Millennium</u>, CSIS, Washington DC, 1997.

[4] Committee for National Security, op. cit., p.26.

- For joint suppression of enemy air defense (JSEAD) in 2010, unattended ground sensors are under development, to be tied to a "robust" C^4ISR system, including a dynamic controller to manage lethal and nonlethal attacks in real time. The ground sensors, equipped with Global Positioning System (GPS) links, will operate from precisely-known locations and provide "highly reliable" data on targets in their vicinity. The dynamic controller will deconflict lethal and nonlethal attacks, maintain an integrated electronic order of battle (EOB), and retask assets as needed.[5]

Mid-term (2010-2020). As one reviewing panel noted, "legacy systems procured today will be at risk in 2010-2020."[6] Defense Secretary William S. Cohen declared in his report to Congress on the FY 1999 budget that the United States needs to "respond to the full range of military challenges throughout the next 20 years" in a "highly dynamic" security environment. This requires "extensive experimentation both to understand the potential contributions of emerging technologies and to develop innovative operational concepts to harness these new technologies."[7] This research is needed because "U.S. technological superiority is essential to achieve the full spectrum dominance envisioned by Joint Vision 2010."[8]

Air Force systems fielded by 2020 to operate in this environment will be products of S&T projects initiated in the 1990s and the first part of the next century. As one analyst noted in 1997, "Joint Vision 2010 and the visions of the services contain many of the capabilities we need in the future. However, the procurement budgets of the services are focused primarily on current systems and do not adequately support the central thrust of their visions."[9] Trying to reach the Air Force vision has already caused some budgetary discomfort. For example, the Defense Technical Objectives (DTOs)[10] had no space goals in 1998, but the Air Force insisted on space being included in the 1999 objectives. Space will be allocated some 20% more of Air Force total obligational authority over the next 20 years at the expense of other programs. Space activities will center on:

- Global information management: creating a pervasive network of nodes facilitating intelligent information gathering, processing, analyzing and advising. Information "superiority" requires "a robust multisensor information grid providing dominant awareness of the battle space to U.S. commanders and forces" and "a sensor-to-shooter grid to enable dynamic targeting and cueing of precision-guided weapons, cooperative engagement, integrated air defense, and rapid battle damage assessment and re-strike."
- Sensors. "Future sensor grids will feature a variety of new imaging and signals intelligence sensors, currently in advanced stages of development, deployed abroad in Global Hawk, DarkStar, and Predator unmanned aerial vehicles (UAVs), as well as new space-based sensor grids, like the high and low-orbit elements of the Space-Based Infrared System (SBIRS)."[11]
- C^4ISR will be integrated across systems to maximize warfighters' view of the battle space, but in this mid-term period there still will be disconnects between incompatible systems. It could cost $1-2 billion per year to make systems talk to each other. Requirements for this integration are now being written. Investment is projected to be $100 billion over the next 20 years.
- Information Warfare/Information Operations (IW/IO). Potential adversaries will have access to sophisticated commercial communications systems,

[5] William S. Cohen, Annual Report to the President and the Congress, Washington DC, 1999, p. 136.

[6] Philip A. Odeen, chairman, Transforming Defense: National Security in the 21st Century, Report of the National Defense Panel, Arlington VA, December 1997, p.iii.

[7] William S. Cohen, Annual Report to the President and the Congress, DoD, Washington DC, 1998, p.117.

[8] ibid, p.142; Joint Vision 2010, published in 1997, is a pivotal document describing the future concepts and capabilities required for U.S. military forces.

[9] Odeen, op. cit., p.iii.

[10] DTOs identify specific technological areas to be developed or demonstrated. They are listed and defined in the Defense Technology Area Plan.

[11] Cohen, 1998 Annual Report, op cit., p. 118, p. 140; DarkStar was subsequently canceled.

Air Force Research and Development Demands Investment

will be aware of U.S. dependence on information dominance, and will act accordingly through asymmetrical responses like jamming and hacking. Information operations to counter them must integrate deception, software, doctrine and tactics.

Long-term (2020 and beyond). Assessing the potential enemy over 20 years in the future is a difficult, risky endeavor. As an Air Force planner noted recently, the future is "not linear: it is chaotic." Even lacking a clear definition of the opposition, the following technologies have been identified as needed for the year 2025 and beyond[12]:

- Sanctuary base: for field deployment, a secure, low-observable, all-weather forward operating base with highly automated base security and support. Because of worldwide terrorism, there will be no other sanctuary, and all sites—even in the United States—must be protected.

- Global surveillance, reconnaissance and targeting system: a space-based, multisensorial collection, processing and dissemination real-time database. UAVs are part of this C^4ISR effort. This marks a further integration of the field global information management architecture.

- Piloted single-stage-to-orbit transatmospheric vehicle: a vertical takeoff rocket and hypersonic air-breathing vehicle that could provide space support and global reach from the earth's surface to low earth orbit using a combination of rocket and hypersonic air-breathing technology and then be able to land on conventional runways.

- Global area strike system: this may involve a transatmospheric vehicle integrated with high-energy laser and kinetic energy weapons or an extended range strike aircraft using hypersonic standoff weapons. Standoff warfare is now receiving a lot of work because of opponents' probable use of WMD to create exclusionary zones.

- Uninhabited combat air vehicle: an unmanned long-endurance vehicle integrated with multispectral sensors and precision-guided standoff munitions.

- Space-based Laser (SBL) system: a space-based multimegawatt, multimode high-energy chemical laser constellation. SBL R&D studies began under the Strategic Defense Initiative in the late 1970s.[13]

- Solar-powered high-energy laser system: same as above, but solar-powered.

- Attack microbots: a class of highly miniaturized robotic systems capable of mass deployment and having wide potential for innovative uses.

The DoD's S&T vision for this period is spelled out in documents such as the Basic Research Plan, giving investment strategy for "six particularly promising technologies: biomimetics [materials that mimic living cells and tissues], nanoscience [the study of processes and devices at the atomic level], smart structures, mobile wireless communications, intelligent systems, and compact power sources."

[12] 2025 Support Office, 2025:Executive Summary, Air University Press, Maxwell AFB, August 1996, p. 34. Also see Appendix A of this report for a list of AFOSR technology objectives.

[13] Dr. Hans Mark, Director of Defense Research and Engineering, recently questioned whether there is in fact a military requirement for SBL.

Ten basic research areas are highlighted for further concentration:

1) atmospheric and space sciences
2) biological sciences
3) chemistry
4) cognitive and neural sciences
5) electronics
6) materials science
7) mathematics and computer sciences
8) mechanics
9) terrestrial and ocean sciences
10) physics

This technology emphasis is based on the Air Force's core competencies:

- Air and space superiority
- Rapid global mobility
- Precision engagement
- Information superiority
- Agile combat support
- Global battlespace awareness

To sum up, the future threat presents both uncertainty and opportunity; it requires an Air Force with the technologies to respond flexibly and decisively to a wide range of threats. The question then becomes whether the Air Force today has the S&T and R&D capabilities in place, together with the appropriate commitment represented through budgetary funding plans, to make available to the warfighter after 2020 those technologies that will be needed.

How U.S. Air Force Research and Development Is Done Today

In December 1990, Air Force Systems Command merged AFSC's thirteen Air Force laboratories[14] to form four "super laboratories." The merger emanated from a 1989 Defense Management Review by the Office of the Secretary of Defense. With an eye on reduced defense budgets, it aimed at improved efficiency and reduced duplication. It was also intended to apply economies of scale and to focus research on the operator of systems.[15] The new laboratories were:

- Phillips, at Kirtland Air Force Base (AFB) (incorporating Weapons, Geophysics and Astronautics Labs)
- Wright at Wright-Patterson AFB (incorporating Avionics, Electronics Technology, Flight Dynamics, Materials, Aero Propulsion and Power, and Armament Labs)
- Armstrong/Brooks AFB (absorbing Harry G. Armstong Aerospace Medical Research, Air Force Human Resources, Air Force Drug Testing, and Air Force Occupational and Environmental Health Labs)
- Rome/Griffiss AFB (with Rome Air Development Center)

In July 1992, at the initiative of Air Force headquarters, AFSC was merged with Air Force Logistics Command, creating Air Force Materiel Command with four directly subordinate technology centers, each responsible for one laboratory:

- Human Systems Center/Brooks AFB (medical, human resources, drugs, ergonomics)
- Space and Missile Systems Center/Los Angeles AFB (space vehicles, directed energy, geophysics)
- Electronic Systems Center/Hanscom AFB (information, sensors)
- Aeronautical Systems Center/Wright-Patterson AFB (aeronautics, information, weapons, materials, sensors)

The creation of AFMC so soon after the AFSC reorganization came in response to: 1) the fact that there were fewer programs to manage (procurement and RDT&E [research, development, test and evaluation] dropped 72% over the decade of the 1980s); 2) concern with the need to control weapons system life cycle costs (a single organization now had control of specifications, system performance, acquisition costs, and service maintainability and reliability goals); 3) an interest in improved organizational efficiency (more than 20,000 positions were cut)[16]; 4) an interest in pushing responsibilities downward; and 5) an emphasis on warfighter needs.

Critics at the time worried that integration would "unravel a perfectly good logistics system or ruin the systems development process," while others asserted that "boutique fleets, especially advanced systems, have the potential for extremely high comparative flying hour costs," but "an integrated AFMC, putting its logistics and product center resources at the disposition of program managers and PEOs [program executive officers], offers the best chance for new economies in existing systems."[17]

In 1997, the four laboratories were consolidated under Air Force Materiel Command as the single Air Force Research

[14] The labs were: Air Force Wright Aeronautical Laboratories (comprising four labs), Air Force Armament Laboratory, Rome Air Development Center, Air Force Geophysics Laboratory, Air Force Weapons Laboratory, Air Force Astronautics Laboratory, Human Resources Laboratory, Harry G. Armstrong Aerospace Medical Research Laboratory, and Air Forces Engineering and Services Laboratory. Included was Phillips Lab, which was from Oct 1982-Dec 1990 subordinate to the Air Force Space Technology Center/Kirtland AFB, reporting to ASC's Space Systems Division.

[15] Rebecca Grant, Materiel World: Developing and Sustaining the 21st Century Air Force, Air Force Association Acquisition, R&D and Logistics Symposium, July 17-18, 1997, Aerospace Education Foundation Forum, Arlington VA, p 4. Grant was president, IRIS Independent Research; In an earlier effort to increase operator say in systems development, Gen. Bernard P. Randolph, commander, Air Force Systems Command, served notice that Systems Command would no longer act as an advocate for systems. AFSC would develop systems and manage acquisitions programs, but wouldn't be "going over to the Hill to sell anything," General Randolph said at the Air Force Association January 1989 Symposium on Tactical Warfare. "Advocacy of systems will be the job of using commands—TAC in the case of the tactical air forces—and the Pentagon," he continued. See John T. Correll, "Back Through the Wringer," AIR FORCE, April 1989, p. 39

[16] AFRL estimates, using new activity-based costing, that overhead is now 22% of the total budget of $2.39 billion , with the other 78% centered on research. Overhead or "product support" comprised civilian (43%) and military (10%) labor, non-R&D contract supervision (15%), depreciation (14%), training (12%), and "other."

[17] Grant, ibid, p. 4.

Air Force Research and Development Demands Investment

Laboratory. AFRL comprises 10 technology directorates:

- air vehicles
- space vehicles
- information
- munitions
- directed energy
- Air Force Office of Scientific Research
- materials and manufacturing
- sensors
- propulsion
- human effectiveness

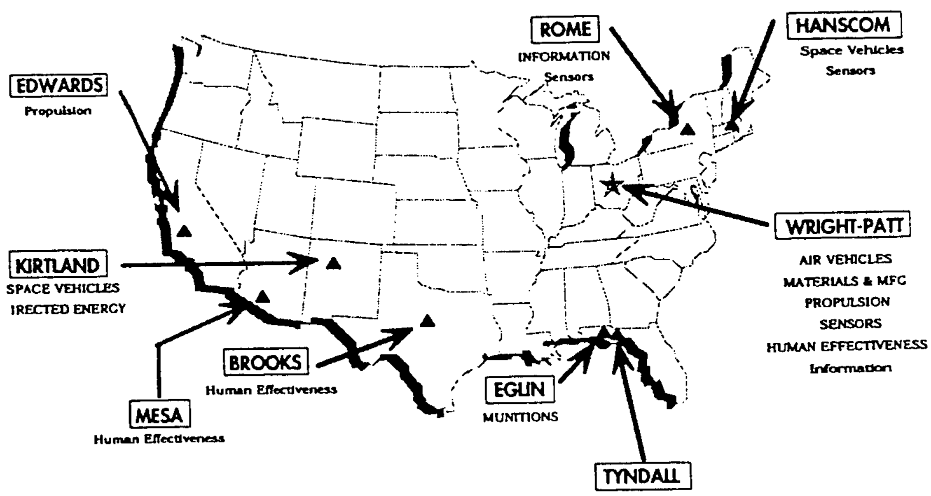
Nearly all of the technology directorates are involved with 6.2 and 6.3[18] activities focused on the six Air Force integrating technology thrusts (space superiority, precision strike, information dominance, aircraft sustainment, training for warfighting and agile combat support). These integrated technology thrusts focus on near-term (1-5 years, the period covered by the annual "POM," or "program objective memorandum," cycle proposing service needs for inclusion in the president's budget submission), mid-term (5-10 years) and long-term (10-25 years). For the near term, in FY 2000 AFRL announced that its budget emphasis will be controlling cost and developing technologies related to space superiority and aerospace expeditionary forces. Of the total obligational authority designated for R&D in FY 2000, 43% is for enabling technologies (primarily 6.2) and 38% is for the integrating technologies (mainly 6.3). Programs under each category typically have 5-6 year lifetimes before being replaced by other programs. The technology thrusts under which each program is fitted have a longer duration and are to be reviewed periodically for relevance by the Air Force's Scientific Advisory Board.

In October 1997, six product sectors (Aeronautics, Space and Missiles, Command and Control, Human Systems and Logistics, Weapons Systems, and Modeling and Simulation) were added within AFRL as single focal points for customers and vendors dealing with nine of the technology directorates (the Air Force Office of Scientific Research operates more independently). This one-stop shopping has been very effective, according to AFRL officers. The product sectors are cross-directorate coordinating bodies, with emphasis on the customer and on recommending changes in AFRL investment. User requirements are received via multiple routes, including Integrated Process Teams (IPTs)[19]

[18] This is a common shorthand reference to the National Defense Authorization Act funding program elements, 0601xxxx(basic research), 0602xxxx (applied research) and 0603xxxx (technology demonstration). "6.2" is exploratory development of the practical applications of basic research—bench testing or "brassboard" testing; "6.3" stands for technology demonstration—building prototypes to determine the feasibility of a particular application, or advanced development based on system application, testing actual hardware in a more operational environment. As an example, the two-dimensional jet engine nozzle used on the F-22 began as a 6.1 paper study, then 6.2 boilerplate, and finally 6.3 flight test hardware.

[19] Also called Integrated Project or Product Teams, IPTs bring together in one funded, decision-making body representatives of all organizations—government and industry—involved in development and manufacture of a system or major subsystem.

AFRL RESEARCH SITES



looking at technologies. Sectors interact with industry, academia and the international community and have representatives within the AFRL technology directorates. Interaction occurs throughout the year at the user level and AFMC "product center" level—occasionally with representatives acting as operating officers. According to AFRL, sectors provide a "better focus" for customers, who now "have more confidence" that they are getting complete answers.[20] "One of the better benefits" of the sector concept is that "we are now developing social relationships with the majcoms[21] that we didn't have before," one AFRL official noted. AFRL supports every evaluation of requirements by the major commands, and AFRL representatives are permanently stationed in Air Combat Command and Air Mobility Command. "Our job is not at our desk," another AFRL official added. Each sector deals with "about 90%" of AFRL, acting as a customer for technologies and an advocate for the major commands "and the product centers."[22]

Doing Basic Research (6.1 Funds). The AFRL requirements and budget (or "investment") cycle works as follows[23]:

- Guidance is received from the Office of the Secretary of Defense (OSD), the Air Force Acquisition Executive (AFAE), and the Air Force Modernization Planning Process (AFMPP), which convey user needs. Guidance is also derived from S&T forecasts: Toward New Horizons,[24] 2025,[25] and the Scientific Advisory Board's New World Vistas.[26] Also used are the more specific planning guidance documents: National Security Science and Technology Strategy,[27] Defense S&T Strategy, Joint Vision 2010,[28] DoD Basic Research Plan, Global Engagement: A Vision for the 21st Century Air Force,[29] and the Air Force Infrastructure Technology Needs.[30]
- AFRL decides which technology areas are to receive attention. The AFRL strategic plan must reflect a balance of major command interests, of promising exploratory technology and of significant advanced technology demonstrations not directly tied to current weapons systems. The strategic plan also interacts with foreign technology activities, particularly with NATO. Additionally, participation of the Air Force in other service S&T programs, as well as DARPA and NASA programs, is vital to the overall health of the national aerospace technology base, and support for investment by NASA and others is essential.
- Plans for R&D are approved and executed by the Air Force Acquisition Executive.
- Plans are also reviewed by the Scientific Advisory Board for quality and long-term relevance, and by the anticipated user for relevance. For example, in its annual evaluation of the Air Force S&T program, the Scientific Advisory Board this year has questioned the short-term nature of basic research.[31]
- Reactions are provided via the Air Force Technology Executive Officer (the AFRL commander) or directly to the Air Force Acquisition Executive for possible modification of plans.

The Air Force Office of Scientific Research "orchestrates" the national Air Force basic research effort, engaging in only "higher risk, longer term, but very high payoff" research. AFOSR is a "science manager," not a research organization. This means that it handles all the 6.1 funding for research in basic and applied sciences. But AFOSR-funded projects are overseen by individual scientists within the

[20] 7 May 1999 briefing by Bert Cream, AFRL/XP/Human Systems and Logistics Sector.

[21] The eight Air Force major commands: Air Combat Command, Air Force Materiel Command, Air Force Special Operations Command, Air Education and Training Command, Air Force Space Command, Air Mobility Command, Pacific Air Forces and U.S. Air Forces in Europe.

[22] 7 May 1999 briefing by David Selegan, AFRL/XP/Aeronautics Sector.

[23] Maj. Gen. Richard R. Paul, September 12, 1998, briefing to the S&T Committee of the Air Force Association.

[24] The seminal forecast of Air Force S&T needs, Toward New Horizons was published in December 1945, in a series of 13 authoritative reports authorized by Gen. Henry H. "Hap" Arnold, commander, Army Air Forces.

[25] 2025, Air University, Maxwell AFB, Alabama, August 1996.

[26] New World Vistas: Air and Space Power for the 21st Century, USAF Scientific Advisory Board, Washington D.C., 1995. Consists of 15 volumes covering aircraft & propulsion, attack, directed energy, human systems/biotechnology, information applications, information technology, materials, mobility, munitions, sensors, space applications, space technology, a summary and a classified volume.

[27] Available at the Office of Science and Technology's website, http://www.whitehouse.gov/WH/EOP/OSTP/nssts/html/nssts.html.

[28] This is the Joint Chiefs of Staff vision statement on future warfare. Available at http://www.dtic.mil/doctrine/jv2010/jvpub.htm.

[29] This is the Air Force's vision statement responding to Joint Vision 2010. It is available at http://www.xp.hq.af.mil/xpx/21/nuvis.htm.

[30] Available at http://extra.afrl.af.mil/info/techneeds97/.

[31] Interview with Dr. Joseph F. Janni, March 18, 1999, at AFOSR Headquarters, Arlington, VA. Janni is the director of AFOSR. The quotations that follow are from that interview.

other AFRL technology directorates. Some research is short-term, directed at immediate weapons applications, but most is longer term. AFOSR is headed by a director who leads a staff of 144 scientists, engineers and administrative personnel. Directorates are responsible for chemistry and life sciences, aerospace and materials sciences, physics and electronics, mathematics and geosciences, external programs and resources interface, and international affairs. In FY 1997, with a $219.5 million appropriation, AFOSR provided $205 million in funding to 513 academic institutions and industries to support 1,500 grants and contracts. Over 350 programs were then in progress in Air Force laboratories, industry and academia. In the same year, 382 programs transitioned from basic research (6.1 funding) to applied research (6.2 or 6.3 funding). Likewise, 352 basic research projects reached the application stage as new or improved products or processes. By contrast, in FY 1998, the appropriation shrank 5.6% to $207.2 million, and only 380 institutions were funded (a 26% reduction) with 1,220 grants and contracts (down 18.7%). In FY 1999, the appropriation was increased to $210.4 million[32], but it still fell short of the FY 1997 level.

Grant proposals are submitted by academia and industry in response to broad requirements advertised by AFOSR.[33] Proposed projects are evaluated through peer merit review by the AFOSR staff. Potential projects need military relevance, a selection criterion which is a "very difficult, tough call" and a risky business itself. It is important that this emphasis on military relevance be balanced against long-term technological goals. The review process is not tied to the budget, but takes place as a continual cycle, frontloaded to the first half of the fiscal year. For grants and contracts, AFOSR has a team of key researchers who work with academia and industry. This process helps with project communications, with the transition of this basic research to applied research or application, and with continuity. Some funding is also provided by DoD, DARPA and BMDO.

Application of basic research, which is "inherently high risk," sometimes takes 10-15 years, but "usually" does not. "Surprisingly often," basic research results are applied directly to military systems. However, the continuing emphasis on military relevance "to some extent cools the risk-taking" and "makes you look a little nearer-term." Duration of research tends to be 5-10 years now, where once it was 15-20 years. AFOSR fosters the transition of research results to industry and government for further study, testing, logistics or systems applications. This transition is handled through the creation of partnerships associated with each research project, incorporating academia, government and industry. Ideas, information and proposals are exchanged through periodic seminars, so that research results are acted on when achieved.

Applied Research (6.2 Funds). Applied research is exploratory development, enabling technology—work which doesn't have a direct set of users, but has a broad base of potential customers. This research is repeatedly described by observers inside and outside the R&D community as the "seed corn" for future work. It is 70% performed by industry, managed through AFRL. The funding largely pays for S&T contracts, but 30% is devoted to sustaining in-house knowledge for proper management of future S&T. AFRL needs to retain expertise in technologies so that the Air Force and the international marketplace are not equal in technologies. The Air Force must maintain the edge. "I don't want every cellular phone to have the same capability I have in my airplane," says one program manager. It is the technology directors' interaction with their customers that helps them anticipate future technology needs. Stealth is one example where

[32] Figures on the latest funding breakdown were not available as of this writing.

[33] See Appendix A.

Air Force Research and Development Demands Investment

this ability to predict uses for future technologies, even without a specific customer, was a precursor to the incorporation of application concepts into the Air Force Strategic Plan. "That's a difficult issue, because it's hard sometimes to get sustained support for those types of things," one AFRL briefer noted in discussing new exotic technologies. One example of a program in 6.2 development in 1999 is Lockheed-Martin's Moving/Stationary Targeting and Recognition (MSTAR) program, funded jointly with DARPA, which involves the prediction of image configurations under a variety of variables. It has potential application to automatic target recognition in intelligent target seekers but as yet has no sponsor. To gain customers for such 6.2 projects, AFRL interacts with potential users, works to understand their requirements, and demonstrates potential technology—both in the 6.2 and the 6.3 process.

Advanced Development (6.3 Funds). Advanced development expenditures are AFRL-administered and are largely for industry contracts devoted to transitioning technologies into weapons. The transition of a project from 6.2 to 6.3 is not well defined but depends on the project's state of development. Having a future customer and a capability ready to be turned into a "product" are necessary before AFRL will undertake a 6.3 program. A 6.3 project is very focused on Air Force core competencies, it has a specific customer, and it has definite beginning and ending dates. This research involves feasibility studies, prototype and advanced development, and the integration of technologies into systems. Part of AFRL's declared current strategy is to prepare for the future aerospace force by sustaining investment in both air and space research while protecting and focusing the "most critical" part of the air investment. "We are not getting out of air": 45% of the AFRL budget is still uniquely air.

The normal implementation of a 6.3 project is as an Advanced Technology Demonstrator. ATDs[34] are paid for by AFRL but focused on at least a single operator. ATDs are approved and prioritized by the major commands. These technology initiatives address major customer needs and can lead to engineering development products in 3-6 years under what is known as 6.4 funding. Although funding continues to be an AFRL responsibility, a technology transition plan is required, which constitutes a formal agreement between AFRL and the potential customer. This plan provides an exit strategy and prevents self-perpetuating programs. The agreement is necessary because there is some difficulty getting 6.3 products moved across the seam into 6.4 engineering development, at which point the using command assumes funding responsibility for the technology. One current example of a system waiting for funding is the Small Smart Bomb, now ready to move into engineering development, which would allow one F-16 to carry the weapons load of eight aircraft, easing support requirements.

A New Element: The Battlelabs. "Perhaps one area where major concerns about an integrated command [AFMC] linger is in science and technology management," one former defense official has said, noting that the Air Force's transition to an air and space force depends on continued exploitation of a range of advanced technologies. Although the AFMC's incorporation of the labs and product centers was "key to linking systems development to operator needs," she said, success in bringing research to fruition "depends on a command structure that stays close to the operator's 'requirements pull.'"[35]

The Air Force vision statement, Global Engagement: A Vision of the 21st Century Air Force, released in November 1996, provides one response to such concerns:

[34] ATDs should not be confused with Advanced Concept Technology Demonstrators (ACTDs). ACTDs, funded through 6.4 engineering development and 6.5 management and support monies, are operational demonstrators of more mature systems closer to procurement. This funding is provided by DARPA and the user commands.

[35] See Rebecca Grant, Materiel World, op cit., p. 6.

Air Force Research and Development Demands Investment

"The Air Force is committed to a vigorous program of experimenting, testing, exercising and evaluating new operational concepts and systems for air and space power. It will provide additional emphasis in six areas of ongoing activity in Air Force centers of excellence. That will be accomplished with a series of focused battle laboratories for space, air expeditionary forces, battle management, force protection, information warfare and unmanned aerial vehicles."

The six Air Force battle labs have the mission of "identifying innovative ideas, assessing their merit, and validating innovative operational concepts."[36] The service battle labs "enable warfighters, developers, and industry to work together to exploit technological advancements and synchronize advanced warfighting concepts," according to Secretary Cohen. The six Air Force battle labs' mission is "rapidly identifying and proving the worth of innovative and revolutionary operations and logistics concepts with near- and mid-term applications," providing opportunities "to reach investment decisions more quickly."[37]

As one knowledgeable observer pointed out, "The Air Force's six new battle labs will soon generate demand for modifications, acquisition, and integration of systems to provide enhanced capability."[38]

AFRL is establishing formal and informal contacts with "most" of the battlelabs, but assignments are voluntary, so these connections are not yet made easily. The battlelabs are not R&D groups but are interested in ideas near implementation. These links can be expected to be more active in the future. However, initial reaction has been mixed: some links to the battle labs seem to be working well; others not so well. Some AFRL-initiated technologies are receiving more rapid demonstration, but the record is spotty. The battle labs' continued search for innovative technologies may force AFRL into an even more customer-oriented outlook. The battle labs do, in most cases, seem more closely linked to the warfighter than AFRL is.

[36] Cohen 1998, op cit., p 145.

[37] Cohen 1999, op cit. pp. 140-141.

[38] Grant, Materiel World, op.cit. p 4.

The Budget Situation

Air Force Research and Development Demands Investment

The Poor Health of Research. Despite all the detailed planning and attention given to the infrastructure, R&D is not doing well in the DoD as a whole, and the problem is money: funding is down another 8% in the FY 2000 budget, although the overall DoD budget decreases only 5% from FY 1996 through FY 2002.

The health of Air Force research is of even greater concern. Ten-year trends for the three services show some stability for the Navy, a little less for the Army, and an unchanging decline for the Air Force (see Chart on p. 16). Expressed in then-year dollars (unadjusted), Air Force R&D funding decreases 5.24% from FY 1995 through FY 2005, while the overall Air Force budget decreases 3.24%. Total Air Force S&T (6.1-6.3 funding) was down 3.25% from FY 1995 to FY 1996, 7.94% from FY 1996 to FY 1997, 5.3% from FY 1997 to FY 1998 and 6.69% from FY 1999 to FY 2000. FY 2000 figures, at $1,182.83 million, are only 84.85% of the FY 1995 level. Basic research (6.1 money) by itself is down to $209.51 million, a 6.74% drop in 6 years from already anemic levels, and it is to drop another $32 million in FY 2001. This places the Air Force—arguably the most technology dependent service—last among the three services in terms of S&T investment. As one source said about S&T funding: "We are beyond cutting muscle: we are getting down to bone." Meanwhile, 6.2 funding for applied research will take a devastating cut of 14.29% in FY 2000.[39]

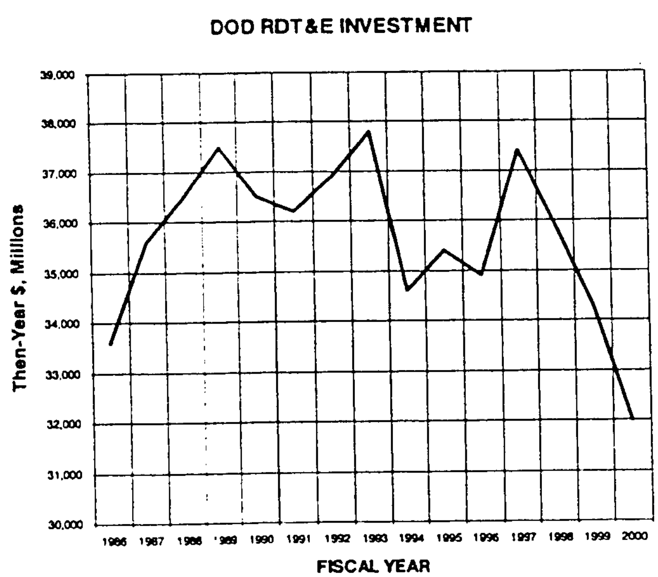
The issue, of course, is that these cuts have lasting effects on future decades of Air Force technology.

This is not a new concern. As long ago as 1985, Gen. Robert T. Marsh, USAF (Ret.), former Air Force Systems Command commander, pointed to "decreasing support" for basic R&D over the prior 20 years.[40] And in 1988, John J. Welch, Jr., then assistant secretary of the Air Force for acquisition, noted that the lack of RDT&E money meant any high-priority system that met development difficulty had to compete for more funding against other programs "that we know we can afford, that are on schedule, and that are performing."[41] In his comment on the

[39] All figures in the above paragraphs are derived from the table in Appendix B. They are expressed in then-year dollars, which represent the actual unadjusted funding level in any given year.

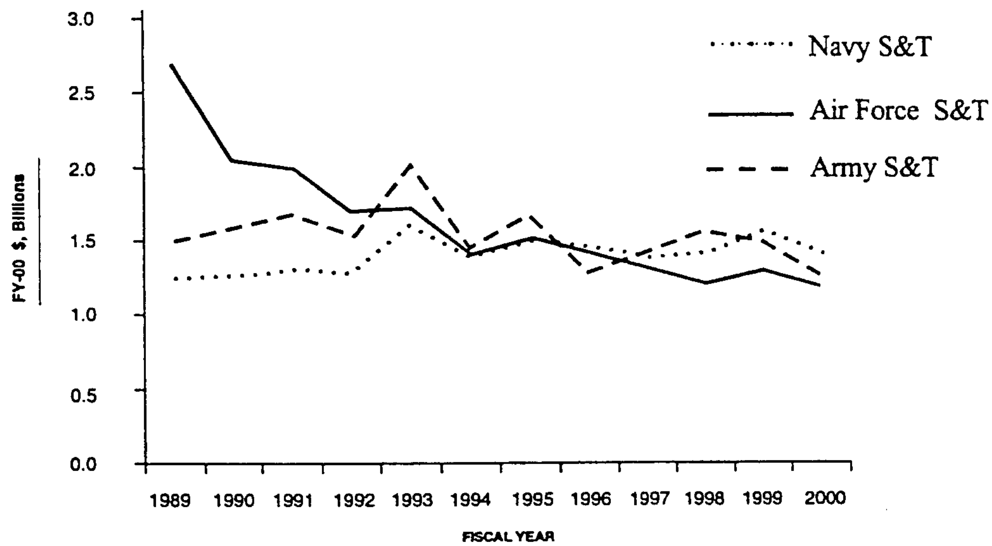
[40] Jacob Neufeld (ed), Research and Development in the United States Air Force, Center for Air Force History, Washington D.C., 1993.

[41] Canan, op. cit., p.92.



Funding for Department of Defense research, development, testing and evaluation has declined precipitously in the latter part of the 1990s. (Figures are shown in then-year dollars, the unadjusted actual funding level in any given year.) Source: The Military Balance, International Institute of Strategic Studies, various years.

SERVICE INVESTMENT



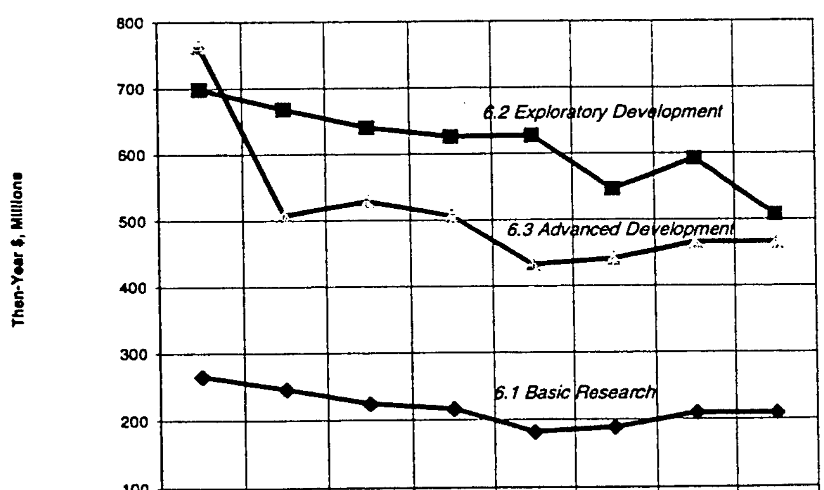
At the end of the Cold War, the Air Force was the unquestioned leader in science and technology investment. In the 1990s, it dropped to third place, behind the Navy and Army. Source: Office of the Secretary of Defense.

May 1997 Quadrennial Defense Review, Chairman of the Joint Chiefs of Staff Gen. John M. Shalikashvili cited the "patterns of the last four years": cutting investment and selling the "force of the future" to "pay current operations and support bills."

Is further shrinkage likely? The CSIS-sponsored Working Group on Technology and the Industrial Base asserted in 1997[42] that "underfunding" of 6.1-6.3 programs had already limited the Air Force's ability to translate "promising, innovative ideas"

[42] Goure, op cit., p.43.

AIR FORCE S&T INVESTMENT

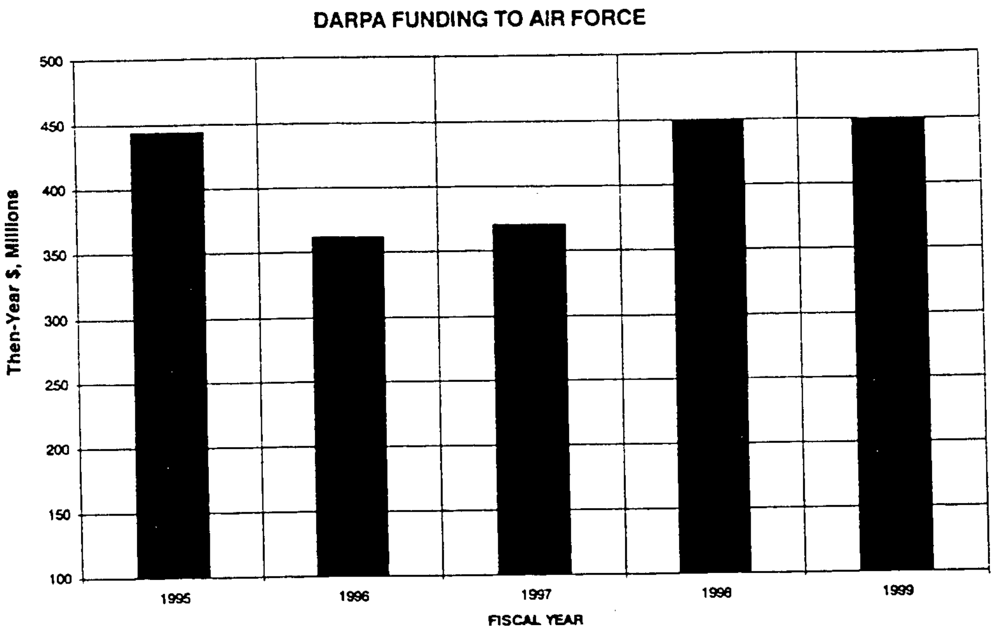


	FY1993	FY1994	FY1995	FY1996	FY1997	FY1998	FY1999	FY2000
6.1 Basic Research	265	246	225	216	182	188	210	210
6.2 Exploratory Development	698	668	640	626	627	547	592	508
6.3 Advanced Development	764	508	529	506	433	441	466	466

FISCAL YEAR

Air Force investment in all of science and technology has declined since 1993, dropping most dramatically in the 6.2 and 6.3 areas, where promising technology is explored and developed. (Figures are shown in then-year dollars, the unadjusted actual funding level in any given year. Source: USAF.)

Air Force Research and Development Demands Investment



Increased funding provided by DARPA to the Air Force benefits joint projects, but it also masks a substantial reduction in Air Force-focused S&T funding. Source: Air Force Research Laboratory.

into real systems. Gen. Robert T. Marsh, USAF (Ret.), former commander of Air Force Systems Command, pointed out that "Air Force investment in the technology base in constant dollars has declined since the early 1960s. Except for a short period of modest growth—4% a year—from 1982 through 1986, it is still declining" and "I say that our store of technology on the shelf is becoming sparse."[43]

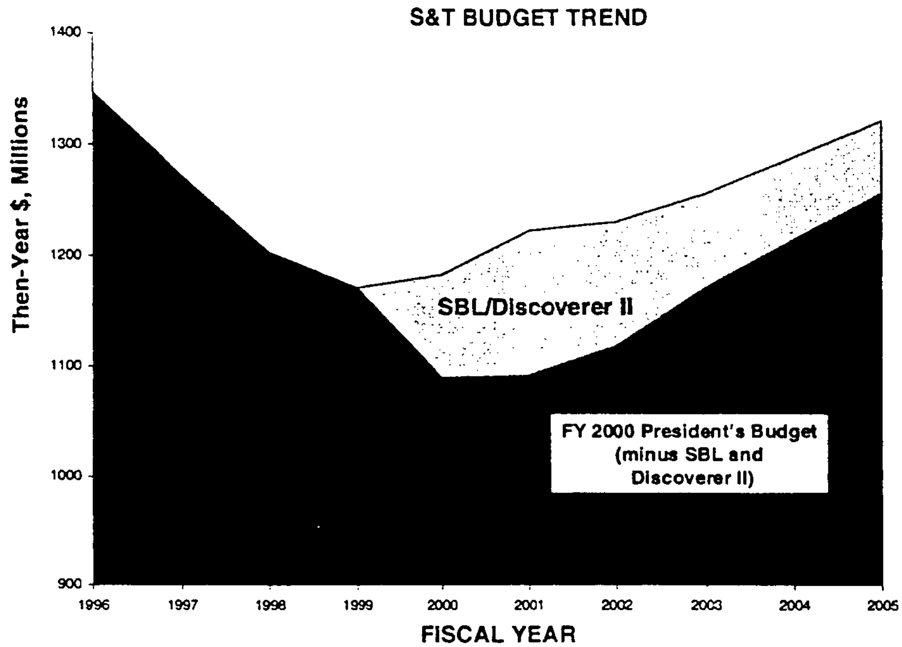
There is little to gain and much to lose from such persistent budget raids on the R&D coffers. S&T accounts for only some 1.5% of Air Force total obligational authority (TOA); it is dwarfed by investments in readiness and modernization. Taking money out of this small sector of TOA can devastate S&T programs, where funding stability is critical because much of the activity is performed by industry. Moreover, cuts to S&T provide a very small return when measured on the scale of regular programs.

At the same time Air Force R&D investment is being raided, the Defense Advanced Research Projects Agency (DARPA) has become more involved in providing funding to the Air Force. In FY 1996, DARPA provided over $360 million to the Air Force; that funding has grown since then to nearly $450 million. But DARPA funding is devoted to research for joint activities, which, in effect, reduces the flexibility the Air Force has in terms of directing and managing the funding. So not only does the Air Force end up with fewer research dollars, it also has less control over how to spend them.

Improving the Process. Does the existing programming and budgeting process itself endanger R&D funding? This two-year process opens when the Secretary of Defense issues annual Defense Program Guidance, giving broad program priorities but seldom including funding figures. The services interpret this guidance and create their annual budget submissions. Air Force submissions originate with resource needs requested by the program element monitors for each program. These program element needs are then consolidated and adjusted by one of 14 mission panels, each a center of expertise for broad Air Force areas like air superiority. This is the last level at which RDT&E is represented as a distinct voice,[44] and even the major commands are not evalu-

[43] Gen. Robert T. Marsh, USAF (Ret.), "Ripe Technologies," AIR FORCE Magazine, June 1989, p. 85. Marsh also served as the chairman of the Air Force Association's Science & Technology Committee.

[44] A separate, informal circuit exists by which program advocates routinely state their cases directly to the Air Force Group, Board and Council members. These evaluating bodies are thus kept informed of program issues and may use this information to question or overturn recommendations from lower-level entities.



By shifting engineering development funding (6.4) for Space-Based Laser and Discoverer II into the basic S&T account, the Air Force artificially boosted overall S&T funding. Without SBL/Discoverer II funding, overall S&T funding drops nearly 22% in 4 years. Source: Air Force Research Laboratory.

ated separately above this level. Options prepared by the panels, and inputs from issue process teams, are forwarded to the Air Force Group, headed by the deputy director for plans and programs (AF/XPP), a colonel, who for the first time creates an integrated Air Force budget program. Recommendations from the Group are then presented to the Air Force Board, headed by either the director of programs, AF/XPP, or the deputy assistant secretary for financial management and budget, SAF/FMB, both major generals. The Board reviews "important" resource allocation issues requiring a corporate resolution and makes recommendations for integrated programs to the Air Force Council. In the course of this entire process, the tough tradeoffs are made between readiness ("today's Air Force"), modernization (the "next Air Force"), and S&T (the "Air Force after next"). The Council, headed by the vice chief of staff, a general, makes final recommendations to the chief of staff and secretary of the Air Force.

Program submissions are then reviewed by program element in the Office of the Secretary of Defense (OSD), which looks for unusual growth or shrinkage. OSD budget negotiations with the services follow, and the resulting revised submissions are consolidated into the Presidential Budget submission. This is where there lately has been some bruising redirection of Air Force thinking on spending. For example, the Air Force tried to gain $94 million in 6.4 funds in the FY 1999 budget by reclassifying the Space Based Laser (SBL) and Discoverer II programs as having "significant" S&T content, shifting both programs from Engineering Manufacturing Development (EMD) to S&T. Again in FY 2001, the Air Force wants to cut $50 million—about 25%—from the S&T account.

The strength of R&D institutional advocacy at key points in the late stages of the four-level Air Force budget decision-making process is cause for concern. This is where tradeoffs are made among readiness, modernization and R&D, and R&D is one of over 600 programs being weighed. Although there are many influential R&D champions in the Air Force, their influence is not apparent in the latter stages of the resource allocation process. This lack of timely advocacy may well explain why overall funding levels are spiraling down from their historical 2% level, a matter of grave concern. There also seem to be too many bureaucratic layers between the Air Force Research Laboratory (AFRL), the major commands, OSD, and the Congress that the Air Force R&D program submission must pass through.

Joint Projects. The cascade of R&D reprogrammings that followed last year's SBL/Discoverer II funding change seriously upset existing Air Force commitments to programs that share R&D costs with the other services and industry. Such "Reliance" programs began 5 years ago, when the services agreed to share facilities and processes as part of DoD attempts to create savings within the services. Reliance programs meld R&D needs to vision statements like Joint Vision 2010. The Air Force-administered and very successful Integrated High Performance Turbine Engine Technology (IHPTET) program is one example. Although shared funding would seem to benefit the resource-strapped Air Force R&D program, the Air Force has previously attempted to withdraw from other Reliance programs, such as high-performance powerplants and hypersonic and missile propulsion. But OSD maintains "robust" oversight of these programs and has thwarted Air Force attempts to pull out of them.

Erratic Implementation. Because of irregular funding, then-Assistant Secretary Welch noted a decade ago that "financial stability and program stability" were missing from what was otherwise a "well-understood and well-structured acquisition process."[45] Industry notes that long-term development is being adversely affected by varying funding levels, which lead to erratic research programs. Funding stability involves two issues: stability within overall DoD funding from year to year, and stability within each service's funding. OSD claims to be "working very hard" [46] on overall S&T funding—with Congress and with the services to assure a "fairly stable number of dollars." But degradation in service Future Years Defense Programs is a concern as programmed obligations turn into expenditures. For example, in FY 1996, when Air Force TOA was $72.992 billion, the projected S&T budget for FY 1999 was nearly $1.5 billion. But 3 years later, actual FY 1999 S&T budget authority was about $1.175 billion, down nearly 22% from those earlier projections, even though actual authority only shrank 12.3% over the same period (see Appendix B). This indicates that program managers have as little control over their planned budgets as they have over their authority to spend.

[45] Canan, op. cit., p. 93.

[46] The quotations that follow come from an interview with Dr. Dolores M. Etter, deputy under secretary of defense for science and technology, April 23, 1999.

Assessing Competing Priorities

Based on budget results, there seems to be a lack of committment on the part of the Air Force concerning the need to invest in a stable, robust S&T and R&D base, not necessarily tied to emerging weapons systems programs. The S&T base in the 1960s that produced AWACS, JSTARS, LANTIRN, AMRAAM, IR Maverick, and the F-117 was founded on many technological projects and on a great deal of risk—including some projects that did not succeed.

The focus of the major commands, and that of Air Force headquarters, is apparently now on near-term payoff and relevance to the existing mission. There is no countervailing Air Force entity arguing for long-term investment and long-term payoff. The reorganized R&D system seems to provide admirable connectivity between customer needs and the requisite technology, although there continues to be criticism indicating that this may be unevenly applied.

But as General Marsh has declared, the conventional requirements process "tends mainly to seek improved variations on existing systems." Without "zealous advocates" "frequently" operating "in the face of a 'show-me' attitude, or even a negative attitude on the part of the operational community and approval authorities," the Air Force risks becoming trapped in a process where needs "pull" technologies into use, unlike the former "push" process, with the result that "we will become trapped in incrementalism and fail to achieve important outflanking capabilities."[47]

There is now a perception that important technologies, such as hypersonics, are being ignored for lack of direct weapon system application. The AFOSR director has himself indicated that even basic research is only initiated if it is considered to have military relevance.[48] Others have warned that the argument for relevance, which is particularly prevalent in times of scarce funding, tends to weed out promising technology not directly coupled to existing or emerging systems.[49] Then-Secretary of the Air Force Edward C. Aldridge said in 1988: "We're on the road to destroying our industrial base" through policies that tend to discourage the risky innovations "necessary to move our technology forward."[50] These admonitions all stress the need for a balance between short-term relevance and the longer-term technology needs identified in the Air Force's own forecast documents.

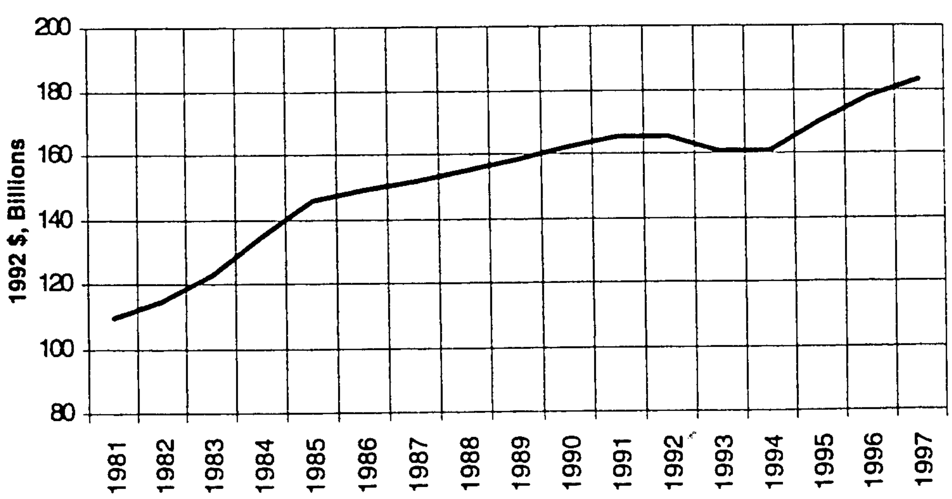
[47] Marsh, op. cit., p 84.

[48] Janni interview, op. cit.

[49] This point was stressed by the Office of Technology Assessment a decade ago. It was also reiterated as recently as 1997 by the Center for Strategic and International Studies, which noted that "industry is not making up for reduced DoD R&D funding" in critical air- and space-related technologies. See Air and Space Power in the New Millennium, op. cit.

[50] James W. Canan, "Backlash for the R&D SuperStandard," AIR FORCE Magazine, March 1988, p. 94.

TOTAL U.S. R&D



Although total U.S. research and development investment continues to increase, little of this is of military use. (These figures are shown in 1992 dollars. Source: Aerospace Industries Association.)

Some technologies which have been pushed aside recently:

- Hypersonics. In 1983, the Advanced Military Spacelift Capability program looked at a hypersonic aerospace plane. Then in 1986 the National Aerospace Plane became a major program. Hypersonic interceptor and hypervelocity weapons were on the 1986 Forecast II list of needs, but were immediately dropped upon cancellation of NASP, despite the views of those like John J. Welch, Jr., then assistant secretary of the Air Force for Acquisition, who said about the National Aerospace Plane and X-30: "We know that the Air Force must be out in front in getting an industrial base for hypersonic technology so that we can be confident of being able to operate in the hypervelocity regime." Welch continued: "Our job is to manage the risks, not to avoid them ...we're not in a risk-free business." The bottom line: "If you want us to be free of risk," he said, "you will not have programs that will keep us the most admired and respected defense capability in the free world."[51]

- Scramjets. Supersonic combustion ramjets (scramjets) are a central part of efforts to develop hypersonic airbreathing propulsion. By using deceleration of the oncoming airstream instead of rotating machinery to compress the flow, they simplify the structure of aircraft engines and provide thrust over an extremely wide range of flight Mach numbers.[52] AFRL continues joint research in this area, but it is not a priority, and recent severe funding cuts have demanded force reductions which are affecting many space-centered programs.

- Ultralight, ultrastrength materials. Under its Future-X program, NASA is investigating reducing the weight of reusable launch vehicles, but the Air Force share of funding for this research is low, and the priority is low.

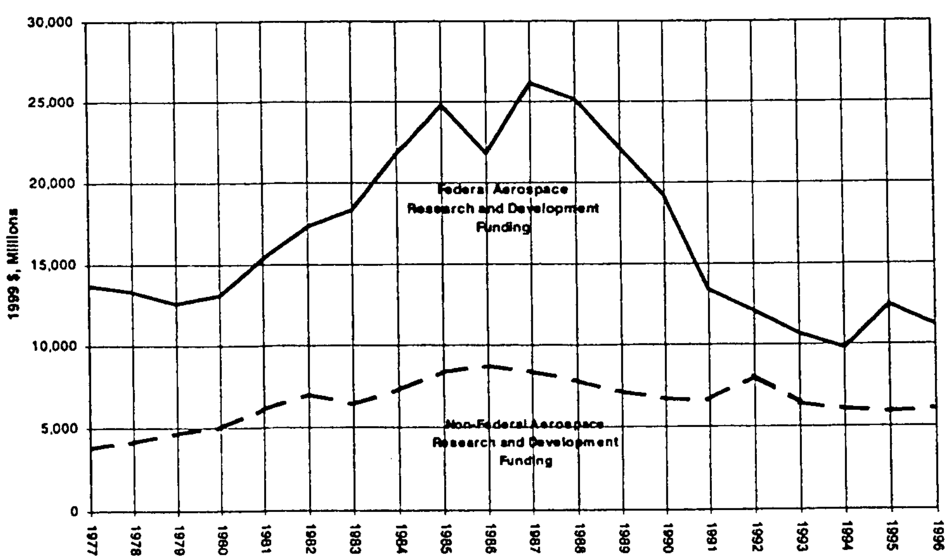
- Advanced directed energy. Most Air Force directed energy research is now centered on ABL.

- Spacecraft defender. Orbital vehicle research is poorly funded, since most of the 6.2-6.3 money for space is now being taken up by the SBL and Discoverer II programs.

[51] Canan, op. cit., p. 95.

[52] New World Vistas, op. cit., "Aircraft and Propulsion Volume," p. 56.

AEROSPACE R&D FUNDING



Overall U.S. research and development investment in aerospace has dropped — most dramatically in government funding. Source: Aerospace Industries Association.

The Industrial Context

The paucity of S&T funding in the last decade has eroded traditional Air Force technology strengths like electronic warfare. At the same time, industry basic research has shrunk dramatically, with a much shorter time horizon than 20-30 years ago. The Air Force's aim, as one planner said recently, should be to "maintain a technological lead of 5-10 years" over potential adversaries, but the Air Force "can't rely dominantly" on industry for basic research. "Alarming"[53] DoD reductions in 6.1, 6.2 and 6.3 funding are being made based on the apparently invalid premise that industry will pick up the difference. As Gen. Lawrence A. Skantze has noted, DoD was the "dominant" user of U.S. industrial technology 25 years ago and on the "leading edge" of avionics and software development. "That has totally changed. DoD is now a minor user, and today the avionics and software state-of-the-art is the most dynamic and dominant technology development in the industrial world."[54]

The commercial space market has also grown about 50% since 1988, with increased associated R&D into, for example, microminiaturized components and new data compression techniques. There definitely are potential military benefits here in the area of avionics and navigation. OSD maintains that DoD "absolutely" has to start "depending more" on industry so that the military can "focus more on those things that industry is not going to do."[55] But defense industry leaders point out that the market drives industry towards research only in areas where it sees a profitable market. If the military has voiced a requirement, research is likely; without a clear need—indicating a future market—such research is unlikely.

For its part, the Air Force clearly needs to push those unique technologies that are not being funded internally by industry. This situation has not changed since the 1980s, when it was pointed out that the defense technology base was becoming "largely inseparable from" the national technology base.[56] The Aerospace Industries Association reports that DoD now accounts for only 29% of aerospace industrial sales, down from 53% in 1988.[57] Since 1989, the government role in RDT&E has been receding, and R&D has more and more become an industry-financed program—"up about 50%"—with "spin-on"[58] benefits accruing to the government. In 1977, industry invested $1 for each $4 in federal funding. Today this is $1 to $2. The federal contribution to industry R&D has held steady since 1994 at about $20 billion, but the overall portion has dropped to about 17% of total investment. Overall U.S. R&D, as a percentage of gross domestic product, is at about at the same level as it was in 1983.[59]

Government reliance on industrial R&D is not without risks. The Committee for National Security found that industries were devoting 80-90% of their R&D resources to short-term product development and process improvement. "We are thus seeing a gap in the innovation system, in funding for mid- and long-range R&D, which threatens to dry up the wells of new technology. Pressure to realize near-term returns is aggravating, in particular, the gap in R&D in the 5- to 7-year time frame."[60]

Business now looks for return on investment in as little as 6-12 months.[61] Industry also considers defense-related R&D to be highly unstable, excessively complex, and characterized by high risk, restricted cash flow and low financial return.[62] Whereas, over the last few years, particularly because of widespread mergers and the resulting economics, industry has adopted an R&D philosophy that is "relatively short-term" (less than 10-15 years), DoD needs to concentrate on "long-term," "unique" research. Industry views the DoD as a customer but no longer as the cus-

53 CSIS, op. cit., p. 145.

54 Gen. Lawrence A. Skantze, "The Legacy Systems Challenge," ARMED FORCES JOURNAL, December 1998, p. 38.

55 Etter interview, op. cit.

56 U.S. Congress, Office of Technology Assessment, The Defense Technology Base: Introduction & Overview, GPO, Washington, D.C., March 1988, p. 5.

57 Interview with John W. Douglass, president, Aerospace Industries Association, April 28, 1999.

58 "Spin-off" involves civilian products resulting from defense research; "spin-on," by contrast, involves products or processes of use to the defense industry resulting from civilian research.

59 Douglass interview, op. cit.

60 Committee for National Security, op. cit., p. 63.

61 Interview with Richard R. Ramseyer, director, business development, Honeywell Technology Center, April 28, 1999.

62 Defense Science Board, The Defense Industrial and Technology Base, Office of the Under Secretary of Defense for Acquisition, Washington D.C., October 1988.

tomer. It will not undertake unique military-related R&D unless funded, because the resulting technology is "different" from civilian needs: tolerances and precision requirements are higher, the market is too small, and funding is too erratic.[63]

There are, however, strong arguments for government risk-sharing with industry. In fact, industry's response to shared funding seems to be positive: AFRL reports that its government-industry programs are very active and that industry is proposing more funding for projects than is required. Today's industry chorus is "show me the money": the military must at least share R&D costs.

The investment of such "seed money" is a tremendous enabler leading to technology beneficial to the Air Force, the government, and the nation. In some technical areas—communications, information technology, microelectronics—such funding is no longer needed. But in other areas—like propulsion, space engineering, directed energy, nuclear power, and stealth—industry still depends on the DoD to fund exploratory S&T. Additional areas where the Air Force needs to continue funding vital interests are large system integration and information protection, both of which are fundamental to development of the future military "system of systems" called for in Joint Vision 2010.

Since industry is extremely market focused, technology development may be at risk if the government pulls out of research altogether. For example, the Boeing Company's recent decision to withdraw from research on the High Speed Civil Transport was dictated by what Boeing perceived as the lack of a customer, and it preceded the withdrawal of NASA from the same research after Congress canceled its funding. All work on this crucial technology was thus suspended.

"If government fails to support advances in pre-commercial technologies, at least on a cost-shared basis, it is very likely that they will not get developed."[64] Meanwhile, the industry asserts that, "right at the same time when DoD is divesting itself of all of its applied research, so is NASA and so is FAA."[65] And no one is looking at the "big picture"—the national research and development investment in aerospace.

There are other "warning signs" of a "real structural problem." Total investment in aerospace R&D is now "less than 8%" of national R&D investment. The president of the Aerospace Industries Association puts the structural issue this way: "Can we live in a long-term competitive global economy with only 8% of our national investment going into aerospace?"[66]

To counter reductions in military R&D budgets and keep industry involved, the DoD espouses a *Dual-action Technology Policy*, recognizing that we "can no longer afford two distinct industrial bases." This process "allows our armed forces to exploit the rapid rate of innovation of commercial industry to meet defense needs."[67] At the AFRL level, this philosophy is represented in programs including dual use, Independent Research and Development (IR&D), and Small Business Innovation Research (SBIR): "the flagships" of Department of Defense research which "everyone else benchmarks against" in government-industry relations. AFRL manages these programs and monitors areas where the Air Force should be doing research and where industry research can be used.

- SBIR research concentrates on concepts leading to products in 3 years or less: 9 months for a Phase 1 first look and 2 more years in concept development if chances look good. Ideas come from industry but respond to military requirements.

- IR&D includes some 4,000 programs run by 100 companies—about 95% of the aerospace industry—totaling some $2 billion. IR&D proposals are

Air Force Research and Development Demands Investment

[63] Ramseyer interview, op. cit.

[64] Committee for National Security, op. cit., p. 63.

[65] Douglass interview, op. cit.

[66] Douglass interview, op. cit.

[67] Both of these quotations are from the Committee for National Security, op. cit., p. ii.

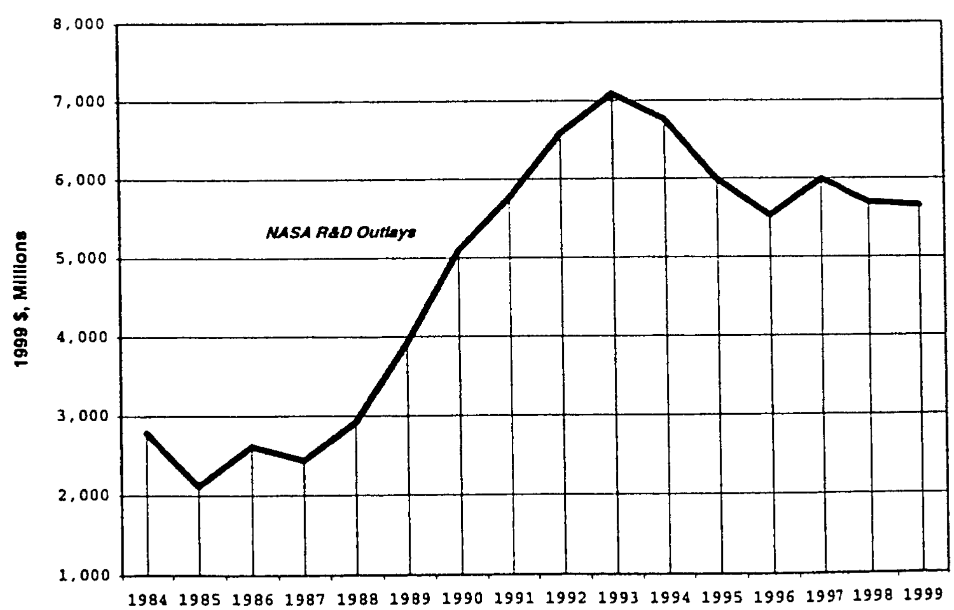
submitted voluntarily to the Defense Technology Information Center, where they are extensively researched against all U.S. Government R&D, using 170 specific Air Force needs centered on operational systems. IR&D is done by industry with government funding, and this program allows the military to ride along. Information is proprietary. As General Skantze has pointed out recently, such a shift to commercial technology "is critical," especially in avionics, where the "capacity growth rate in both memory and processor chips is 40% per year."[68] He makes a good point. Other industrial R&D of government interest totaled nearly $140 billion in FY 1998.

- The dual-use S&T program is congressionally mandated, facilitated by the OSD Director of Defense Research & Engineering (DDR&E) and funded jointly by the services. This program has opened up Air Force S&T to industry. Funding is 50% by industry, 25% by the DoD Dual Use Science & Technology Program, and 25% by USAF (usually AFRL). The military pays until a technology matures (i.e., through 6.3), then leaves industry to carry it to market. The military then benefits by buying the products. If the technology is "too risky," this military contribution will often get industry "off the dime."[69] This also prevents the military from having to reproduce 6.1-6.2 testing leading to a military product. The FY 2000 USAF contribution is $17.9 million, and it will continue at the $19-20 million level through FY 2004. Duration and funding levels are proposed by industry, not government, so research can be tied to industry's return-on-investment time limits. The dual-use S&T program seems to provide a positive answer to the question: Will industry do R&D for the military? Industry has to spend a dollar for every military dollar spent. When DARPA recently went out with $500 million in seed money, it received $6.8 billion in proposals—a 13:1 exchange. Another example of this is "Warfighter-1," a commercial imaging program 74.5% paid by Orbital

[68] Skantze, op. cit., pp 39.

[69] Briefing by Richard Flake, AFRL/XPTT dual use S&T program manager, May 6, 1999.

NASA R&D INVESTMENT



At the same time that Air Force research and development investment has been dropping, so, too, has R&D spending by NASA. Source: Aerospace Industries Association.

Sciences Corp. and 25.5% by AFRL. Hyperspectral images will ultimately be sold commercially and also made available to the military.

Although some industries—like information technology—are driven by their markets into new areas of technology, the application of this research to military needs may be limited. Special research may be required for weapons systems, but, even in that case, future support for the resulting military systems will be problematic because of rapid generational turnover in the civilian technology marketplace. Also, market-based research is incremental, and does not provide the quantum leaps needed to keep ahead in military weaponry.[70]

Additionally, knowledgeable Air Force oversight is essential for such industrial research into unique military applications. As the cadre of Air Force officers involved has shrunk, this oversight has become less comprehensive and informed, another consequence of the erosion in the stature of R&D as an Air Force career opportunity. To assure continued attention to its vital needs, the Air Force should identify critical core technologies and develop high-quality internal research capabilities to investigate them.

Several critical technologies are perceived as not being supported by industry, e.g., electronic hardening, ballistic missile protection, munitions, detectors, anti-chemical warfare (CW)/anti-biological warfare (BW) agents. Other technologies of concern include engines, avionics, precision-guided munitions, stores separation, aeromechanics, computational fluid dynamics, stability and control, aerodynamics, propulsion integration, analysis and testing, air vehicle design synthesis, operational flight software, manufacturing technology, and low observables (stealth).[71] The following chart illustrates the broad areas and where research is expected to be funded:

[70] Interview with Robert Haffa, Northrop-Grumman Analysis Center, April 9, 1999.

[71] Douglass interview, op. cit.

New Technologies	Source of Development Funding
Information	Industry
Precision targeting, strike	Industry, DoD
Long-range strike	DoD, USAF
Air and space survivability	USAF, NRO
Stealth, counterstealth	DoD, USAF
All-weather strike	USAF
Noncooperative Identification Friend-or-Foe (IFF)	USAF
Space operations vehicle	Industry, USAF
Hypersonic projectiles	USAF
Hyperspectral imaging	Industry, USAF
Space-based laser	USAF

Is the Future Really a Priority?

This report has documented a continuous, precipitous decline in Air Force basic research funding, a drop in Air Force applied research investment—the "seed corn" of the future—and a reduction in technology demonstration funding. These trends suggest that R&D has not been treated as an Air Force priority, which leads to a more important question: Is the future a priority of the Air Force?

Despite Air Force protestations to the contrary, and in the face of a profusion of visionary forecast documents, the budgetary and planning actions of the Air Force seem to reflect an intent to carry the past into the future rather than to innovate. Items:

- As documented extensively in this report, R&D has been deliberately used as a funding source, with funds diverted to help fund mature technologies for procurement and Operations & Maintenance (O&M) needs. As a result, the amount of new technology being developed is constantly decreasing—in quality and quantity.

- In the latest episode of programmatic manipulation, the Air Force returned the Space-Based Laser and Discoverer II programs to 6.3 S&T status (they had been moved into engineering development status in FY 1997), creating the impression that research into space was increasing, but requiring at the same time that the existing S&T budget cough up the funding—$94 million in FY 2000, $131 million in FY 2001, and more to follow—to keep the two programs going. Many existing S&T programs—including other space projects—were badly damaged, while nearly $3 billion was freed up for non-R&D expenses over the coming FYDP period.

- In prior fiscal years, the Air Force tried to cut R&D as much as 50% and only restored the funding when it was directed to do so by OSD.

- In FY 1997, the Air Force made a poorly coordinated attempt to eliminate graduate studies at the Air Force Institute of Technology, the training ground each year for some 550 R&D-specialist officers. By doing so, the Air Force in effect decided to shortchange its future ability to initiate or properly manage new technologies. More immediately, it sent a strong message to officers that there is no longer an R&D career track within the Air Force.

Air Force research and development continues to suffer most from a lack of funding. Although the Air Force has an extensive planning infrastructure throughout all levels of the superstructure, it is not protecting the very R&D needs that this planning highlights, partly because of a multi-layered programming process that does not include R&D advocacy at the highest levels. At the same time, the Air Force must have the flexibility to adjust its resources to provide and sustain a robust S&T program.

Air Force R&D organizations have extensive ties to industry's R&D capabilities, but industry takes a market-centric view. The Air Force, therefore, cannot and should not count on industry to make up for its shortfalls in basic research and development.

Air Force R&D is synonymous with the future of the Air Force. By neglecting R&D, the Department of Defense and the Air Force have shortchanged the nation's future military-technological edge. Recovery from this failure to invest cannot be measured in time — it is a mistake that could cost the nation dearly on future battlefields.

Appendix A

Broad areas of interest against which the Air Force Office of Scientific Research evaluates research proposals from academia and industry. Proposals must have military relevance.

Aerospace and materials sciences

- Structural mechanics
- Mechanics of composite materials
- Unsteady aerodynamics and hypersonics
- Turbulence and rotating flows
- Combustion and diagnostics
- Space power and propulsion
- Metallic materials
- Ceramics and nonmetallic materials
- Organic matrix composites

Physics and electronics

- Plasma physics
- Space electronics
- Atomic and molecular physics
- Imaging physics
- Optoelectronic information processing
- Optical and photonic physics
- Quantum electronic solids
- Semiconductor materials
- Electromagnetic materials

Chemistry and life sciences

- Polymer chemistry
- Surface science
- Theoretical chemistry
- Molecular dynamics
- Chronobiology and neural adaptation
- Perception and cognition
- Sensory systems
- Bioenvironmental science

Mathematics and space sciences

- Dynamics and control
- Physical mathematics and applied analysis
- Computational mathematics
- External aerodynamics and hypersonics
- Optimization and discrete mathematics
- Signals communication and surveillance
- Software and systems
- Artificial intelligence
- Upper atmosphere physics

Appendix B

R&D INVESTMENT

TY $M	FY1995	FY1996*	FY1997	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005
DoD TOA[1]	254,000.00	254,900.00	251,600.00	250,700.00	256,300.00	262,800.00	269,600.00	277,500.00	284,600.00		
DoD RDT&E[2]	35,400	34,900	37,400	35,900	34,300	32,000	30,900	31,500			
USAF TOA[3]	73,550	72,992	73,216	76,284	76,905	79,128					
USAF 6.1	224.64	216.34	181.66	188.22	209.73	209.51	177.51	178.52	182.01	186.19	200.02
USAF 6.2	640.30	625.99	627.42	546.70	592.26	507.64	536.92	554.35	600.13	631.16	651.26
USAF 6.3	529.10	506.34	432.52	440.91	465.59	465.69	508.96	497.09	474.29	470.56	469.66
Total USAF R&D	1,394.04	1,348.67	1,241.59	1,175.82	1,267.58	1,182.83	1,223.39	1,229.97	1,256.43	1,287.91	1,320.93
FY-00 $M	FY1995	FY1996	FY1997	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005
USAF TOA[3]	81,774.00	79,099	77,680	79,196	78,408	79,128					
USAF 6.1	240.77	227.73	188.05	192.06	210.78	207.02	172.51	170.35	170.42	170.66	179.39
USAF 6.2	686.28	658.93	649.50	557.85	595.24	501.62	521.79	528.96	561.92	578.52	584.09
USAF 6.3	567.09	532.99	447.74	449.91	467.93	460.17	494.61	474.33	444.09	431.31	421.22
Total USAF R&D	1,494.14	1,419.65	1,285.29	1,199.82	1,273.95	1,168.80	1,188.91	1,173.63	1,176.43	1,180.49	1,184.69

NOTES:
1. Source: Assistant Secretary of Air Force, United States Air Force Statistical Digest FY 1997, GPO, Washington D.C., 1998
2. Source: The Military Balance, International Institute of Strategic Studies, London, various years
3. Source: Digest, op. cit. and William S. Cohen, Annual Report to the President and the Congress, Department of Defense, Washington D.C., 1999

—Top table shows USAF S&T funding for FY-1995 to FY-2005. Budget figures for the years 1995-1999 are actual funding levels (then-year dollars). 1999-2005 funding is from FY2000 President's Budget

—Bottom table shows USAF S&T funding from FY-1995 to FY-2005 in constant FY-00 dollars.

Appendix C

List of Acronyms

ABL	Airborne Laser
ACC	Air Combat Command
ACTD	Advanced Concept Technology Demonstration
AF/XPP	Air Force Directorate of Plans and Programs
AFA	Air Force Association
AFAE	Air Force Acquisition Executive
AFB	Air Force Base
AFMC	Air Force Materiel Command
AFMPP	Air Force Modernization Planning Process
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AFSC	Air Force Systems Command
AMC	Air Mobility Command
AMRAAM	Advanced Medium-Range Air-to-Air Missile
ATD	Advanced Technology Demonstration
AWACS	Airborne Warning and Control System
BMDO	Ballistic Missile Defense Organization
BW	Biological warfare
C⁴ISR	Command, control, communications, computers, intelligence, surveillance and reconnaissance
COIL	Chemical oxygen-iodine laser
CSIS	Center for Strategic and International Studies
CW	Chemical warfare
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director of Defense Research and Engineering
DoD	Department of Defense
DTO	Defense Technical Objectives
ECM	Electronics countermeasures
EMD	Engineering manufacturing development
EOB	Electronic order of battle
FAA	Federal Aviation Administration
FY	Fiscal year
FYDP	Future Years Defense Program
GPS	Global Positioning System
IFF	Identification friend or foe
IHPTET	Integrated High Performance Turbine Engine Technology
IO	Information operations
IOC	Initial operational capability
IPT	Integrated Product, Process, or Project Team
IR	Infrared
IR&D	Independent research and development
IW	Information warfare
JSEAD	Joint suppression of enemy air defenses
JSTARS	Joint Surveillance Target Attack Radar System
LANTIRN	Low-Altitude Navigation and Targeting Infrared for Night
MAJCOM	Major command
MSTAR	Moving/Stationary Targeting and Recognition
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
NATO	North Atlantic Treaty Organization
NRO	National Reconnaissance Office
O&M	Operations and maintenance
OSD	Office of the Secretary of Defense
PEO	Program executive office
POM	Program Objective Memorandum

QDR	Quadrennial Defense Review
RDT&E	Research, Development, Testing, and Evaluation
S&T	Science and Technology
SBIR	Small Business Innovation Research
SBIRS	Space-Based Infrared System
SBL	Space-Based Laser
TOA	Total obligational authority
UAV	Unmanned Aerial Vehicle
WMD	Weapons of Mass Destruction

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