Document created: 29 September 99

The First Essential of Airpower: The Case for Air Force Laboratories

Maj Daniel E. Bullock

The first essential of airpower is pre-eminence in research.

General Henry H. (Hap) Arnold

In 1944 General Hap Arnold made the above statement, one so powerful the commander of the Air Force Research Laboratory (AFRL) uses it on his closing chart in many of his briefings. In this day of down-sizing and budget-cutting, however, there seems to be a school of thought that there is less need for the Air Force to do laboratory work. Some think that many, if not all, of the basic research and technology development activities of the Air Force are being made unnecessary by the use of off-the-shelf commercial products. Another view is that the Air Force's science and technology (S&T) program can be entirely contracted out to industry and academia. Recent cuts in the Air Force S&T budget imply that technology development is seen by some decision makers as less important than our other needs. I submit, however, that there is a continuing need for laboratories within the Air Force, staffed by civilian and military, performing military-unique technology development, with a balance between in-house and contract efforts, and that we would damage our national defense capability by eliminating them.[1]

The one generalization that can be made with certainty about our scientific era is that it will remain uncertain; that the rapid stream of technology will bring new weapons we did not predict.

The Strategy of Technology[2]

We in the Air Force are enamored of technology, and enjoy our self-proclaimed status as the most technologically advanced armed service (whether it's still true or not). The Air Force is a young service, born out of a technological revolution in heavier-than-air flight, and in fact dependent on it. We lionize the likes of Douhet, Trenchard, and Mitchell for their innovative thinking on the use of new aviation technology. We like to think we have "the right stuff." We believe, as the air pioneers did, that the airplane revolutionized warfare. Colonel Phillip S. Meilinger, in his article "Ten Propositions Regarding Airpower," proposes as one of his Propositions, "Technology and airpower are integrally and synergistically related."[3] It's part of our culture.

Challenges to the Air Force Laboratories

If the Air Force is known for embracing new technology, why then do I believe there is a need to defend Air Force laboratories? Consider two recent developments that affect the science and technology arena:

Declining funding

First is the steep decline in funding for Air Force S&T. As the Air Force Association says, "the double digit decline in funding support for the S&T effort over the past decade is a matter of serious concern."[4] Let's look at some specifics.

The Air Force S&T budget—which encompasses basic research, applied research, and advanced technology development—has been on a severe downward trend. The fiscal year (FY) 1987 total Air Force S&T budget was $2.26 billion (in FY 1999 dollars); it has been declining ever since. The FY 1997 total was $1.30 billion; FY 1998 was $1.19 billion, and FY 1999 is $1.17 billion.[5] In the FY 2000 President's Budget it looks slightly better, at $1.18 billion, but in fact, is worse: at this writing, it includes the addition of two major space programs—Space Based Laser and Discoverer II Space Based Radar—without any accompanying increase in funding. These programs will cost $92.5 million in FY 2000, resulting in an effective budget for the rest of the S&T program of $1.09 billion. U.S. Representative Tony Hall, in a letter to Acting Secretary of the Air Force F. Whitten Peters, said the proposed FY 2000 funding would result in the loss of about 10 percent of the Air Force's current research work, and said, "Deep cuts in the science and technology program will destroy significant research capabilities of the Air Force—capabilities which were built up over many years and which would take many years to restore."[6]

So, what about the much-heralded boosts in defense spending proposed in Washington lately? Will that take care of this trend? Perhaps not. As of the writing of this article, the White House said the President's Budget for FY 2000 included long-term sustained average real increases of about 1 percent annually in total defense funding. Aviation Week and Space Technology, however, reports DoD's combined research, development, test and evaluation funding will decrease from $37.4 billion in 1999 to $34.4 billion in 2000, and by 2005 it will decrease another $200 million.[7] Air Force S&T in the FY 2000 President's Budget does show gradual slight growth from $1.18 billion in FY 2000 to $1.32 billion in FY 2005 (in then-year dollars), but there are two reasons for concern. One is that these amounts constitute 1.8% of the Air Force's total obligation authority in 2000, but decline to 1.6% in 2005.[8] The other is that just such an upward trend in the out years has been part of the President's Budget for the last four fiscal years, but has never been achieved, and the actual trend has continued downward. Whatever comes to pass in future years, the message being sent today is that we care less than we used to about developing new technology for the warfighters.

It could be argued that the cuts in the S&T program are roughly proportionate to other budget and force structure cuts throughout DoD. I suggest, however, that we cannot treat S&T like force structure, acquisition programs, or military construction when parceling out budget cuts. Just because we have decided we can make do with fewer new F-22s, or fewer bases, or fewer people, doesn't mean the required level of technology decreases by the same percentage. The research and development that goes into creating a B-2 bomber is same no matter how many you buy. Some cuts may be appropriate and necessary, but we can't expect to keep the same qualitative military advantage we've enjoyed in the past with a 50% or greater cut in our research budget.

> *Remember that the seed comes first; if you are to reap a harvest of aeronautical development, you must plant the seed called experimental research.*
>
> General Henry H. (Hap) Arnold

Over-dependence on the Promise of Commercial Technology

The recent DoD efforts toward making the most of commercial technology seem to be taken in some circles as evidence that the Air Force need not be engaged in as much, if any, technology development. I share the Air Force Association's concern about that perception:

> Commercial industries—the national industrial base—will now presumably meet defense needs. Certainly the commercial sector can meet many of the military's needs, and acquisition reforms will allow it to meet more of them. Nevertheless, the decline of an industrial base that can meet them in a timely manner remains a matter of serious concern to the Association. The Association remains skeptical that the commercial industrial base can effectively meet unique military needs such as stealth, armor, very-high-performance aircraft, large-caliber guns, deep-earth penetrating munitions, and rocket engines. Many of these technologies have no commercial use and virtually no intersection with commercial industry.[9]

The primary reason for this perception is the vast changes taking place in the way we do our RDT&E business in DoD. Much has been written, spoken, and implemented, in a relatively short time, and it can be easy to misunderstand. Air Force Chief of Staff General Michael E. Ryan said recently, "We must take advantage of new commercial technologies to the maximum extent possible, and use them to help develop new systems with military applications--that's mutual dependency, and it is here to stay."[10] In 1996, General John M. Shalikashvili, then Chairman of the Joint Chiefs of Staff, said, "We must continue to push with all energy acquisition reforms, commercial off-the-shelf opportunities, privatization, outsourcing of non-core activities, and further reductions of our infrastructure."[11] The former Secretary of the Air Force, Dr. Sheila Widnall, said, "It is clear that we will be moving toward increasing reliance on the commercial sector for every aspect of our operations."[12] Dr. Jacques S. Gansler, Under Secretary of Defense for Acquisition and Technology, has spoken of DoD's need for a "Revolution in Business Affairs," and says, "We must learn to capture commercial technology (both product and process technologies) wherever applicable and apply them to defense-unique use."[13] Secretary of Defense William S. Cohen, in his 1998 report to Congress on streamlining acquisition, says, "In many areas, industry is now demonstrating that it does a far better job of staying on the leading edge of technology…DoD must be able to take advantage of this."[14]

It's not hard to see how someone could infer that DoD intends to give up its own in-house technological development capability, and depend entirely on commercial or contractor products. Perhaps this perception is related to the continuing decline in funding. That would be taking acquisition reform principles out of context, however. I believe that's not the road we should go down, and I believe it's not the road our senior leadership intends for us to go down. They are looking for increased use of commercial technology and practices where applicable and cost-effective; my point is that there will still be unique areas where commercial technology and practices are <u>not</u> applicable, and we will need AFRL to be the agent to meet Air Force needs in those areas. We need to understand more clearly the real purpose behind these changes in our way of doing business, and do our part to find the right balance.

We Still Need Technological Superiority

Superiority in military technology is the prerequisite of strategic success.

Strategy Of Technology[15]

As the foundation for the following discussion, note that our top-level guidance is clear about the need for continued technological superiority. Joint Vision 2010 names technological innovation as one of the two "enablers" of our future military capability. It says, "This era will be one of accelerating technological change. Critical advances will have enormous impact on all military forces. Successful adaptation of new and improved technologies may provide great increases in specific capabilities. Conversely, failure to understand and adapt could lead today's militaries into premature obsolescence and greatly increase the risks that such forces will be incapable of effective operations against forces with high technology."[16] Secretary Cohen has said, referring to critics of base closings and other cost saving measures, "ultimately, they need to be prepared to answer the question of how many more casualties they are willing to accept in some future conflict where we don't have the best technology in the hands of our warfighters."[17]

The Air Force understands this, too. Our vision statement, Global Engagement, says "The rate of technological change has accelerated and the nation's future force must keep pace to maintain its military edge. We must reinvigorate the spirit of innovation and creativity that has long been the hallmark of the United States Air Force." [18]

So there appears to be no fundamental disagreement about the need to have the best, most advanced technology in the hands of our military forces—the debate is over how to achieve it, and how much to spend on it.

Risks of Commercial Technology

Why can't the commercial marketplace provide us what we need? Often it can, but becoming completely dependent on commercial developments has three major shortcomings.

One, mentioned above, is the Air Force's need for systems and technologies that have no commercial application. We can use the marketplace for desktop computers, electronic components, even space launch vehicles—but we also need aircraft, weapons, and other systems that just aren't very useful in the civilian world. The private sector develops what it expects to bring a profit on the open market. Many of these products will have military use, of course, but not all.

Ironically, some of the apparently commercial products touted as examples for the military to use have their origin in military-unique research. An example is the Global Positioning System (GPS) program. In 1963-64, a study found that the U.S. needed to give more attention to space-based navigation. Opposed by the services, the GPS program was continued only by order of the Secretary of Defense. Those with vested interests in existing navigation methods, such as LORAN or inertial guidance, didn't want GPS. Individual programs didn't want to fund something that would benefit them, but also benefit many others for free. Finally, in the 1990's, the constellation of GPS satellites was complete and low-cost receivers became available not only for the military, but also for commercial and private recreational use. It would be easy today to say "GPS is an off-the-shelf system, let's use it instead of a mil-spec system," without understanding the long struggle to create it at military expense. If defense dollars had not developed the technology, we would not have a GPS system at all, let alone inexpensive receivers available for off-the-shelf purchase.[19]

Even if we accept that we need military-unique end items, can't we then incorporate commercial technology in military-unique products? Yes, we can—and often do—but that leads us to the second shortcoming in relying exclusively on independent commercial developments. Commercial technology is available in many technical areas, and it is appropriate for us to take advantage of it, but if we can buy it off the shelf, so can others, and they can incorporate it into their military systems as well. In fact, other nations may well be able to take advantage of off-the-shelf technologies more quickly than we do, because they may be more likely to forego militarization, safety concerns, or formal testing. Dr. Robert Hebner, Acting Deputy Director of the National Institute of Standards and Technology, said

> It is obvious that if U.S. military systems are assembled solely from commercially available offerings, then potential adversaries could easily counter—and, perhaps, surpass—our capabilities. Next generation weapons systems must employ advanced technologies not easily available to adversaries. Achieving the optimal balance between commercial technology and security-driven technology development will be a continuing challenge.[20]

Some of these capabilities are being delivered to our potential adversaries on a silver platter. Consider the emerging market in satellite imagery. The Russian satellite SPIN-2 produces images at two-meter resolution, marketed by Aerial Images, Inc., and available on the Internet. Technology Review reports at least two companies are planning to launch satellites in 1999 that will produce one-meter resolution images, and asks, "What if, for example, Saddam Hussein had access to one-meter spy-satellite data during the Gulf War?"[21]

The third shortcoming I see is that even if we do not conduct military unique technology development, others will. Other nations may not have the financial resources we do for military scientific research, but they will do what they can. Some have surpassed us in various areas in the past, and if we wait for commercially available products, we'll just make their job that much easier. Besides, military technologies and products created in one country can quickly migrate to others. Libya has bought Scud-B missiles from Ukraine. France has sold Mirages to Pakistan. Russia is selling anti-tank missiles to Syria.[22] Even though the U.S. leads the world in arms exports, we seem to realize the risk some of these transfers pose: in 1997 we bought 21 MiG-29s from the Republic of Moldova to prevent their sale to Iran.[23]

We need to remember that in this day and age, our friends and enemies are all pursuing opportunities to gain a technological edge. Army Vision 2010 says it well: "While at the moment we have technological superiority, advanced warfighting capabilities are available to any nation with the means to procure them." It's not limited to nations, either. Our enemies now include, as Secretary of State Madeleine Albright has said, "terrorist coalitions that don't answer fully to any government, that operate across national borders and have access to advanced technology."[24] That technology need not be large-scale weapons, such as aircraft, ships, or missiles. It could just as

easily be Sarin nerve gas, backpack-sized nuclear bombs, or the means to conduct cyber-attacks against our computer systems.

> *It is true that technology has a momentum which cannot be halted; but the direction and timing can be changed drastically. The interdependence of technology will eventually produce improvements in weapons whether you want them or not; but it does not guarantee sufficient improvement when the enemy has been devoting considerable effort to his own improvements while you have been waiting for what will come inevitably.*
>
> *Strategy Of Technology*[25]

The Need For Air Force Laboratories

We can see there is good reason, and solid support from the DoD leadership, for fostering technological innovation and development for the military, but why not simply contract it all out? Hire companies or universities to do it for us? Why keep Air Force-unique laboratory facilities? Won't the contractors who develop and produce our weapons systems, under the pressure of competition, offer us the best technological improvements at the best price?

Let's look first at systems acquisition programs. Paying contractors to develop technology as part of systems acquisition programs has a practical limit. We have moved to a new model of defense contracting, where instead of rigidly prescribing what we want the contractors to do and exactly how to do it, we state our performance requirements. We tell the contractors what we want the final products to do, and allow them to choose the best ways to achieve it. This allows greater opportunity for contractors to be innovative and efficient, especially if the contracts are written with proper incentives. The limitation is that contractors are in business to make money, not to create inventions. They are rewarded by their customer, the Government, for delivering a product that meets operational requirements, to be sure, but they are equally rewarded for doing it on schedule and at acceptable cost. They are rewarded by their shareholders for doing it profitably. No contractor will sign a fixed-price contract, or agree to a fixed schedule, to provide something that is not yet technically possible. Expecting military-unique technological innovation (especially basic scientific research) as part of a major acquisition program is not reasonable. (Note that I am speaking here of systems acquisition programs, which develop specific end products or systems. S&T activities are separate from systems acquisition programs, but may provide technologies for their use.)

Looking specifically now at the research side of the acquisition process, AFRL does hire contractors to do much of the Air Force's S&T work—78% of the total FY 1998 AFRL budget went to contracts[26]—but these are projects to conduct basic scientific research and technology development, not to develop and procure specific systems. This relationship with industry and academia is well worth nurturing. I agree with former Secretary Widnall's statement that, "Federal spending on research at universities and in industry is an investment in the future."[27] This is essential so we can take advantage of the knowledge and research capabilities outside the Air Force, and it would be prohibitively expensive to try to duplicate such capability in-house. The greatest value of the Air Force laboratory structure is in pursuing a unified vision of which technology areas should be investigated to meet future Air Force needs, rather than in trying to do all the work itself. AFRL's staff, civilian and military, with proper scientific and engineering expertise, can then direct the work of industry and academic researchers with the focus on that unifying vision.

That said, however, I believe it is still important to maintain some in-house research facilities and personnel, including both military and civilian. One reason is the level of secrecy required in certain areas, such as intelligence, stealth, countermeasures, and the like. Another reason is AFRL's unique facilities and corporate knowledge built up over many years that cannot be easily replaced via contracts. A third is that AFRL can react quickly to changing warfighter needs, and can adjust its priorities and resources in-house to meet the most important requirements. Another is that it can be more cost-effective—I suspect that when we eliminate Government capabilities, only to buy the same capabilities from contractors, we are at least sometimes paying more, not less.

A final reason to maintain an in-house research program is to grow our own managers and leaders. Indeed, if we are to have a unified vision for Air Force S&T, linked to Air Force missions and goals, then the leadership that creates

and pursues that vision, and the project managers who control the contracts, must thoroughly understand the S&T business. Scientific research is a very different discipline from most other military work, and there's no substitute for getting your hands dirty and doing it yourself to understand it.

Having some military personnel in the laboratories is crucial, too, for the same reasons we have military staffers in the Pentagon, military pilots in aircraft program offices, and military engineers in our depots. The field experience brought by military members keeps the work better focused on meeting combat needs, and the laboratory experience they leave with enhances their understanding and abilities in later assignments. A military component also facilitates communication and credibility with AFRL's customers. As Theodore Von Karman said, "Scientific results cannot be used efficiently by soldiers who have no understanding of them, and scientists cannot produce results useful for warfare without an understanding of the operations."

The Defense Science Board Task Force on Outsourcing and Privatization, in its report, Improving the Combat Edge Through Outsourcing, March 1996, concluded that many DoD support functions could be outsourced, resulting in savings and performance improvements. Interestingly, though, the report does not propose outsourcing technological development. It emphasizes support functions much later in the acquisition cycle, mostly in the area of day-to-day support of operational systems—such things as depot maintenance, parts distribution, and disposal. It acknowledged the importance of advanced technology for future warfighting, but didn't propose outsourcing it. Could this be tacit acknowledgement by the Defense Science Board that DoD should maintain its own in-house technology development function?

> *Technological leadership is perishable. If we do not modernize our capabilities, we will be overtaken and surpassed.*
>
> Air Force Association 1998 Statement of Policy

Are The Laboratories Giving Us The Right Stuff?

So we've seen some reasons we still need Air Force laboratories, but do they provide the right results to satisfy our operational requirements? Are they able to respond to user needs and adapt to the acceleration of technological change? Or are they simply sandboxes, places for Ph.D.s to do their research and publish papers without regard for military utility? Are they worth what they cost?

For one thing, there is a clear policy and a well-defined science and technology planning process in DoD and the Air Force. This is documented in Joint Vision 2010, the National Security Science and Technology Strategy, the Basic Research Plan, the Defense Technology Area Plan, Joint Warfighting Science and Technology Plan, AF Policy Directive 61-1 (Management of Science and Technology), and others. I won't describe the details here, but most of the documents are available from the Defense Technical Information Center,[28] or can be found in the Defense Acquisition Deskbook.[29]

The AFRL commander follows this guidance to execute the Air Force S&T program, and considers many competing concerns. He must determine the appropriate investment into each of AFRL's nine technology areas.[30] He must address the various MAJCOMs' requirements. He must divide efforts appropriately across basic research, applied research, and advanced technology development. Does the operational customer get the right results? My view is that there have been some problems in this area, but AFRL is working hard to improve it.

AFRL has recently organized its work along Integrating Technology Thrusts which align with AF core competencies, address major customer needs, have schedules & milestones, and are intended to produce transitionable technology products in 3-6 years. The strategy includes completing the MAJCOMs' highest priority Advanced Technology Demonstrator (ATD) programs. It calls for transitioning 90% of all ATDs, in accordance with Technology Transition Plans co-signed by AFRL, the developer, and the using MAJCOM. One element of the

strategy calls for pursuing affordability technologies which reduce cost of ownership by at least 50% for the four major AF product lines—spacecraft, aircraft, weapons, and command and control. Another is that 50% of technology investment should align with enabling the Expeditionary Aerospace Force structure.

Many of the above initiatives are just now getting underway, but AFRL has a good track record for meeting customers' needs in the past, as well. Any list that would fit in this article would be incomplete, but AFRL and its predecessor organizations have been instrumental in the development of such now-familiar technologies as fly-by-wire flight control systems, radar, jet engines, "smart" munitions, fiber optics, advanced composite materials, and rocket propulsion. The results of AFRL technology development are found in all of today's Air Force aircraft and weapon systems, and AFRL continues to develop new technology in these and other areas of interest to the Air Force.

AFRL also works with industry to produce the best blend of in-house and commercial capability. One example is the **Air Force Independent Research & Development (IR&D) program**. AFRL matches user technology requirements with a database of industry IR&D projects. Customers get quicker solutions to their needs when a match is found with existing industry work; companies get a market for their research work; and AFRL avoids duplicating industry's efforts. Another is the Air Force Small Business Innovation Research (SBIR) Program, managed by AFRL. SBIR stimulates technological innovation by small business, increasing its contribution to Air Force's needs, and fosters commercialization of that technology. Still another is the *Air Force Dual Use Science & Technology (DUS&T) Program, which* cost-shares research projects with industry that have both military utility and commercial potential. *Under DUS&T, AFRL had* 47 projects totaling over $90 million approved in FY 1997 and 1998 for development of dual use technologies.

The operator directly benefits from Air Force laboratories, as well. One example: in the case of upper forward fuselage skin cracking on the C-5A aircraft, a high maintenance problem and potential safety of flight issue, a contractor proposed retrofitting the fleet with acoustically treated engine inlet cowlings to reduce acoustic energy from the engines. AFRL's Air Vehicles Directorate proved that the real cause of the cracking was corrosion, not acoustic energy. The Air Force realized a cost avoidance of over $100 million by not purchasing unnecessary new cowlings.

AFRL provides direct support to customers with TECH CONNECT, a telephone hot line that provides free, one-stop access to Air Force technology information for Air Force users, the rest of DoD, industry, and academia. The TECH CONNECT team not only provides information, they can help with accelerating transition of the technology to those who need it.[31]

Finally, AFRL leverages the Air Force's investment with funding from non-Air Force sources to provide a more robust S&T program than would be possible with Air Force dollars alone. In FY 1998, the Air Force received $994 million—nearly as much as the Air Force's own S&T appropriation—from external sources such as Ballistic Missile Defense Organization and Defense Advanced Research Projects Agency to conduct research in areas of mutual benefit.[32] Eliminating the Air Force's research capability would impact not only the Air Force, but these other customers as well.

Conclusion

I believe these are sound reasons to retain a strong Air Force laboratory system. Admittedly, we can't fully defend Air Force laboratories using strict quantitative return-on-investment. Research is a business, after all, where failure is a success—to determine that one approach to a problem does not work brings you a step closer to one that does work. Some savings are quantifiable; others are not. In this business, we spend now to realize a benefit many years later. How much did we save because of stealth technology, precision-guided munitions, or GPS in the Gulf War? What is it worth to win a war instead of lose it? I believe our past scientific investments have been cost-effective, but the more fundamental reason to maintain a robust Air Force S&T program is that we continue to have need for technological superiority.

Yes, budgets are tight, there are tough tradeoffs to be made, and we must pursue ways of improving our efficiency. AFRL has done much in this respect, and still has much to do. I am convinced, however, that it's a false economy to neglect technology development in general, and an Air Force organic laboratory capability in particular. Air Force laboratories are responsive, capable, and cost-effective, and are working hard to become more so. They have been, and continue to be, instrumental in preventing the United States from having the most expensive luxury in the world—a second-best military.

> *We never want to send our young men and women into a conflict to win 51-49. We want to win our battles 100-0. Providing our people with the most technologically advanced and capable tools we can will assure we have no fair fights.*
>
> *General Michael E. Ryan, Chief of Staff, U.S. Air Force*
>
> *Victory smiles upon those who anticipate changes in the nature of war.*
>
> Giulio Douhet

Notes

1. A note on semantics: The Air Force Research Laboratory (AFRL), formed in 1997, is the Air Force's single laboratory organization. Previously, there were several Air Force laboratories, which are now part of AFRL. In this article, when I speak of laboratories in the plural, I mean the various individual research organizations that make up AFRL. I believe this conveys my meaning without getting mired in the organizational hierarchy.

2. Stefan T. Possony, Jerry E. Pournelle, and Col Francis X. Kane, USAF (Ret.), *The Strategy of Technology (Electronic Edition)*, Chapter 4, "Strategic Analysis." This book has been used as a text at the Service Academies, Air War College, and National War College. It is out of print, but is available electronically on the Internet at www.jerrypournelle.com/Strat.html.

3. Col Phillip S. Meilinger, USAF, "Ten Propositions Regarding Airpower," Air Chronicles Contributors' Corner

4. Air Force Association, *1998 Force Capabilities Policy Paper*

5. These figures are the total of Basic Research (6.1), Applied Research (6.2), and Advanced Technology Development (6.3a). It is the funding appropriated in the DoD budget; it does not include funding received from external customers. Amounts are in constant FY 1999 dollars unless indicated otherwise. Information provided by AFRL/XP.

6. Timothy R. Gaffney, "Deep Job Cuts A Concern," Dayton Daily News, 26 February 1999, 5B

7. David A. Fulghum and Robert Wall, "Pentagon Budget Up, But Research Withers," Aviation Week and Space Technology, 8 February 1999, 28

8. Information provided by AFRL/XP

9. Air Force Association.

10. Gen Michael E. Ryan, Remarks at the National Defense Industrial Association 48th Annual West Coast Dinner, Los Angeles, 6 Feb 1998

11. Gen John M. Shalikashvili, Posture Statement before the Committee on Armed Services, United States Senate, 5 March 1996, 19

12. Secretary of the Air Force Sheila E. Widnall, Air Force Policy Letter Digest, June 1996, Office of the Secretary of the Air Force

13. Under Secretary of Defense for Acquisition and Technology Jacques S. Gansler, "Competition By Design: Building Affordable Weapon Systems For the 21st Century," remarks to the Professional Services Council, Tyson's Corner, Virginia, 1 June 1998

14. Secretary of Defense William S. Cohen, Report To Congress, "Actions To Accelerate The Movement To The New Workforce Vision," (Section 912(c) Report), 1 April 1998

15. Possony, Pournelle, and Kane, Chapter Three, "The Nature of the Technological Process"

16. Joint Vision 2010: America's Military Preparing for Tomorrow, Department of Defense, July 1996, 11

17. Cohen, remarks to the Center for Strategic and International Studies, 22 May 1997.

18. Global Engagement: A Vision for the 21st Century Air Force, Department of the Air Force, 1997

19. This example is described in more detail in *Strategy of Technology* (referenced above), Chapter 2, "**An Overview Of The Recent History of the Technological War."**

20. Dr. Robert Hebner, Acting Deputy Director, National Institute of Standards and Technology, "The Future of Commercial and Military Measurements, Calibrations, and Standards," Remarks at the Ninth Air Force Worldwide Precision Measurement Equipment Laboratory Workshop, June 29, 1998

21. Ivan Amato, "God's Eyes For Sale," Technology Review, March/April 1999, 38. For further discussion of this area, see Lt Col Larry K. Grundhauser, USAF, "Sentinels Rising: Commercial High-Resolution Satellite Imagery and Its Implications for US National Security," Airpower Journal, Winter 1998, 61-81

22. Arms Trade News, December 1996/January 1997 issue and June 1998 issue

23. Cohen, DoD News Briefing on **Cooperative Threat Reduction Initiative, November 4, 1997**

24. Secretary of State Madeleine K. Albright, Remarks at the Carnegie Endowment for International Peace, Washington, D.C., September 17, 1998

25. Possony, Pournelle, and Kane, Chapter 4, "Strategic Analysis"

26. Information provided by AFRL/XP

27. Widnall.

28. See Defense Technical Information Center's index of defense science and technology planning documents at http://www.dtic.mil/dstp/index.html

29. The Defense Acquisition Deskbook is accessible at http://web.deskbook.osd.mil/

30. The nine major technology areas that AFRL is organized along are Air Vehicles, Space Vehicles, Human Effectiveness, Sensors, Information, Directed Energy, Materials and Manufacturing, Munitions, and Propulsion.

31. TECH CONNECT's telephone numbers are toll-free (800) 203-6451, DSN 986-9030, commercial (937) 656-9030

32. Information provided by AFRL/XP

Disclaimer
