Defense Advanced Research Projects Agency

Technology Transition

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FOREWORD

The Defense Advanced Research Projects Agency (DARPA) was created in 1958 to ensure technological superiority for U.S. military forces by fostering innovation and pursuing high-payoff, frequently high-risk projects. Each conflict since that time has demonstrated the wisdom of having an entrepreneurial technical organization unfettered by tradition or conventional thinking. For example, in Operation Desert Storm, the Persian Gulf War of 1990, some of the revolutionary capabilities, such as the F-117 stealth fighter, the Joint Surveillance and Target Attack Radar System (JSTARS), and the Precision Guided Munitions were the direct result of initiatives of this small agency in the preceding years.

Successful though DARPA has been, the introduction of new capabilities into our forces has been relatively slow for a variety of reasons. It is important to examine past transitions of technology to military applications in order to improve the processes and to understand the right investment strategies.

Introducing high-quality military capabilities is obviously important and, historically, has been the department's dominant goal. In today's less certain world, in which many potential adversaries have access to technology almost as rapidly as does the U. S. military, the time it takes to apply new technology takes on new significance. It is hoped that this study will go a long way to focus attention on improving the transition process and timeline.

William J. Perry

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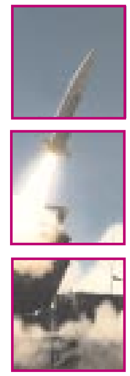

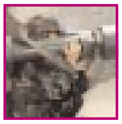

PREFACE

The Advanced Research Projects Agency (ARPA), formally established by the Secretary of Defense in the Department of Defense (DoD) Directive Number 5105.15, dated February 7, 1958, was the culmination of heated debates between the Office of the Secretary of Defense and the Military Departments in response to presidential urgency. While the Agency initially reported to the Secretary, over time the reporting channel was revised so that the Agency reported through the director, Defense Research and Engineering, which is the current mode. Congress endorsed the creation of ARPA in Public Law 85-325, dated February 12, 1958. This law cited the authority of the Secretary of Defense or his designee, "to engage in such advanced projects, essential to the Defense Department's responsibilities in the field of basic applied research and development which pertain to weapon systems and military requirements, as the Secretary of Defense may determine after consideration with the Joint Chiefs of Staff; and for a period of one year from the effective date of this Act, the Secretary of Defense or his designee is further authorized to engage in such advanced space projects as may be designated by the President." It was in the context of this statement that space projects in ARPA were transferred in late 1959 to the Military Departments and the National Aeronautics and Space Administration (NASA).

The DoD Directive explicitly refers to the Agency's being "responsible for the direction or performance of such advanced projects in the field of research and development as the Secretary of Defense shall, from time to time, designate by individual project or by category." At the outset, ARPA was assigned certain space projects in response to national urgency. Nevertheless, enduring characteristics of the Agency, emphasized in debates in the DoD and in Congress, were the need to address a broad range of research and development relevant to more than one Service and to address capabilities for future military systems. In addition, DARPA was chartered to address high-payoff developments that entailed too much risk for others to pursue.

The success of DARPA has been measured historically by the transition of its technologies and concepts into military capabilities in the hands of U.S. forces. By that measure, the Agency has been phenomenally successful, considering its size; scanning the examples in this report will demonstrate that success. In fact, most readers will be surprised to find DARPA initiatives as the sources of many military systems.

The purpose of this study is to examine transitions of the past with an eye to improving the processes and time that it takes to introduce advanced technologies and revolutionary concepts into the Services.

By congressional or presidential direction over the past several years, the name Advanced Research Projects Agency (ARPA) was changed to Defense Advanced Research Project Agency (DARPA), then back to ARPA, and most recently (FY 1996) back to DARPA. Although references in this report refer to both ARPA and DARPA, for simplicity, DARPA is used in the remainder of this report.

ACKNOWLEDGMENTS

DARPA wishes to thank James C. Goodwyn, who with the able assistance of Robert A. Moore, Wesley Jordan, James Richardson, Sven Roosild, Peter Worch, Joe Mangano, Howard Frank, and Duane Adams created this documentation of technology transitions from the Agency to Military Departments, other government organizations, and private industry. The Agency also wishes to thank the military organizations, private industry, former DARPA directors, and former and current staff members who provided valuable inputs to the study. The administrative support provided by Patrick Radoll, Shelli Jurado, Tammy Meade, Tammi Porche, John Sherburne, and Robert Kassel was essential to the successful completion of this effort.

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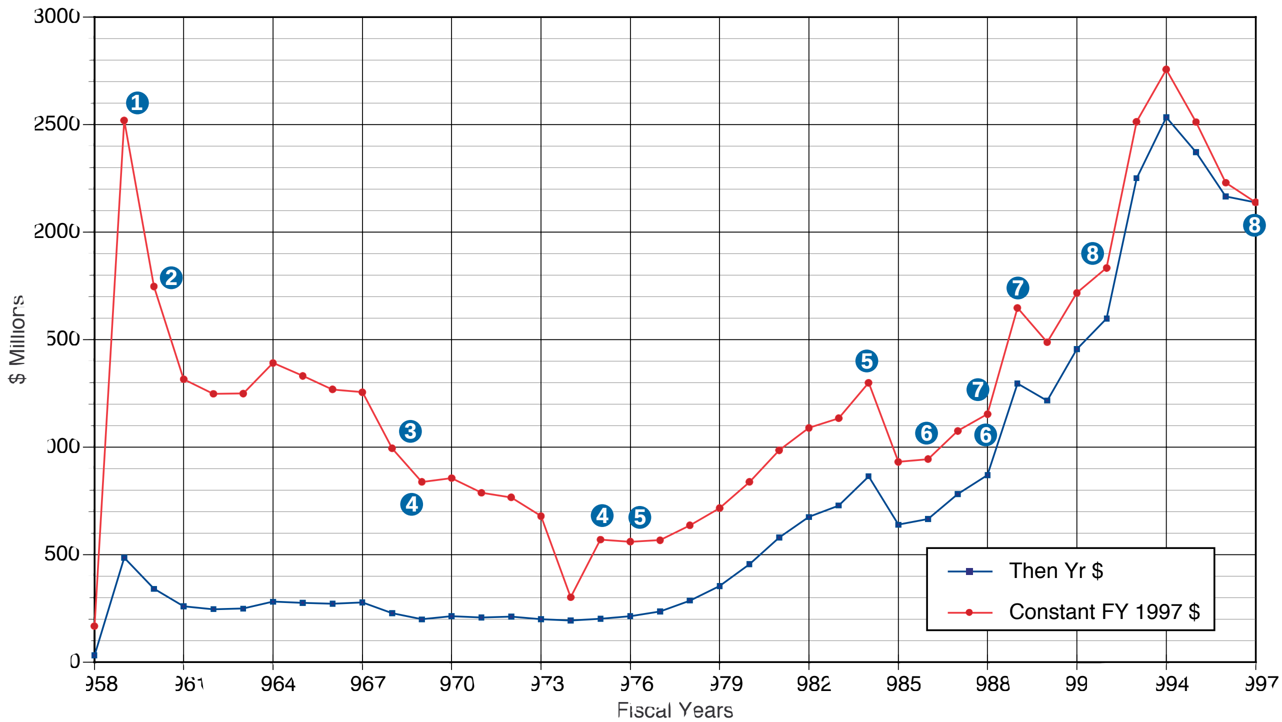
EXECUTIVE SUMMARY

The thrust of DARPA's Research and Development Program has varied over the years in response to external events, such as the Soviet launch of Sputnik, as well as internal DoD needs to continue as a leader in technological advancement and to avoid technological surprises by potential adversarial countries. The perception of this environment by the Office of the Secretary of Defense and the DARPA staff has provided the impetus for the structuring of the Agency program. The response of the Agency to these needs and the limitations of funding available to Defense R&D (research and development) left its imprint on the fiscal history of the Agency. A graphic representation of the funding chronology of DARPA reflects the influence of these factors on the Agency program.

DARPA Budget History



Legend

1. Response to Sputnik
2. Space for Peace
3. Transfer Project Defender to Army
4. Quick reaction support to S.E. Asia
5. Demonstration programs (EEMIT)
6. Submarine technology, Defense manufacturing technology
7. Packard Comm. prototypes, NASP
8. Dual-Use technology development

The funding profile shows external and internal factors that helped shape the Agency's thrusts through the years. These thrusts are expanded and described in the Appendix, and resulting transitions are identified by decade. In constant FY 1997 dollars, DARPA's total budget for its thirty-nine-year existence is approximately $50 billion.

This report focuses on the success stories of the Agency represented by transitions of technologies into the Military Services and other agencies. The ultimate success is achieved when military systems employ the research and development products in hardware and equipment provided to war fighters that enhances their ability to carry out missions.

The survey was made possible by inputs from present and former DARPA staff who managed the technology programs, the military organizations that were partners in many of the programs and recipients of the technology, and by inputs from representatives of private industry who responded with information about the R&D programs they executed. These inputs were invaluable because much of the documentation was unavailable.

Virtually every current military system has been affected to a substantial degree by DARPA work in information technology, microelectronics, and materials.

The approach taken was to document and illustrate those technology transitions for which data were available. Clearly, this process is not all-inclusive; and the reader may recall some technologies not reported herein. In some cases, these technologies may have been considered but not included because the transition could not be documented clearly. However, since a database is being established to retain this history and capture future transitions, new information should be offered to the Agency for consideration and included if it is adequately supported.

In addition to specific technology transitions, three broad categories of transitions are documented in the report: Basic Technologies, Major Transitions, and Prototypes and Advanced Concept Technology Demonstrations (ACTDs). See the introduction for a discussion of these broad categories and specific transition examples.

For decades DARPA has invested in the fundamental technologies that have been most important in the military technological revolution: information technology, microelectronics, and materials. Virtually every current military system has been affected to a substantial degree by DARPA's workin these fundamental technologies. Arguably, the most important and pervasive of these is information technology, and Chapter 1 details the contributions in this area. Similar impacts are clearly found in microelectronics, the obvious basis for computing, among other things. The direct traceability is more difficult to document.

Chapter 2 of the report, titled "Selected Technology Transitions by Users," is a collection of descriptions and illustrations of specific technologies that were implemented in military programs. Some of the most prominent technologies are included in this summary with brief synopses.

■ *Stealth Fighter.*

■ *Stealth Fighter*

Early efforts by DARPA led to the development of the Air Force F-117 tactical fighter that was so successful in the Desert Storm operation, flying 1,271 sorties without a single aircraft loss, penetrating air defenses, and delivering 2,000 tons of ordnance to account for some 40% of all targets with an 80%-85% hit rate.

■ *Affordable Short Takeoff, Vertical Landing (ASTOVL) fighter/aircraft.*

■ *Affordable Short Takeoff, Vertical Landing (ASTOVL)*

The DARPA Affordable Short Takeoff, Vertical Landing (ASTOVL) Program, later called the Common Affordable Lightweight Fighter (CALF) Technology Demonstration Program, investigated the technical feasibility of a lightweight, affordable Short Takeoff, Vertical Landing (STOVL) fighter/attack aircraft and derivative Conventional Takeoff and Landing (CTOL) fighter aircraft for the Air Force. ASTOVL was expanded to include a Navy application and has been transitioned to the DoD Joint Strike Fighter (JSF) Program.

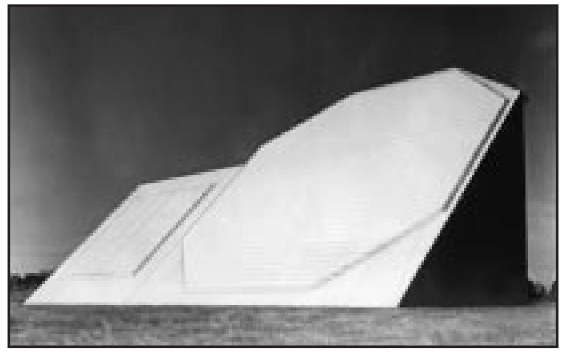
■ *Stealth Bomber.*

■ *Stealth Bomber*

DARPA's support to the design and fabrication of the *TACIT BLUE* low-observable stealth aircraft contributed directly to the development of the B-2 Stealth Bomber. Most notably, the TACIT BLUE was the first aircraft to demonstrate a low radar cross section using curved surfaces, along with a low probability of intercept radar and data link.

■ *Phased Array Radars*

DARPA pioneered the construction of large, ground-based, phased array radars, such as the FPS-85, with a program called Electronically Steered Array Radar (ESAR). The FPS-85 phased array radar had a range of several thousand miles and could detect, track, identify, and catalog earth-orbiting objects and ballistic missiles. The FPS-85 quickly became part of the Air Force SPACETRACK system and is operational today.



■ *Phased Array Radars.*

■ *Joint STARS*

DARPA and the Air Force jointly developed an airborne target acquisition weapon delivery radar program, Pave Mover, under the DARPA Assault Breaker Program. The Pave Mover system was the demonstrator and became the basis for the Joint STARS airborne target detection and weapon assignment program that was so successful in Desert Storm as real-time support to the commanders for both battle area situation assessment and targeting roles. The system is under production and will be operated by the Air Force.

■ *E-8C Joint STARS Aircraft.*

■ *Uncooled Infrared (IR) Sensors*

The U.S. military has "owned the night" because of generations of cryogenically cooled IR sensors. These sensors were a major reason for the ground victory in Desert Storm. Unfortunately, the high cost of cooled sensors has precluded wide distribution to combat troops for human-portable applications. The Low Cost, Uncooled Sensor Program (LOCUSP) at DARPA initially developed, fabricated, and demonstrated this new technology. The uncooled IR technology, furthered under DARPA's dual-use initiatives, is a reality and has been accepted into the Army as a prototype and awaits production for fielding.

■ *Uncooled IR Sensors.*

■ *Head-Mounted Displays.*

■ *Head-Mounted Displays*

This program enabled soldiers to view information from a head-mounted sensor and also from a wearable computer. It developed a capability that never before existed and was not expected to exist until well into the twenty-first century.

DARPA awarded separate development contracts for miniature displays and an integrated head-mounted display system. They were mated under a technology development and integration effort. DARPA's head-mounted subsystem is being integrated into the Army's Land Warrior Program and the Generation II soldier. Both of these Army programs plan to upgrade their systems with DARPA-developed display technologies.

■ *M16 Assault Rifle.*

■ *M16 Assault Rifle*

The M16 Assault Rifle is the standard issue shoulder weapon in the U.S. military. It marks a departure from normal ballistics in that it uses a smaller, high-velocity round (5.56 mm caliber vs. 7.62 mm). This results in a smaller and lighter weapon as well as smaller ammunition, significantly decreasing combat load. The M16 is based on the Colt AR-15. Through Project AGILE, DARPA purchased 1,000 AR-15s and issued them to combat troops in Southeast Asia for field trials. The subsequent DARPA report, documenting the lethality of the AR-15, was instrumental in the adoption of a modified AR-15 as the U.S. military's individual weapon of choice.

■ *Army Tactical Missile System (ATACMS)*

The Army Tactical Missile System (ATACMS) is the centerpiece of the Army's precision strike modernization effort. It is a long-range, quick-response, surface-to-surface artillery rocket system with all-weather, day/night capability to be deployed against a wide range of targets, including critical mobile targets. It saw action during Desert Storm, where it was used to neutralize or destroy several surface-to-air missile sites, a logistics site, a refueling point, vehicles on a pontoon bridge, and other targets.

The parent program to ATACMS was DARPA's Assault Breaker, which was conducted during the late 1970s.

■ *Army Tactical Missile System (ATACMS).*

■ *Tomahawk Cruise Missile Engines*

At the onset of Operation Desert Storm, long-range cruise missiles were employed with great effectiveness against high-priority targets in Iraq.

DARPA played a key role in the early development of the turbofan cruise missile engine. The Individual Mobility System (IMS) Project (1965-69) was a joint effort with the Army, the purpose of which was to extend the range and endurance of the Bell Rocket Belt developed for the Army in the 1950s. With the DARPA funding, Bell replaced the vertical lift rocket system with a compact, highly efficient, turbofan engine that had been developed by Williams Research Corporation. Improved versions of the Williams engine (now the F107 series) power all of the air, surface, and subsurface launched cruise missiles in the Navy and Air Force inventory.

■ *Tomahawk Cruise Missile Engines.*

■ *Endurance Unmanned Air Vehicle.*

■ *Endurance Unmanned Air Vehicles*

DARPA developed the first endurance unmanned aerial vehicle (UAV), Amber. DARPA-developed technologies from that and related programs led to the Gnat 750 UAV, the Air Force-operated Tier 2 Predator UAV that was used in Bosnia. Operating at altitudes of up to 25,000 feet for periods exceeding forty hours, the Predator operated successfully as an element of Exercise Roving Sands in early 1995 and has been deployed to the Bosnia crisis to support UN and NATO operations. Originally a Navy-Army joint effort, the Predator UAV was transitioned to the Air Force in 1995 for operation and maintenance

■ *Cermet Materials for Armor.*

■ *Cermet Materials for Armor*

The Lanxide material discovered by M. Newkirk at Lanxide Corporation has resulted in hundreds of patents. Variations have been used successfully as appliqué armor for the Marine Corps' Light Armored Vehicles (LAV) in Operation Desert Storm (particularly for roof protection from artillery). This insertion was funded by the DARPA ceramic insertion program. Seventy-five LAVs were up-armored. Products were adopted in 1993 for the M-9 Armored Combat Earthmover (ACE) and for several transport aircraft, such as the C-17.

■ *Unmanned Undersea Vehicle.*

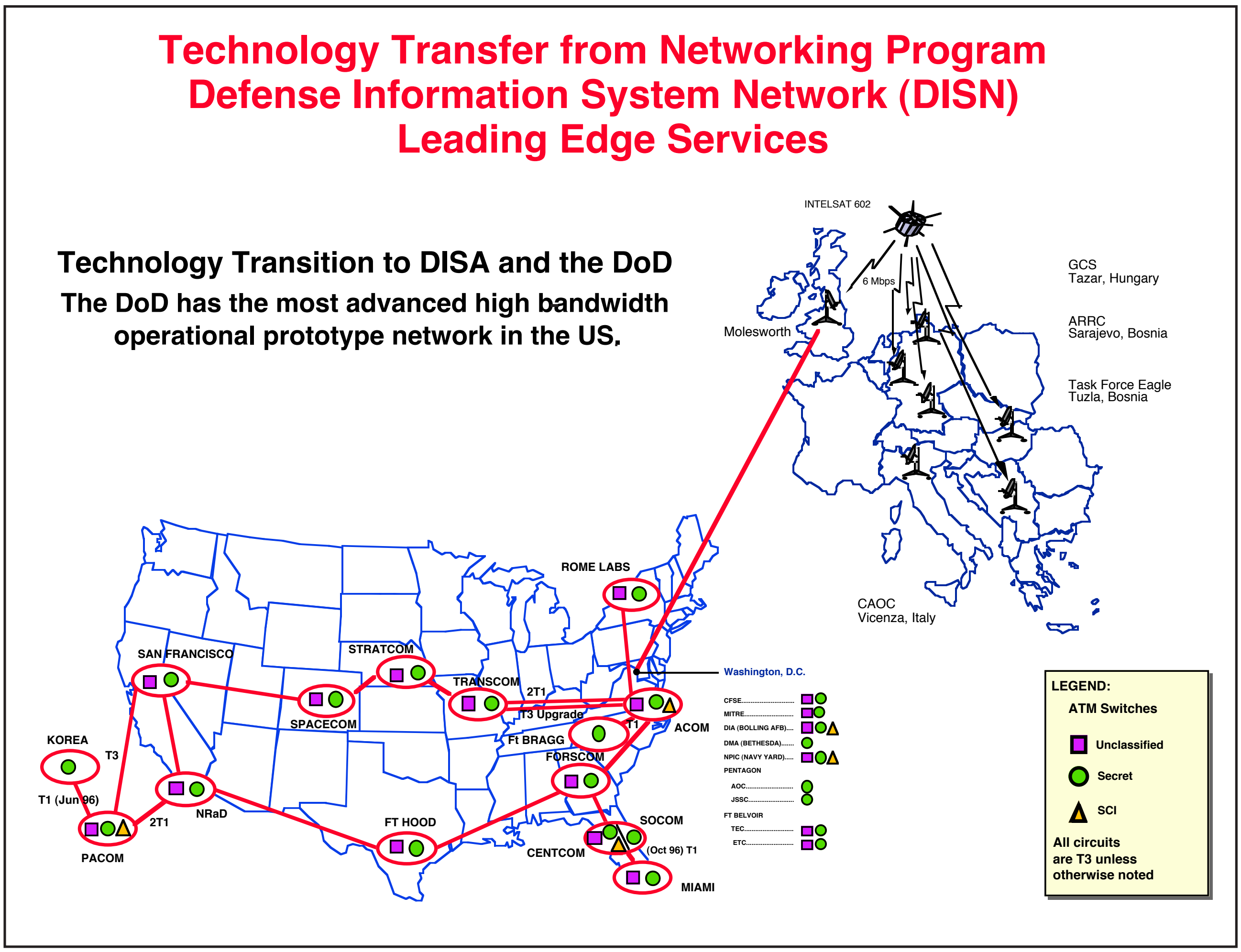
■ *Unmanned Undersea Vehicle*

There are a number of Navy missions in the littoral that cannot be performed safely by a full-sized, manned platform. They include mine location and avoidance as well as remote surveillance. In 1988 a joint DARPA/Navy Unmanned Undersea Vehicle (UUV) Program was initiated with the goal of demonstrating that UUVs could meet specific Navy mission requirements.

The Navy initially pursued a submarine launched UUV that would either guide the submarine through an area that might be mined or search an area for mines. As a result of the end of the Cold War, the Navy revised the program with the objective of developing a tethered shallow water mine reconnaissance vehicle for littoral warfare. A system will be demonstrated in the Joint Mine Countermeasures Advanced Concept Technology Demonstration (ACTD) in 1998.

INFORMATION TECHNOLOGY

DARPA's impact on the military's use of information technology has been pervasive.Technology transition has followed two paths: (1) creation of specific technologies for direct transfer to one or more Services and (2) development of technologies that stimulate revolutionary changes in the commercial market and that result in new commercial off-the-shelf products and services for the DoD. For example, packet switching, implemented in the ARPANet in the 1970s, was adopted first by the Defense Communications Agency for the "Defense Data Network." In the 1980s, the technology was used in the National Science Foundation's NSF Net for research community networking. It then became the dominant network technology throughout private industry and the government.



Another major 1990s network technology development was Asynchronous Transfer Mode (ATM) networking. This technology is becoming the communication industry's broadband voice-data-video technology. Today ATM provides advanced communications capabilities in the DISN Leading Edge Service (DISN LES) operated by the Defense Information Systems Agency (DISA) and has connections to major military locations in the United States and Bosnia.

DARPA's investments in computing are used by all the Services. The common "mouse" and the industry standard graphic user interface originated in DARPA research. The DARPA/Navy Hyper D Project resulted in new distributed computational architectures and systems for shipboard computing. This technology is being implemented in the Navy's Baseline 7 Aegis cruiser, scheduled for completion in 1998. DARPA's software investments resulted in the development of Berkeley Unix, whose use is pervasive in the DoD. DARPA's work on Very Large-Scale Integration (VLSI) energized an entire industry. DARPA's contributions to "open systems" are enabling the Services to migrate from closed, "stovepipe" systems to more affordable standards-based commercial systems.

DARPA's investments in Reduced Instruction Set Computing (RISC) in the 1980s led to today's generation of commercial products from IBM, Sun, Silicon Graphics (SGI), Hewlett Packard (HP), and Intel's next generation P7 microprocessor. DARPA's investments in scalable parallel processing began with the 1970s, Illiac 4 and the 1980s, Strategic Computing Initiative. The world speed record-setting Massively Parallel Processing developments of the 1990s became the basis of industry's mid- and high-end products. These products are acquired routinely by the Services, the intelligence agencies, and DoD's High-Performance Computing Modernization Office. The technology was acquired by the Department of Energy (DoE) for its Advanced Strategic Computing Initiative for nuclear weapons stockpile stewardship.

Factors Contributing to a Successful Transition

The responses from the military and industrial organizations to the requests for transition data included their views of what factors led to successful transition. The factors most frequently cited include the following:

- Vision of need
- Good technology
- Persistence of technologists
- Good working relationship with partners
- Jointly supported programs
- Strong user support
- Transition planning

Afterassessing the transition process from the DARPA perspective, important considerations on the part of participants may be summarized as follows:

DARPA

- Maintain highly qualified staff with direct technical management of all programs.
- Maintain a continuing relationship with operational forces to ensure understanding of military needs.
- Develop a well-prepared plan for transition early in the technology program.
- Set up teaming arrangements with the military organization; make it a joint effort where possible.
- Sustain adequate funding to provide for successful demonstration.
- Establish the need for the technology by showing where it will enhance mission accomplishment.
- Recognize "windows of opportunity" where technology can be inserted into military systems.

Military Services

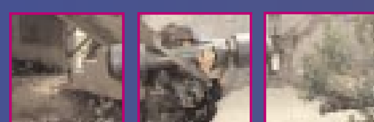
- Assign highly qualified scientists and engineers with vision to work at DARPA and to work at the interface between DARPA and the Service.
- Examine the future generic technology needs of the Service and make them known to DARPA.
- Participate in the transition planning process; establish out-year funding budgets to sustain application of the technologies.
- Support jointly funded technology programs at DARPA.

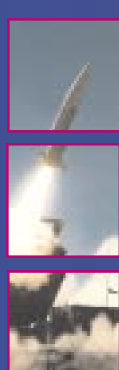
Congress

- Recognize military technology needs that may not be documented in operational requirements.
- Support the risk-taking by DARPA where high payoff potential is shown.
- As a quasi-venture capitalist, recognize the importance of "staying-the-course" where future potential is high.
- Support joint program activity and assist the transition process by demonstrating appropriation flexibility.
- Recognize the impact of earmarking funds on the success of the DARPA programs.

Industry

- Surface good ideas to enhance military capabilities.
- Make technology progress visible to DARPA staff for planning purposes.
- Leverage independent research and development (IR&D) investments by an awareness of DARPA technology thrusts and needs.
- Assist with transition planning through an awareness of military future needs.
- Look for opportunities to insert DARPA-supported technologies into military systems.
- Assist DARPA in making the military aware of the potential for inserting technology into military systems.





INTRODUCTION

INTRODUCTION

This report documents the transition of many DARPA-sponsored technologies to the Military Departments and other organizations for exploitation and illustrates the manner in which the various technologies have been exploited to this time. Since the process of transition is continuously evolving, it is expected that this process will improve with the passage of time. The Agency's goal is for systems derived from DARPA technologies to reach the hands of the war fighter, hence this analysis of transition.

Addressing the Agency's thirty-nine years of support to advanced research and development and attempting to isolate contributing factors to technology transition have been formidable tasks, particularly because of the lack of comprehensive documentation about technology transitions of specific programs. Two documents found most useful to the study are "The Advanced Research Projects Agency," prepared by Richard J. Barber Associates, Washington, D.C., December 1975 (Reference 1) and "DARPA Technical Accomplishments, An Historical Review of Selected DARPA Projects," prepared by the Institute for Defense Analyses, Alexandria, Virginia, July 1991 (Reference 2). Reference 1 provides an historic sketch of the early years of ARPA, descriptions of some of the early technical thrusts of the Agency, some program descriptions, and reminiscences about the early directors of ARPA. Reference 2 addresses the evolution of selected programs considered key by former directors and managers of the Agency. It traces progress through the late 1980s and illustrates involvement of the Military Services in the programs during certain phases. However, neither of these references presents the technology transition process addressed in this study.

The Agency's goal is for systems derived from DARPA technologies to reach the hands of the war fighter.

To supplement the references and various internal DARPA reports, it was considered essential that a wide spectrum of military, industrial, academic, and not-for-profit organizations that have been part of the DARPA process be solicited for information on technology transition. More than 300 such sources were solicited, and excellent responses were received. In addition, former DARPA directors, office directors, and program managers were contacted, as well as the current DARPA staff. Information collected was processed for inclusion in this report, and a "technology transition" computer database was set up to retain the essential information and to receive transition data in the future. A list of sources whose responses were incorporated into the report is in the List of Contributors.

TECHNOLOGY TRANSITION MODES

There are many variations in the processes by which technologies transition from DARPA to programs and military systems. Further, some programs and technologies were transferred from DARPA to an agency or department of the federal government other than the DoD. Many technologies found their way into commercial products or systems and from there frequently back into military systems.

Every DARPA management regime and most professional program managers were concerned about technology transition. Although it is not mandatory at the initiation of a technology effort, eventual endorsement by one or more of the Military Departments is generally sought during the later stages of an effort. Some DARPA programs integrated maturing technologies and demonstrated a new system concept, whereas others developed devices or component technologies that were candidates for new systems or the upgrading of old systems. To illustrate the contributions of DARPA programs to war-fighter capabilities during its history, the technology transitions generally fit into four different modes:

1 *Transfer of the program, the system concept(s), and the enabling technologies.*

- Early space technology programs to NASA
- Project DEFENDER anti-ICBM program to the Army
- Stealth HAVE BLUE program to the Air Force for F-117
- Large Aperture Marine Basic Data Array to the Navy (LAMBDA)
- Directed Energy Technology to BMDO

2 *Transfer of the system concept but not the specific program.*

In this mode, the Service prepares a new operational requirement, issues a Request for Proposals (RFP), and conducts an open competition.

- PRAEIRE UAV technology to the Army converted to AQUILA
- SIMNET technology to the Army became a basis for Combined Arms Tactical Trainer/Close Combat Tactical Trainer (CATT/CCTT)

3 *Transfer of subsystem or component technologies that become key elements or enablers of new service systems or of system upgrades.*

- Electronics–Microwave and Millimeter Wave Monolithic Integrated Circuits (MIMIC), Gallium Arsenide (GaAs) microelectronics, VLSI circuits, IR detectors and focal plane arrays, phased array radars
- Materials–ceramic, carbon-carbon, metal-ceramic matrix composites, rapid solidification rate processing (RSR), explosive forming processes

4 *Transfer of an operational facility or institute established and supported by DARPA and possibly one or more of the Services or other agencies.*

- ARPA Maui Optical Station (AMOS) to the Air Force

■ *Large Aperture Marine Basic Data Array (LAMBDA) to the Navy (SURTASS).*

- Arecibo Ionospheric Observatory to NSF to become the National Astronomy and Ionospheric Observatory (NAIC)

While these transition modes were selected to facilitate the process of tracing DARPA R&D activities that were incorporated into military systems, there are other technology transitions that may not fit the mold. Most notable are the following:

- Extended support by DARPA of basic technologies such as materials, devices, signal processing, and mathematics has played a major role in maintaining a force multiplier via superior military systems. If these technologies were traced to operational systems, DARPA would be found to have enabled or significantly affected virtually every military system.
- Likewise, information technologies focused on by DARPA, such as networking, software development and engineering, artificial intelligence, and neural networks, have permeated most military systems.

An important path for the transition of DARPA technologies to the war-fighting systems historically has been via industry.

While these broad technology areas are ultimately critical to all progress in military technology, this study makes no attempt to trace these diffuse transitions. Only a few of the more direct and clear transitions in these areas are included. Generally, the reader can appreciate the effects of electronics or material technologies. Information technologies will be more difficult to recognize; for that reason, Chapter 1 summarizes the impact of DARPA information technology.

An important path for the transition of DARPA technologies to war fighting systems historically has been via industry. The typical model is described as follows:

- DARPA funds an industrial firm to develop a new capability or to solve a problem.
- When a Military Service seeks proposals for systems to which this capability applies, the firm bids its developed DARPA technology to gain competitive advantage.

This process provides transition, albeit not always in a traceable way. The disadvantage, of course, is the often lengthy delay from technological availability to fighting capability.

BROAD CATEGORIES OF TECHNOLOGY TRANSITION

Three broad categories of technology transition are described in this section: Basic Technologies, which include structural and electronic materials and devices; Major Transitions, such as directed energy, ballistic missile defense (BMD), space surveillance and optics, submarine technology; and Prototypes and ACTDs, which include numerous DARPA experimental technology demonstrators and Advanced Concept Technology Demonstrators more closely coupled to the war fighter.

Basic Technologies

DARPA has understood from its very inception the value of investing in basic technology to enable the U.S. military to obtain the most capable war-fighting systems. Research programs in advanced materials, and electronic devices and circuits have played a major role in DARPA's investment strategy for a long time. This investment has paid high dividends. A great deal of the military leverage, often referred to as the "force multiplier," that our military forces enjoy over all adversaries can be attributed to this foresight. Since the F-15 entered the military inventory, almost every advanced military system has incorporated some technology that would not have happened or would not have been ready in time if DARPA had not had the vision to initiate high-risk, high-payoff basic R&Ds long before anyone envisioned a use for them. A number of such projects have made major contributions to the modern war-fighting systems. To illustrate this point, a few examples follow:

- Rapid solidification rate (RSR) processing of metals enables mixing metals that otherwise would separate because they are nonequilibrium mixtures. Such nonequilibrium combinations can result in multimetal systems that have superior temperature and wear characteristics. One such metal combination is found in the F-100 engine that powers both the F-15 and F-16 fighters as well as the F119 engine designed for the F-22.

- Explosive forming technology was a mid-1960s DARPA project. It developed a cost-effective process for forming a variety of metals and metal alloys that results in remarkably high reproducibility (~0.5%) for complex, large metal structures. Used extensively in DoD projects, the applications include making afterburner rings for the SR-71, jet engine diffusers, Titan "manhole" covers, rocket engine seals, P-3 Orion aircraft skin, tactical missile domes, jet engine sound suppressors, and heat shields for turbine engines.

The SR-71.

■ *Cermet Materials for Armor.*

■ Lightweight "ceramic matrix" tiles are providing armor protection for both Air Force cargo aircraft and Marine Corps Light Armor Vehicles. DARPA sponsored the discovery of a novel materials processing technology that allows for the production of relatively low-cost ceramic composites. In particular, particulate silicon carbide-reinforced aluminum oxide is being attached to vehicles and aircraft via Velcro sheets glued to the surfaces.

■ In the early 1970s DARPA launched a major effort to determine the feasibility of establishing an electronic device technology based on GaAs as the semiconducting material. GaAs had properties that were promising for achieving higher frequencies than the common silicon-based technologies, but it necessitated the use of doping technology based on ion implantation. GaAs high-speed integrated circuits are widespread today, found, for example, in the front end of the Global Positioning System (GPS) receivers and in upgrades to the P-3 Orion Inverse Synthetic Aperture Radar (ISAR) processor and the OH-53D digital signal processor.

■ From 1973 to 1980 DARPA funded the R&D that reduced to practice a totally new concept for obtaining IR images of targets. The utilization of Schottky barriers IR imaging devices built on standard integrated circuit grade silicon enabled the realization of large, two-dimensional arrays of IR-sensitive detectors that are reliable and cost-effective. Tests on a B-52 in the early 1990s proved so successful that the crew retained test units until those in production become available. This IR camera, the AAQ-23, is in production and will be retrofitted to the Air Force's entire B-52 fleet.

An unfortunate truism has been, and to a large extent still is, that basic technology takes up to twenty years to find its way into a military system. This truism is well substantiated by the examples cited above. The transition route is arduous and sometimes extremely difficult to trace. Inclusion of basic technology advancements are never called for directly when new military systems are specified. Military systems project offices consider such demands to be too risky to cost and schedule. It is left to the military systems houses to propose incorporating new basic technology, but they do not have many incentives to take the risk of being the first to utilize a technology that has not been proven in a systems context. In the 1960s and 1970s DARPA spawned numerous technological advances in universities and industrial laboratories, proved their capabilities, and then was often at the mercy of industry, a federally funded research and development center (FFRDC), or an enlightened service laboratory to maintain the expertise until an application came along that needed the technologies. Oftentimes during this "incubation" period, such proven basic technologies are at risk of perishing. DARPA recognized this dilemma in the late 1980s, and subsequently funding has been made available for "insertion programs." At the end of a successful R&D project, prototype subsystems are built utilizing these proven new technologies. Once the advantages of a technology are demonstrated in a military systems environment, the technology is much more readily accepted for enhancing systems performance via upgrades. Prime examples of this process are the insertions of artificial neural networks (ANN) technology into the Comanche helicopter for target recognition and GaAs digital electronics technology into the digital signal processors (DSPs) to improve the resolution of the ISAR on the P-3 Orion.

■ *The Comanche helicopter.*

Major Transitions

■ ***Ballistic Missile Defense (including the Army Ballistic Missile Defense Agency (ABMDA) and the Strategic Defense Initiative Organization (SDIO later BMDO) transitions)***

DARPA, since its inception in 1958, pioneered advanced Ballistic Missile Defense (BMD) technologies that have proven to be essential to providing a quantitative understanding of ballistic missile defense options and to preserving the credibility of U.S. strategic missile systems. These advanced technology efforts formed the basis of two major transitions in which DARPA BMD programs, together with the cognizant program managers, were transitioned to newly formed DoD agencies. These agencies had responsibility for continuing to develop these technologies as well as for continuing critical measurements programs. These focused DARPA technology programs became the foundation of Service BMD programs and were later combined into a single program under the Strategic Defense Initiative by presidential directive in 1983. In 1967 the first of these programs, called Project DEFENDER, was transitioned to the ABMDA, which later became the Army Strategic Defense Command. In 1983 all of the high-power laser programs in the DARPA-Directed Energy Office and the space surveillance technology of the Strategic Technology Office were transitioned to the newly formed Strategic Defense Initiative Organization (SDIO, now BMDO), as were the conventional missile interceptor programs that had grown out of Project DEFENDER within the Army BMD organizations. The Army BMD programs were aimed at negating reentry vehicles in either endo- or exo-atmospheric flight, while the DARPA technology programs were focused on directed energy concepts aimed at midcourse and boost phase kill. The technologies that grew out of these DARPA programs and were subsequently pursued by SDIO are believed to have contributed significantly to ending the Cold War in the late 1980s.

The technologies that grew out of these DARPA programs and were subsequently pursued by SDIO are believed to have contributed significantly to ending the Cold War in the late 1980s.

Early DARPA efforts in BMD were initiated with Project DEFENDER in 1958. This program focused on developing large, electronically steered, phased array radar technology that later became the basis for early warning radars and other large, ground-based space surveillance radars. These service radar systems include AEGIS (Navy), PAVE PAWS (Air Force), and Cobra Dane and SPACE-

TRACK (Air Force). During this time period, DARPA also performed key measurements of target and background signatures (PRESS and TABSTONE) to support BMD concept development and evaluation and to determine the fundamental feasibility of IR satellite early warning systems against Intercontinental Ballistic Missiles (ICBMs) in boost phase. Project PRESS (Pacific Range Electromagnetic Systems Studies), under the DEFENDER program, was the major field measurement element of DARPA's research on the phenomenology of ICBMs' reentry into the earth's atmosphere. The largest part of the DEFENDER Program, PRESS and the Army's follow-on Kiernan ReEntry Measurements System (KREMS) Program, played a key role in ensuring credibility of the U.S. ICBM offensive deterrent and in U.S. decisions concerning BMD R&D and system deployment during the decades of the sixties, seventies, and eighties. Airborne optical and IR measurements, originated under PRESS and continued under DARPA sponsorships within the Strategic Technology Office, have contributed to the design of sensors for midcourse homing intercept systems, which were considered for SDIO systems.

The largest part of the DEFENDER Program, PRESS and the Army's follow-on Kiernan ReEntry Measurements System (KREMS) Program, played a key role in ensuring credibility of the U.S. ICBM offensive deterrent

DARPA recognized early the promise of speed-of-light weapons based on lasers and particle beams, and a major program in developing laser technology that was scalable to the high power levels required by BMD was initiated under the DEFENDER Program. These laser programs remained in the DARPA Strategic Technology Office upon transfer of DEFENDER to the Army in 1967. During the 1970s and 1980s essentially all of the new high-power lasers that were invented resulted from DARPA programs. These new lasers included Solid State Lasers, Gas Dynamic and Electron Beam Sustained CO^2 lasers, HF/DF lasers, rare gas halide lasers, and free electron lasers. These programs spun off laser technology to all three Military Services that sought to develop tactical weapon systems based on these laser systems. In 1980 the Directed Energy Office was formed at DARPA to exploit newly emerging laser and particle beam technologies for BMD applications. During this time, the DARPA Directed Energy Office initiated the TRIAD, which developed low-pressure, high- power HF/DF laser technology (Alpha), large optics (LODE), and ultraprecise laser pointing and tracking technology (Talon Gold) for space-based laser defense against ballistic missiles and aircraft. In addition, ground-based, high-power excimer and free electron laser technology programs were initiated for space defense applications, including defense against satellites. In 1983 all of these high-power laser programs together with cognizant personnel in the Directed Energy Office were transitioned to the newly formed SDIO (now BMDO).

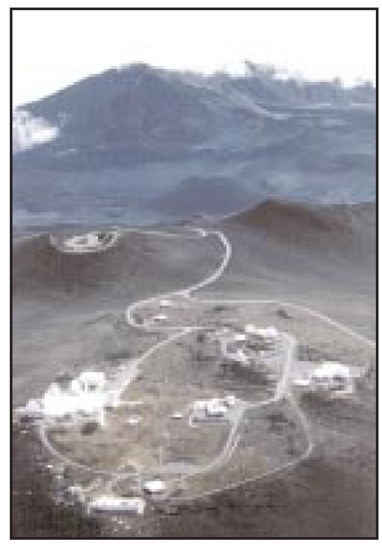
■ *Space-Based Laser.*

■ *Space Surveillance and Optics*

As was noted in the Preface and the Executive Summary of this report, DARPA's original charter included space in addition to BMD. The Agency responded to the challenge of the Soviet Sputnik launch by an aggressive effort to develop larger, higher performance space launch vehicles. Large-thrust engine development such as the F-1 engine and the early liquid oxygen and liquid hydrogen RL-10 space engine were initiated and subsequently transferred to NASA; similarly, DARPA's Saturn Launch Vehicle and CENTAUR Upper Stage were initiated and transferred to NASA.

Early efforts in space vehicles included studies of satellites for ground surveillance, ICBM launching, detection of nuclear testing in space, navigation, meteorological monitoring, and communication. These early activities were transferred to the Military Services in late 1959.

DARPA's interest in space turned to space surveillance, both from ground- and space-based platforms. Detection and discrimination of objects in space were of continuing importance to the BMD mission and to intelligence gathering. Ground-based detection and discrimination of space objects was advanced by DARPA's research in large IR focal plane arrays using charge coupled devices. These devices were employed for both detection and processing. These devices, referred to as CCD^2, were especially important for space-based surveillance because in-array processing enabled much improved clutter rejection, thus enhancing imagery resolution. Compensated imaging technology using adaptive optics and deformable mirrors greatly corrected for the image blurring caused by atmospheric turbulence. A major transition occurred with the transfer of the ARPA Maui Optical Station (AMOS) to the Air Force in the early 1980s.



■ *The ARPA Maui Optical Station (AMOS).*

Space-based surveillance continued to be of high interest since it obviated the atmospheric turbulence problem and improved the IR signal-to-noise factor. Using focal plane detectors/processors (CCD^2), telescopes could be used in a staring mode, thus avoiding the limitation of spatial line scanning techniques used in the early IR satellites. Development of lightweight optics was pursued using thin glass or metal membrane faceplates on high-stiffness-to-weight-ratio supporting structures. These space platform surveillance technologies were supported by the DARPA High Altitude Large Optics (HALO) Program in the 1970s and 1980s. Techniques were transferred to the Air Force and the SDIO.

■ *Submarine Technology*

Specific examples of submarine and antisubmarine technologies that transitioned to the Navy are discussed in Chapter 2. However, in Public Law 100-180, the National Defense Authorization Act for Fiscal Years 1988/1989, Congress established an Advanced Submarine Technology Program (SUBTECH), to be managed by DARPA. This program was the umbrella under which sixty-four projects were executed and transitioned to the Navy between 1990 and 1996. The objective of the program was to improve submarine performance by developing new hull, mechanical, and electrical system technology and transitioning the technology to the Navy as soon as possible.

The program was funded at a level of approximately $100 million a year for nearly five years. It addressed all areas of submarine platforms except for the power generation portion of the propulsion system. Emphasis was placed on periscopes, control surfaces, hull design, materials, automation, quieting, and hydrodynamics. The projects were grouped as follows:

- *Full-Scale Prototypes (10)*. Full-scale technology demonstrations that are tested either at sea or on land. Examples are the Nonpenetrating Periscope and the enhanced Surface Tube Condenser.
- *Partial-Scale or Component Prototypes (16)*. Partial-scale models of particular technologies or full-scale individual components. Embedded sensors are an example.
- *Capabilities (17)*. Demonstrations of technologies or tools for use in research and development. Examples are the Hydrodynamic/Hydroacoustic Technology Center and Electromagnetic Signature Reduction.
- *Knowledge Base (21)*. Reports, analyses, or evaluations that identified potential for further development or application. Examples are studies in Advanced Drag Reduction and Advanced Propulsor Concepts.

These technologies could not be transitioned immediately because the Navy would require alteration of existing submarines or construction of new submarines, a major procurement action. The Navy has gradually inserted some of these technologies into new submarine designs. The Navy Advanced Submarine Research and Development Office (NAVSEA 92-R) was assigned the responsibility for the transition of appropriate technologies. DARPA has worked closely with this Office to ensure that these technologies would be useful and could be transitioned to the operational Navy when needed. Sea tests of SUBTECH technologies have been conducted on operational submarines with the support of NAVSEA 92-R.

Prototypes and ACTDs

DARPA's activities in prototyping can be traced to the mid-1970s and the creation of a major new 6.3 program element entitled Experimental Evaluation of Major Innovative Technologies (EEMIT). It soon became one of the largest program elements in DARPA and remained so until FY 1996, when Congress divided it into six program elements. The rationale for EEMIT was that some advanced technologies needed to be demonstrated in a "systems context" after integration with other technologies. The motivation to exploit the DARPA technology base was strong. While U.S. and NATO technology was superior in the laboratory, the Soviet Union was moving ahead of the West in terms of technical capability in fielded systems, as indicated by Office of the Secretary of Defense (OSD) Net Technical Assessments. Fortunately at that time, withdrawal from Southeast Asia and reduction in expenditures for Operations and Maintenance and Ammunition Procurement made it possible to increase the R&D budget and to proceed with major systems modernization. EEMIT was conceived as a process by which technology demonstrations would be carried out to decrease technical risks and thereby accelerate the integration of advanced technology into new systems.

The time between initiating a new acquisition program and achieving Initial Operational Capability (IOC) had grown from a few years in the 1940s to more than a decade in the 1970s.

The new EEMIT Program and its projects were strongly supported by the Director, Defense Research and Engineering (DDR&E) (then "acquisition executive"), OSD, Congress, and industry because of the great concern in that period with the lengthy and growing "procurement cycle." Several studies indicated that the time between initiating a new acquisition program and achieving Initial Operational Capability (IOC) had grown from a few years in the 1940s to more than a decade in the 1970s.

Some of the key programs carried out under EEMIT are listed below. Most were conducted in the late 1970s and 1980s.

- HAVE BLUE leading to F-117
- X-29 Advanced Aircraft Technology Demonstrator
- X-31 Enhanced Fighter Maneuverability
- Air Defense Initiative (Advanced Infrared Measurement System [AIRMS]; Cruise Missile Defense, Airship/Aerostat)
- Advanced Space Technology (Light Sat)
- Advanced Cruise Missile
- Armor/Anti-Armor
- Mine/Countermine Technology
- Tactical Airborne Laser Communications (Aircraft-Submarine two-way)
- Smart Weapons Application Program (Sensor Suite for Advanced Cruise Missile)
- Advanced Submarine Technologies
- Shallow Water ASW Sonar Technology

X-29 Advanced Aircraft Technology Demonstrator.

- Advanced Unmanned Undersea Vehicle (UUV Enabling Technologies, Deployable Surveillance System, Mine Countermeasure System)
- BETA correlation and fusion demonstration
- Advanced Simulation and Defense Simulation Internet
- Distributed Wargaming
- ASTOVL/COTL Common Affordable Lightweight Fighter

In the mid-1980s, the Packard Commission on Defense recommended that DARPA should be given the new role of demonstrating some "prototypes" in advanced development activities in order to reduce the cost and technical uncertainties prior to starting full scale development.

In the mid-1980s, the Packard Commission on Defense, commissioned by President Reagan, recommended that the Defense Department use more prototyping in acquisition programs to reduce the technical and cost uncertainties prior to making the formal commitment to acquire the system. The Commission specifically recommended that DARPA be given the new role of demonstrating some "prototypes" in advanced development activities to reduce the cost and technical uncertainties prior to starting full-scale development. A key role model for a DARPA prototype was the HAVE BLUE Program, which reduced the uncertainties in the F-117 full-scale development program and helped enable successful development of the F-117 in a much shorter than normal time.

The DARPA prototyping initiative in response to the Packard Commission recommendations was somewhat limited in scope and effect by the small budget allocation, the concerns of Congress over beginning new programs before requirements were established, and the reluctance of the Services to commit to accepting the projects after prototyping was finished.

Three programs were initiated in 1986-87. Only one of these programs, the Unmanned Undersea Vehicle project, was not Special Access and can be described herein. The prototyping initiative was not continued after the initial projects were completed or phased out.

The OSD ACTD initiative was started in 1993. In contrast to EEMIT and Packard prototyping, ACTD programs require a partnership between the war fighter and the developer. The decision to acquire the system is specifically not addressed until after demonstration and user evaluation have occurred. Another key difference is the intent to leave the equipment with the war fighter so that it can be "deployed" and used, at least in some limited way. In addition, ACTD projects have the option to build a limited number of production systems for deployment following the ACTD completion. DARPA quickly became a major player in ACTDs and initiated a number of ACTD programs, including the following:

- Advanced Joint Planning
- Cruise Missile Defense
- High-Altitude Endurance UAV
- Synthetic Theater of War
- Battlefield Awareness and Data Dissemination
- Bosnia Command and Control Augmentation (not formally ACTD but structured as ACTD)
- Combat Vehicle Survivability
- Joint Logistics
- Miniature Air Launched Decoy
- Navigation Warfare (GPS Joint Project Office lead; DARPA supporting with technology development)
- Semiautomated Imagery Processing

■ *High Altitude Endurance (UAV).*

Candidate FY 1997 ACTDs in which DARPA will play a major role include the following:

- Counter Camouflage, Concealment and Deception
- Information Warfare Planning Tool
- Military Operations in Urban Terrain
- Sea Dragon
- Unattended Ground Sensors

The ACTD approach and programs have created a powerful coupling of the war fighter and developer. The war fighters today are eager to come to grips with an uncertain future and are looking at innovative technology, systems, and tactics alternatives. ACTDs provide a means to experiment, evaluate new concepts, and provide better feedback to the developer. The developer can now extend the laboratory to include the battlefield and thus develop a new capability that comes closer to the war fighter's needs. ACTDs provide a unique partnership that historically has existed only in times of crisis or war.

INFORMATION TECHNOLOGY

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DARPA has been credited with "between a third and a half of all the major innovations in computer science and technology."

DARPA began to invest in information technology nearly thirty-five years ago. The period since then has seen significant changes in the field unlike any in the history of technology. In 1962 computers were scarce and expensive. Mainframes, the only available computers, were accessible to a few individuals who had direct access to a computation center. There was no field of computer science nor any computer science departments in our universities. There were no computer networks.

The Department of Defense, an early user of computers, was using computing technology in the design of nuclear weapons, in guiding ICBMs and in providing an air defense system for the United States. Today, only thirty-five years later, the Internet links tens of millions of users across the world. Real-time digital communications systems link individual war fighters and weapon systems on the battlefield to their commanders and on to the National Command Authority. Nearly every office worker has a computer on his or her desk, usually linked to a network. Weapon systems such as the F-22 will have millions of lines of software to control the aircraft, its avionics, and weapon systems. The peak processing power of leading-edge computers has increased by 6,000,000 times. DARPA, more than any other government agency or any single corporation, has been responsible for this revolution.

DARPA's role in fueling the information revolution has been pervasive and enduring. DARPA has been credited with "between a third and a half of all the major innovations in computer science and technology" (*What Will Be*, by Michael Dertouzos, Harper Collins, 1997) (Reference 3). These innovations include time-sharing, computer networks, landmark programming languages such as Lisp, operating systems like Multics (which led to Unix), virtual memory, computer security systems, parallel computer systems, distributed computer systems, computers that understand human speech, vision systems, and artificial intelligence.

DARPA's investment strategies followed a variety of paths and often were implemented in partnership with other funding agencies, with industry, and with other DoD partners. In some cases, DARPA invested in the original work in an area such as packet switching networks. In other areas, such as language understanding, DARPA provided sustained funding over many years. Today this area is maturing to the extent that defense will be able to field practical applications such as translations of command messages between Korean and English. In still other areas, DARPA provided the critical mass of funding to move an idea from a concept to the point where it could be commercialized and widely distributed. This was done with Unix and RISC.

Information technology is a vital element of DoD's strategic superiority. DoD requires a wide range of information technologies, and its high-end demands for computing, communications, and information technology place it at the leading edge of all users. For example, in earlier periods, electromechanical gunnery computers on ships represented the state of the art. In the 1970s computing limitations defined the physical structure and detailed shape of the stealth aircraft prototype, HAVE BLUE. Defense's needs for instant worldwide communication between forward forces and the continental United States (CONUS) lead the needs of the commercial sector.

Many defense needs for high-end information technology exceed those of the commercial sector, but many other defense requirements can be met with suitably structured commercial offerings. Defense invests in information technology to create defense-specific systems that the commercial world will not produce on its own and to stimulate commercial developments to move in directions that meet defense needs. DoD dual-use developments have had a significant positive impact on the commercial sector. Often the best way to transition a technology into DoD is to transition it to commercial industry so that it can be made available to DoD in the form of commercial off-the-shelf products and services. Computing technologies such as RISC microprocessors, parallel processing, and networking technologies such as packet switching and ATM systems are notable examples of technology transitions to industry that resulted in products now purchased routinely by the Services and Defense Agencies from the commercial sector.

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In some cases, DARPA creates specific technologies for direct transfer to one or more Services. In other cases, DARPA develops technologies that stimulate revolutionary changes in the commercial market and then result in new commercial off-the-shelf products and services for DoD. Frequently, technologies developed for defense transition to industry at a later date, with dramatic results. For example, packet switching, implemented in the ARPANet in the early 1970s, was adopted first by the Defense Communications Agency for the Defense Data Network in the mid-1970s. In the 1980s, the technology was adopted by the NSF Net for the Nation's research community. In the 1990s, the technology became the dominant network technology throughout industry and government, and DoD now purchases standard commercial communications products such as network routers and switches for many of its routine needs.

DARPA's information technology investments, while leading to an extraordinary range of products, systems, and capabilities, have broader implications when viewed over a sufficiently long period. Three such implications stand out:

1 *Infrastructure Creation.* DARPA's investments have led to the collection of people, institutions, and educational programs that allow new developments in information technology to be sustained. Infrastructure creation (primarily at universities), although not a direct goal or program, was a critical by-product of DARPA-sponsored research. Centers of excellence established in the 1970s at

three universities—Massachusetts Institute of Technology (MIT), Stanford, and Carnegie Mellon—made significant technical contributions to the DARPA programs and also awarded hundreds of Ph.D.s. Today, numerous departments offer programs in computer science. Most can trace some part of their history or faculty to DARPA support.

The CERT was formed by DARPA in response to the first large-scale attack on Internet hosts. It has become the world leader in the fight against computer intruders.

DARPA has also built significant infrastructure capabilities through sponsoring the creation of specific capabilities such as the Computer Emergency Response Team (CERT). CERT was formed by DARPA in response to the first large-scale attack on Internet hosts. It has become the world leader in the fight against computer intruders. The DARPA CERT is the template for other CERT organizations worldwide, including DISA's ASSIST. The DARPA-initiated CERT, now a self-sustaining organization, has become a locus for creation and dissemination of protective software, tools for system security administration, and establishment of "best practice" for site computer security.

2 *Industry Creation.* Much of the technology developed by DARPA finds its way into existing major information technology or defense industry companies. Many companies were formed directly as a result of research sponsored by DARPA. Examples of companies founded to provide DARPA-funded technology include the following:

- *Sun Microsystems, Inc*. With 1996 revenues of $7 billion, Sun Microsystems, Inc., was created to market a product based on the DARPA-supported VLSI research project at Stanford University and the DARPA-supported Unix research project at the University of California at Berkeley. Today, Sun workstations are distributed throughout the DoD. For example, in 1996 the U.S. Air Force awarded Sun a multiyear contract worth $950 million to provide workstations, software, maintenance, and a variety of support services. The Air Force is using the equipment for tactical battle management, R&D, weapons testing, and other mission-critical applications.

- *Silicon Graphics Incorporated (SGI)*. SGI, with 1996 revenues of $2.9 billion, was founded to capitalize on the DARPA-supported Geometry Engine Project at Stanford University. SGI recently acquired Cray Research, which develops supercomputers used by the DoD and intelligence agencies. Among Cray's leading products is the T3D supercomputer. The T3D technology was jointly developed by DARPA and Cray Research in one of the first "other transaction" agreements that DARPA sponsored. SGI machines are also found throughout the DoD. SGI has been the leading supplier to the Major Shared Resource Centers of DoD's High-Performance Computing Modernization Program. The company is also a key provider of systems for defense and intelligence image analysis and fusion.

- *Fore Systems*. Fore Systems grew out of the DARPA-supported Nectar project at Carnegie Mellon University. Nectar was one of the DARPA-NSF-sponsored Gigabit Testbeds that pioneered the use of ATM in private networks. Fore is now a $400 million per year company that markets ATM and other network products. It has been a key supplier to many defense projects, and Fore switches comprise the backbone network of DARPA's Advanced Technology Demonstration Network as well as DISA's DISN Leading Edge Service.

- *Cisco Systems.* Cisco, with $4 billion in 1996 revenues, is the market share leader for internetworking solutions targeted at private networks and the Internet. Cisco, founded in the mid-1980s, was among the first wave of companies that result from DARPA's development of packet switching. The company offers a wide range of local, regional, and long-haul products that are used widely throughout the Defense Department. Cicso provides routers for the Secure IP Router Network (SIPRNet) backbone. This network is the communications backbone of the Global Command and Control System (GCCS).

3 *Open System Architectures*. For many years there was tension between the concept of open, interoperable systems and proprietary solutions controlled and marketed by a single company. Proprietary systems advance the interests of their individual companies by locking users and subsystem developers into specific product lines and inhibiting broader community development of standards and architectures. DARPA has advanced open systems developments in several ways including providing early support to commercial efforts aimed at building common standards, such as the ATM Forum and the Object Management Group (OMG), and by developing a range of technologies that promote open systems and interoperability. Key contributions include:

DARPA has advanced open systems developments in several ways, including providing early support to commercial efforts aimed at building common standards, such as the ATM Forum and the Object Management Group (OMG), and by developing a range of technologies that promote open systems and interoperability.

- *Unix*. Unix was chosen by DARPA to be the common operating system for the Image Understanding and VLSI research projects. Under DARPA support, a virtual memory version was developed by UC Berkeley for the VAX. The wide availability of Unix, and later Mach, was a significant benefit to researchers who were developing new operating system concepts and applications and also was the basis for a generation of Sun Microsystems, SGI, and supercomputer products.

- *Transmission Control/Internet Protocol (TCP/IP)*. TCP/IP, designed by DARPA to provide interoperability across computer networks, has become the universal network protocol. This protocol, the foundation for interoperability across the Internet, is a DoD standard and is now available on almost every commercial computing product from desktop to supercomputer.

- *Software Engineering Institute (SEI) Capability Maturity Models (CMM).* CMM was developed by the SEI, an FFRDC. Under DARPA sponsorship, CMM provides an effective method for a software development organization to assess its capability to develop software in a predictable, efficient manner. CMM is now widely used in industry to develop DoD systems. SEI also has developed maturity models for system engineering and risk assessment. In combination, these models raise the DoD's capability to assess the risk in a software development effort and to mitigate that risk.

SPECIFIC DARPA CONTRIBUTIONS

Computing Systems

DARPA's impact on computing systems has been pervasive. DARPA computing technology is used by all of the Services. The common "mouse" and industry standard graphic user interface originated in DARPA research. Among DARPA's many accomplishments are the development of scalable parallel computer architectures for increased performance. Technology developments include the processor architectures, which led to Sun's SPARC and Silicon Graphic's millions of instructions per second (MIPS) chips, new cache and memory system architectures such as message passing and distributed shared memory, new computer interconnect systems, including backplanes, crossbar, and mesh routing for high-performance, low-cost, redundant array of inexpensive devices (RAID), high-performance disk storage systems, and high-performance communications network interfaces.

DARPA's world speed record setting massively parallel processing developments became the basis for industry's mid- and high-end computing products.

■ *Reduced Instruction Set Computing (RISC)*

The microprocessor industry achieved major gains in performance and cost through DARPA-developed RISC-based technology. The technology was adopted for a wide range of computing platforms, including workstations, shared memory multiprocessors, and massively parallel architectures. DARPA's investments in RISC, which began in the 1980s, led to today's generation of commercial products from IBM, Sun, Silicon Graphics, Hewlett Packard and Intel's next generation P7 microprocessor. In addition, compilers and compiler technology for RISC systems, developed initially at Rice University under DARPA sponsorship, were transferred to IBM, Intel, Motorola, Silicon Graphics, and Texas Instruments.

■ *Redundant Array of Inexpensive Devices (RAID)*

DARPA was responsible for the development of the RAID storage system technology. This technology is the architecture of choice for high-performance, high-capacity, high-reliability input/output systems. DARPA research spawned developments at more than twenty companies, including IBM, StorageTek, DEC, Compaq, NCR, and Sun.

■ *Massively Parallel Systems*

DARPA's massively parallel processing, which set world speed records, became the basis of industry's mid- and high-end computing products. Starting with the 1970s' Illiac 4 Project, continuing into the 1980s with DARPA's Scalable

Computing Initiative, and continuing further into the 1990s with DARPA's Scalable Computing Program, DARPA's investments established scalable parallel processing as the commercial standard for high-performance computing.

The previously mentioned systems provided the technology base for the $2 billion midrange, high-performance market which expanded DoD's access to high performance computing while reducing costs to the government. DARPA-developed, massively parallel systems enabled the near-term computing technology for DoE's Advanced Strategic Computing Initiative for nuclear weapons stockpile stewardship. Technology milestones included the demonstration of 100-gigaops class systems as part of joint projects with Cray Research (T3D), Intel Corporation (Paragon), and International Business Machines (SP-1, SP-2) and were responsible for the delivery of Cray T3D and T3E massively parallel systems. Today parallel computing products are acquired routinely by the Services, the Intelligence Agencies, and DoD's High-Performance Computing Modernization Office.

The early 1990s DARPA/Navy Hyper D Project resulted in a newly distributed computational architectures and systems for shipboard computing. This technology is being implemented in the Navy's Baseline 7 Aegis Cruiser, scheduled for completion in 1998.

■ *Processor Interconnection*

Many modern defense systems use "fleets" of processors to supply the computing power and reliability required for military missions. The performance, reliability, cost, power, size, and weight of such systems depend as much on the way the processors are connected as on the processors themselves. The early 1990s, DARPA/Navy Hyper D Project resulted in newer distributed computational architectures and systems for shipboard computing. This technology is being implemented in the Navy's Baseline 7 AEGIS Cruiser, scheduled for completion in 1998.

Recent DARPA-sponsored work at CalTech and Myricom resulted in Myrinet, a low-power, low-cost, local area network switch for connecting processors. The 10-gigabits-per-second bisection data rate of the Myrinet switch is a measure of how quickly it can rearrange data between network hosts. Switches with comparable bisections are cabinet-size units requiring hundreds of watts and costing hundreds of thousands of dollars. The Myrinet switch operates with eleven watts, is the size and shape of a small pizza box, and costs $2,400. Myricom's technology has been licensed to Intel and Cray Research. Myricom is working closely with military-system suppliers such as Lockheed-Martin and Hughes to insert this technology into future military ground, air, sea, and space systems.

Software Technology

Software, a critical element in the operation of tactical and strategic systems, represents a huge investment for the DoD. Software systems must be sufficiently flexible to meet new and unforeseen challenges. Software development poses a great risk because of often uncertain development costs, schedules, and reliability. DARPA software technologies have significantly improved software capabilities for the DoD. DARPA investments have been aimed at improving software functionality and improving DoD's ability to develop quality software.

DARPA-sponsored research in operating systems led to the development of Multics, virtual memory Unix, and Mach. These systems contained many innovations that included file and memory sharing without interference between users, networked computing, and secure and survivable systems.

■ *The Ada Language*

The Ada programming language, developed under DARPA sponsorship, is the DoD's primary language for developing mission-critical software systems. Ada introduced key techniques for encapsulation (isolating software components from one another to enable more modular systems), separate compilation, and distribution and synchronization of multiple computational processes. These techniques influenced other programming languages in general use, such as C++ and Java. The Ada language has dramatically increased DoD's ability to develop large software systems. DARPA also developed the first version of Ada that supports scalable computer systems. DADA, a product of Rational SW, enables explicit parallelization of Ada codes over multiprocessors or clusters of workstations.

■ *Software for High-Performance Systems*

The highly parallel systems developed by DARPA to meet the DoD's most demanding computational tasks require specialized system software to exploit the processing power of those machines. DARPA supported the development of the High-Performance Fortran (HPF) language, implementing this language in prototype compilers. HPF is now a defacto industry standard. Other DARPA developments of industry standard, new and extended programming languages for parallel machines include FORTRAN-D, Split-C, and data parallel and object parallel C++.

DARPA also supported the development of SCALAPACK, a scalable version of the LAPACK library, which is the new standard for dense linear algebra. This development demonstrated the proof of concept of performance-tuned libraries of mathematical codes to enable applications to be written in machine-independent fashion while achieving high efficiency on various high-performance computing (HPC) computer architectures. SCALAPACK has been adopted by virtually all major systems vendors worldwide and is one of the most widely used mathematical library packages for high-performance machines.

■ *Operating Systems*

DARPA-sponsored research in operating systems led to the development of Multics, virtual memory Unix and Mach. These systems contained many innovations that included file and memory sharing without interference between users, networked computing, and secure and survivable systems. These features are the basis for today's widespread interconnection of computers and networks. Systems procured from Sun Microsystems and Silicon Graphics that are widely used throughout DoD are built on the virtual memory Unix operating system that was developed under DARPA contracts with University of California Berkeley, and Stanford University. DARPA sponsored the development of microkernel operating system technology, which forms the theoretical foundation for Microsoft's Windows NT.

The DARPA-developed Mach Operating System (OS) is the operating system of two major scalable computing machines. It led to a generation of continued innovations in operating systems, including the TMach technology for secure systems. TMach is the first trusted OS technology based directly on commercial operating system technology. Through close coordination with developers of commercial versions of Mach, TMach will inherit both performance enhancements and functional enhancements from its commercial variant. DARPA developed and demonstrated a prototype trusted version of this system that is the basis for the National Security Agency (NSA) MISSI trusted network operating environment anticipated for future deployment to military organizations.

■ *Algorithm Developments*

Improving the underlying approach to problem solving can extend the power of existing computing systems by requiring less processing power to do an equivalent task. DARPA has found many better ways to solve key defense computational problems. For example, DARPA pioneered the development and use of ordered binary decision diagrams that can represent state transition systems efficiently and hence allow very large systems to be checked. This approach has been used to verify protocols, hardware designs, and more recently, software properties.

DARPA used wavelet-based technology to develop automatic target recognition algorithms for the Army's Longbow Fire Control Radar System, with tested results that used less than 30% of the processing required by the baseline classifier algorithm. These wavelet-based algorithms will be inserted into the Longbow system as part of the Performance Improvement Program. DARPA supported the development of fast multipole methods, which have led to significant advances in modeling electromagnetic scattering of low observable platforms. These fast multipole methods are from 10 to 1,500 times more efficient than those currently in use and have been used by Boeing in the design of the Joint Strike Fighter (JSF). They also are being used by other major airframe manufacturers and are being extended to handle low frequency problems that will be encountered in advanced aircraft designs.

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Microsystems Design

DARPA VLSI research began in the late 1970s. It is widely regarded as having had a tremendous impact on VLSI design. The program funded academic research, led to a number of industrial start-ups and technology transfers, and broadened access to the advanced design capabilities.

■ *Computer-Aided Design*

DARPA was, to a great extent, responsible for the development of the computer-aided design software industry. DARPA-sponsored university research led to fundamental results in layout, simulation, and synthesis tools. Companies such as VLSI Technology, Cadence, and Synopsis developed the ideas into commercial implementations.

■ *Semiconductor Modeling*
DARPA developed computationally efficient models of semiconductor devices that enable the accurate prediction of electrical behavior from physical structures. For example, DARPA's efforts in the area of computational prototyping enabled the design of circuits to evaluate hot-carrier lifetimes in digital circuits operating at above 300 MHz. This technology was transferred to HP, Intel, and Analog Devices.

■ *Very Large-Scale Integration (VLSI) Fabrication*
DARPA provided the computer science community with low-cost access to advanced VLSI fabrication technology thereby enabling university research that lead to industry standards for design frameworks, electronic design exchange formats, and tool interoperability standards. DARPA demonstrated the first virtual factory-integrated circuit process simulation. Today's state-of-the-art integrated circuit fabrication lines cost as much as $1 billion. DARPA developed virtual prototyping techniques to optimize and tune the process before committing to fabrication lines. DARPA also developed the concept of the multichip wafer, which allowed multiple designs to share a single silicon fabrication run. Together with the design tools and services created by DARPA, this capability made a low-cost, fast-turnaround silicon foundry a reality.

■ *Very Large-Scale Integration (VLSI) Chip Implementation*
DARPA developed MOSIS (Metal Oxide Semiconductor Implementation Service), the first network-based implementation service for VLSI systems. MOSIS capabilities initiated low-cost brokered access to submicron complementary metal oxide semiconductor (CMOS) technology by offering low-cost fast-turnaround fabrication services to the research community.

DARPA's world famous development of packet switching and the Internet began with the development of the ARPANet, and its associated TCP/IP network protocol architecture.

Networking

■ DARPA's world-famous development of packet switching and the Internet began with the development of ARPANet and its associated TCP/IP network protocol architecture. These 1970s, developments were responsible for the creation of today's multibillion dollar computer networking industry. The TCP/IP protocol suite has been adopted by all major computing and communications vendors as the basis for their future networking products. Packet switching is now the fundamental element of both public and private network approaches and spans the DoD, the federal government, the U.S. industry, and the world.

■ *Asynchronous Transfer Mode (ATM) Technology*
DARPA's network research programs have had many other significant results, such as the widespread adoption of ATM technology by DoD and industry. DARPA's pioneering activities in ATM technology began in the 1970s with the development of packet-switched voice protocols. Packet video protocols, developed in the 1980s, provided early proof of the concept that packet technology would work for voice, data, and video. In 1990, DARPA began the development

(in collaboration with the NSF) of a number of gigabit networking test beds. These test beds developed high-bandwidth network technologies, promoted the development of high-bandwidth services by telecommunications service providers, accelerated the availability of high bandwidth networking services to defense and commercial customers, and provided an experimental platform for issues such as compatibility and interoperability. Arising from the test beds was a new generation of commercial companies such as Fore Systems, which developed into a major provider of ATM switches.

In 1995, DARPA established an ATM and SONET prototype network among six DoD customers in the Metropolitan Washington, D.C. area. The program was a commercial technology driver that enabled DoD to acquire advanced commercial technology.

In 1995, DARPA established an ATM and SONET (Synchronous Optical Network) prototype network among six DoD customers in the Metropolitan Washington, D.C. area. The network, called ATD Net, is an OC48 (2.4 GBit/sec) rate, four-fiber ring with OC3c (155MBit/sec) and OC12c (622 MBit/sec) tributaries. The program was a commercial technology driver that enabled DoD to acquire advanced commercial technology. This experimental test bed helped DISA gain experience with flexible, high-performance network management and operations and extended the ATM user community to other government agencies such as the NSA, the Naval Research Laboratory, and the Defense Intelligence Agency. The technologies were then transitioned into the DISN Leading Edge Service. Today DoD has the most advanced nationwide operational ATM network in the United States (with extensions to Bosnia), and ATM is the long term-broadband architecture for the telephone industry.

■ Multicast Technology

The DoD is the leading user of multicast technologies for such applications as advanced distributed simulation, collaboration, and command and control. DARPA developed advanced video, audio, and shared multimedia collaboration capabilities as well as a multicast packet capability. Using this technology, multimedia services operating over private networks or routed across the Internet will soon be able to request finely tuned data handling by using RSVP (Resource reSerVation Protocol). With RSVP, applications can give detailed guidance to the network about the end-to-end resources required. This enables the network to allocate resources more efficiently, resulting in better overall service on the same infrastructure. RSVP has become an Internet standard and is being implemented by many vendors, including Cisco, Bay Networks, Precept, Intel, and IBM. At Cisco, RSVP is currently under test at sites including those operated by the DARPA/DISA Joint Program Office for the Defense Simulation Internet. The new products will enable DISA to expand the services of a number of its networks, such as the Secure IP Router Network.

■ *Wave Division Multiplexing*

DARPA-funded consortia are fielding multigigabit optical wave division multiplexing (WDM) technology. The first demonstration of an all-optical network technology in a DoD test bed was successfully conducted over ATD Net, the

DARPA advanced developmental network jointly managed by DARPA and DISA. A 10 GBit/sec point-to-point transmission between NRL and NSA was demonstrated over lossy commercial fibers. The WDM technology has the potential for greatly expanding the capacity of DoD networks at low incremental costs. Another major step in proving the feasibility and benefits of WDM was taken when a DARPA consortium successfully demonstrated a 2,000-km transmission with eight wavelengths at 2.5 GBit/sec per wavelength. These techniques are scalable to larger number of wavelengths and higher modulation speeds, thereby opening the way for major increases in capabilities for defense networks without corresponding increases in cost. The experiment firmly establishes the potential for future deployment of WDM systems in long-distance terrestrial networks.

Computer Graphics

The development of computer graphics had vast implications for defense and industry, including today's pervasive "what you see is what you get" document systems, scientific visualization, phenomenal use in the entertainment industry, and the still untapped potential of virtual reality for DoD's training, planning, and rehearsal needs. DARPA's initial activities in this field launched both the technology and the industry. Research in the 1960s and 1970s included the DARPA-funded leading program in computer graphics at the University of Utah. At that time, nearly all pictures of three-dimensional objects were drawn with lines, and the resulting images appeared to be of wire frames.

Some of DARPA's accomplishments include the invention of the "mouse" at Stanford Research Institute and the development of the technology in the Altos, Star, and Macintosh desktop computers that led to today's pervasive graphic Windows and Mac interfaces.

During a two-decade period, DARPA sponsored a variety of research activities, including algorithms for drawing and for surface shading and hidden surfaces, graphic programming tools, conic display hardware technology, inexpensive storage tube displays, and graphical user interfaces and technologies for human-computer input. Some of DARPA's accomplishments include the invention of the "mouse" at Stanford Research Institute and the development of the technology in the Altos, Star, and Macintosh desktop computers that led to today's pervasive graphic Windows and Mac interfaces. In addition to these specific developments, many individuals who started companies such as Adobe and Silicon Graphics received their training through DARPA research projects. Today industry provides the DoD with a stunning array of alternatives made possible by the earlier DARPA research.

Language Understanding

DARPA launched its Speech Understanding Program in 1971. The first systems built in the 1970s were brittle and primitive. Technology was rudimentary, and there were no computers capable of understanding speech in near real time. DARPA revisited speech technology as part of its Strategic Computing Initiative in the mid-1980s. The goals of the research were to get a computer to understand spoken input. The 1980s, efforts led to dramatic advances in systems that could understand speech in constrained environments. DARPA's third and most successful effort at attacking the speech understanding challenge began several years ago.

The results of DARPA's current efforts are a range of speech understanding technologies that are being adopted in both commercial and military systems.

The results of DARPA's current efforts are a range of speech understanding technologies that are being adopted in both commercial and military systems. Although a complete solution to the speech understanding challenge is still not here, progress enabled DARPA to provide translingual communication devices to members of Task Force Eagle. The goal of the translingual effort was to support one-way translation between English and either Serbo-Croatian or Russian to improve communication in the critical areas of force protection, land-mine management, and counterintelligence. The operator speaks English phrases into a headset microphone. The phrases are then translated into the corresponding Serbo-Croatian or Russian phrases. The system can be learned and employed successfully with fewer than three hours of training. The devices are being used in Bosnia by the 18th Military Intelligence Brigade, the 1st and 2nd Brigade Military Police, and Civil Affairs units.

DARPA investments in speech understanding are excellent examples of successful dual-use technology. For example, a new telephone information access service, "VoiceBroker," is offered by the securities brokerage firm Charles Schwab. VoiceBroker is the first telephone service using speech recognition technology to provide customers with real-time quotes on listed stocks, mutual funds, and market indicators. Schwab devoted more than two years to adapting DARPA technology to the brokerage industry. The result is a fast, accurate quotation system that can recognize over 13,000 security names as well as major regional accents throughout the United States. As another example, Dragon Systems recently announced its new continuous-speech dictation product, designed to recognize spoken language from a customizable 30,000-word active vocabulary on a typical business PC. The modest resource requirements for memory, processing power, and weight are a direct result of the DARPA goal of making this technology available on handheld devices. The same recognition engine is also being incorporated into the next generation of systems such as the one currently deployed in Bosnia. The new system is expected to improve the ease of use and ease of training for both the Bosnia application and other applications of significant value to DoD.

SELECTED TECHNOLOGY TRANSITIONS BY USERS

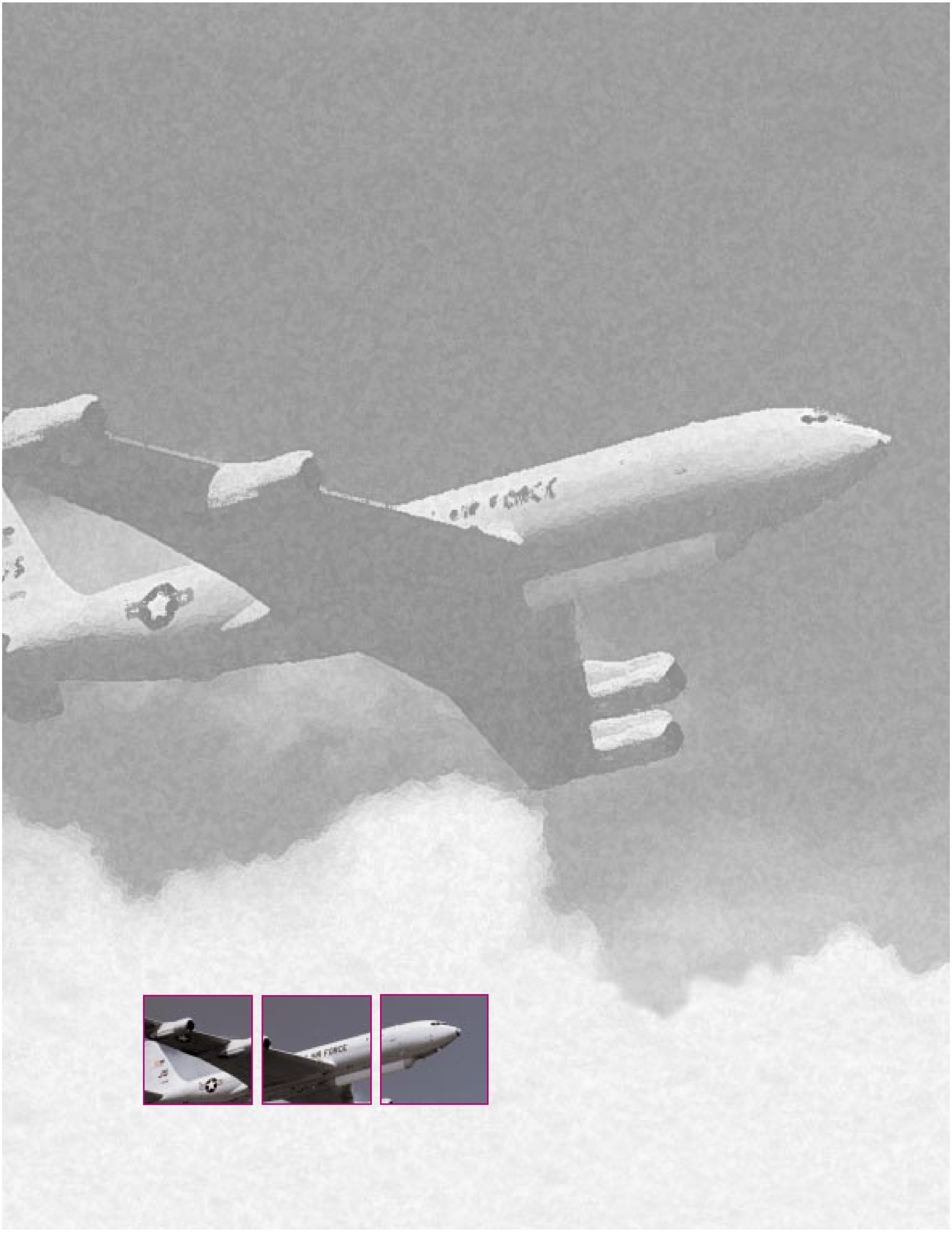
2

This section presents short descriptions of the major identified technology transitions to the military and other users. Where available, illustrations of military and other systems that have incorporated the technologies are included with a brief description of the system and DARPA's role in the development. The information was obtained from various DARPA, military, and other source documents, and includes responses from solicited organizations and individuals. (See the List of Contributors.)

For clarity, the transitions are grouped by recipients of the technology and chronologically by decade. The grouping by recipient is as follows:

- Transitions to the Air Force
- Transitions to the Army
- Transitions to the Navy
- Transitions to the Marine Corps
- Other Transitions (including multiple users, other government departments, and industry)

The ultimate transition to the military occurs when the technology is incorporated into fielded military hardware that performs to high standards in the hands of the war fighter. Technologies transitioned to non-military recipients such as other government departments and industry contribute to the advancement of National goals. Space assets attributable to DARPA R&D, advances in computer science and data processing, and materials research fall into this category.



TRANSITIONS TO THE AIR FORCE

1990s

Taurus Launch Vehicle
Pegasus Air-Launched Vehicle
Endurance Unmanned Air Vehicles
Affordable Short Takeoff, Vertical Landing
Schottky IR Imager for the B-52 (replacement for the AAQ-6)
Materials Technology for the F-22
Technology for Transport Aircraft
Affordable Tooling for Rapid Prototyping
X-31 Aircraft
Sensor Fuzed Weapon (CBU-97/B)

1980s

Stealth Fighter
Stealth Bomber
Joint STARS
X-29 Forward Swept Wing Aircraft Technology
Pilot's Associate
Materials Technologies for the F-15 and F-16
Low Probability of Intercept Airborne Radar
Advanced Cruise Missile

1970s

ARPA Maui Optical Station
Materials Technologies for the Titan
Over-the-Horizon Radar
Extended Long Range Integrated Technology Experiment
Advanced Medium-Range Air-to-Air Missile
Materials Technologies for the SR-71
Nuclear Test Monitoring Satellites

1960s

Phased Array Radars

TAURUS LAUNCH VEHICLE

This Small Standard Launch Vehicle (SSLV) is capable of placing a 1,900-pound payload into a 400-nautical mile polar orbit with high accuracy.

■ *Taurus Launch Vehicle.*

The Taurus Small Standard Launch Vehicle (SSLV) was developed by DARPA and is critical to achieving quick-response, low-cost launch of tactical satellites from ground facilities. The SSLV is equipped with a transportable launch platform and can be launched from an unprepared site with as little as one week's notice. The developed SSLV was provided to the Air Force.

The Taurus SSLV demonstrates the ability to rapidly launch satellites from a ground unit. The Taurus is a four-stage, solid propellant, inertially guided, transportable, ground launch vehicle. It combines the proven technologies of a Peacekeeper first stage motor with a modified Pegasus for the second, third, and fourth stages. It is transported to its launch site in three vehicles with accompanying integration, erection, launch support, and launch operations vehicles.

The SSLV is capable of placing a 1900-pound payload into a 400-nautical-mile polar orbit with an orbital insertion accuracy of ±30 nautical miles and 2° inclination. Taurus successfully launched two payloads on March 13, 1994, with a final orbit of 291 x 301 nautical miles, 105.012° inclined, compared with the specified Taurus SSLV, 293-nautical-mile circular orbit inclined at 105.0°.

PEGASUS AIR-LAUNCHED VEHICLE

The DARPA Pegasus Air-Launched Vehicle (ALV) was developed to provide quick-response, low-cost launch of tactical satellites for crisis situations. The program developed a B-52-carried launch vehicle capable of carrying 450-pound class payloads to low orbit, demonstrated the capability, and transitioned it to the Air Force. Since the ALV is capable of being carried aloft by a B-52 long-range bomber from any paved runway of sufficient length, it has the capability to be deployed worldwide and to place into orbit a variety of lightweight satellites.

■ *Pegasus mounted under B-52 wing.*

Carried aloft by a B-52, the Pegasus Air Launched Vehicle (ALV) is a low-cost vehicle capable of inserting a 450-pound payload into low earth orbit.

The Pegasus ALV provides a responsive space capability and reduces the dollar-per-pound to orbit that is usually associated with small launch vehicles.

The first payload launched was the three-function payload known as PEGSAT, which deployed a Navy experimental communications relay satellite, an instrumentation package to provide data during the launch sequence, and a NASA barium experiment.

After two successful flights under DARPA auspices, Pegasus was transitioned to the Air Force on April 23, 1993.

TRANSITIONS TO THE AIR FORCE

ENDURANCE UNMANNED AERIAL VEHICLES

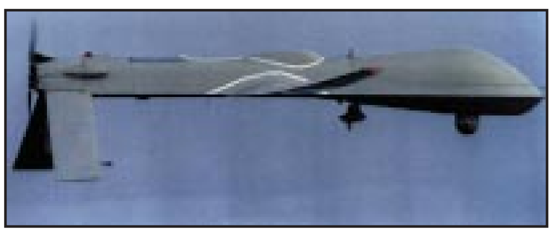
The Amber Unmanned Aerial Vehicle (UAV) has demonstrated (1988) thirty-eight hours of continuous endurance. It is designed to carry sensors such as EO and radar.

■ *The Amber I Unmanned Aerial Vehicle.*

DARPA developed the first medium-size endurance unmanned aerial vehicle (UAV), Amber, which directly led to the Gnat 750 UAV and the Air Force-operated Tier 2 Predator UAV used in Bosnia. Operating at altitudes of up to 25,000 feet for periods exceeding forty hours, the Predator operated successfully as an element of Exercise Roving Sands in early 1995 and has been deployed to the Bosnia crisis to support UN/NATO operations. Originally a Navy-Army joint effort, the Predator UAV was transitioned to the Air Force in 1995 for operation and maintenance.

The Amber Program was initiated in 1984, under DARPA's rapid prototyping philosophy. The goal was operational suitability, with only minimum essential field specifications. In June 1988, the Amber UAV demonstrated thirty-eight hours of continuous endurance, thus launching a new era in long endurance unmanned flight. Simultaneously, DARPA conducted a radar development program to design and construct an experimental radar of the type Amber might carry.

The Predator Unmanned Aerial Vehicle carries a synthetic aperture radar and EO/IR sensors. It is a medium altitude endurance UAV.



■ *The Predator Unmanned Aerial Vehicle.*

The basic design of the Amber emerged as the Gnat 750 (Tier 1) UAV and was the first UAV to be deployed to the Bosnia theater of operations. The UAV was developed to improve intelligence gathering capabilities. It has a 450-pound payload and carries an electro-optic (EO) sensor suite as well as a data link to pass intelligence to the ground.

The Tier 2 Predator medium-altitude endurance UAV evolved from the Amber and Gnat 750-45 designs as a next stage of size and endurance. The Predator carries a synthetic aperture radar and EO/IR for imagery intelligence. In mid-1995, ten air vehicles with two mission ground stations were delivered by the Navy and the Defense Reconnaissance Office (DARO).

AFFORDABLE SHORT TAKEOFF, VERTICAL LANDING

TRANSITIONS TO THE AIR FORCE

The DARPA Affordable Short Takeoff, Vertical Landing (ASTOVL) Program, later the Common Affordable Lightweight Fighter (CALF) Technology Demonstration Program, investigated the technical feasibility of a lightweight, affordable Short Takeoff, Vertical Landing (STOVL) fighter/attack aircraft and derivative Conventional Takeoff and Landing (CTOL) fighter aircraft for the Air Force. It was expanded to include a Navy application. It has been transitioned to the DoD Joint Strike Fighter (JSF) Program.

■ *DARPA's Affordable Short Takeoff, Vertical Landing (ASTOVL) technology.*

The CALF Technology Demonstration Program was conceived by DARPA to conduct missions currently performed by the AV-8B, F-18, and F-16.

DARPA's original program was divided into three major phases. Phase I consisted of STOVL, Advanced Tactical Fighter Engine (ATFE) derivative propulsion system, and airframe design studies and was completed in September 1991. Phase II consisted of critical technology validation, common airframe design studies, and affordability analyses. Phase II was completed in March 1996. Because of the merger with JSF, the FY 1995 and FY 1996 Phase II efforts have been integrated into the JSF concept development contracts with each airframer.

DARPA's affordable Short Takeoff, Vertical Landing (ASTOVL) technology is being integrated into the DoD JSF Program.

SCHOTTKY IR IMAGER FOR THE B-52 (REPLACEMENT FOR THE AAQ-6)

■ *Schottky infrared camera mounted on the B-52.*

Infrared (IR) imagers provide exceptionally valuable targeting information about enemy assets. In Desert Storm such imagers were used very successfully to locate tanks and other war-fighting equipment buried in sand.

Prototype IR imaging systems, based on Schottky barriers mated to standard silicon technology, were customized for flight testing on the B-52 by the Air Force's Rome Laboratories at Hanscom Air Force Base, Massachusetts. These tests by Strategic Air Command's (SAC) 416th Bomber Wing were so successful that the evaluating wing commander asked to retain the test units until those in production become available.

Schottky barrier technology provides the highest resolution and lowest cost cooled infrared imager for the U.S. B-52 bomber fleet.

In March 1996, the Air Force began the conversion of all B-52 IR imagers to the Schottky version. The Schottky IR imager will be warranted for a mean-time-between-failure (MTBF) of 2,700 hours vs. 350 hours for the best forward-looking infrared (FLIR) systems of today. This reliability will permit the Air Force to go from a three-level to a two-level maintenance system, resulting in a projected saving of $15,000,000 per year when the entire B-52 fleet is converted.

From 1973 to 1980, DARPA funded the R&D that reduced to practice a totally new concept for obtaining IR images of targets. The utilization of Schottky barriers on standard integrated circuit-grade silicon enabled the realization of large, two dimensional arrays of IR-sensitive detectors that are reliable and cost-effective.

MATERIALS TECHNOLOGY FOR THE F-22

TRANSITIONS TO THE AIR FORCE

New materials technologies played an important role in the electronic warfare (EW) subsystem, currently in acquisition, of the Air Force's newest fighter, the F-22. The high packing density of modern electronic components, which permits greatly increased functionality, requires new approaches to heat removal. Metal matrix composites, developed during a decade of research at DARPA, provide the necessary means to overcome the heat removal dilemma.

■ *The F-22 fighter aircraft.*

As electronics subsystems become an ever increasing fraction of modern war fighting systems, removal of heat from these subsystems becomes a major problem. DARPA has developed packaging materials to solve this problem.

DARPA began a program in ceramic composites in 1985. The development concentrated on novel ceramic composite synthesis concepts. After initial success, the program continued into the development of processes and systems for manufacturing of this novel material. Silicon carbide-reinforced aluminum heat sinks, one of the products of the DARPA program, are now utilized in printing the wiring board cores of the F-22 EW subsystem. This heat-spreading material is also used in the Longbow Missile, the EA-6B, the SMUG, and the power supply subsystem for the F-18. The ubiquitous applicability of this new material in solving a multitude of heat distribution problems of modern electronic subsystems illustrates one contribution of fundamental materials research conducted at DARPA.

TECHNOLOGIES FOR TRANSPORT AIRCRAFT

TRANSITIONS TO THE AIR FORCE

The DARPA Advanced Air Load Planning System (AALPS) was initially tested on the C-130 and has also been applied to the C-5.

DARPA technologies are being deployed on the entire fleet of Air Force cargo aircraft, including the C-130, C-141, C-5, and C-17. The Advanced Air Load Planning System (AALPS), an earlier DARPA software development, has reduced the time required for planning the loading and balancing of the C-141 for its Bosnia missions from six days to two hours. The AALPS system was initially tested on the C-130 and has also been applied to the C-5.

Lightweight ceramic matrix tiles are providing armor protection against small-arms fire in Bosnia, where the C-141 is flying at an altitude of only several hundred feet. These tiles replace steel armor, reducing the armor weight from 2,400 pounds to 1,400 pounds.

- *Top: Air Force cargo aircraft C-130.*
- *Bottom: Air Force cargo aircraft C-5.*

To date, ceramic armor has been adopted to 18 C-141s, 57 C-130s and 9 C-17s. Last, the C-17 will utilize nacelle accessory doors, which have superior durability and maintainability, on all C-17s from P41 through program completion. The nacelle doors are the result of DARPA's Affordable Composites Program (ACP). This technology will also have applications to other components of aircraft, making future aircraft structures more affordable.

The AALPS system is the result of DARPA's efforts in the late 1970s to apply its software advances to complex military problems. DARPA developed the silicon carbide/aluminum nitride "ceramic matrix" material under its Armor/Antiarmor Program in the early 1980s, and the nacelle material came from DARPA's Technology Reinvestment Project started in 1993.

AFFORDABLE TOOLING FOR RAPID PROTOTYPING

TRANSITIONS TO THE AIR FORCE

DARPA led the development of affordable tooling for the production of military and civilian aircraft. The C-17 leading-edge fairing low-cost metal arc-sprayed composite tools are in production, replacing the original, higher cost, less durable tools in less lead time. Success of this effort will lead to applications of arc-sprayed tools for more parts on the C-17 and other DoD aircraft.

The Affordable Tooling Program, a cost-shared effort, led to the demonstration and validation of the parameters for the metal arc spray composite tooling process. The program developed low-cost tooling for composite parts, using metal arc spray over a low-cost master and backed up by low-temperature composites.

■ *The C-17 leading-edge fairing composite tools.*

The Affordable Tooling Program, led to the demonstration and validation of the parameters for the metal arc spray composite tooling process.

X-31 AIRCRAFT

TRANSITIONS TO THE AIR FORCE

The X-31 aircraft, jointly supported by DARPA and the German Air Force, demonstrated the feasibility of poststall flight by incorporating a multiaxis thrust vectoring system with conventional aerodynamic controls.

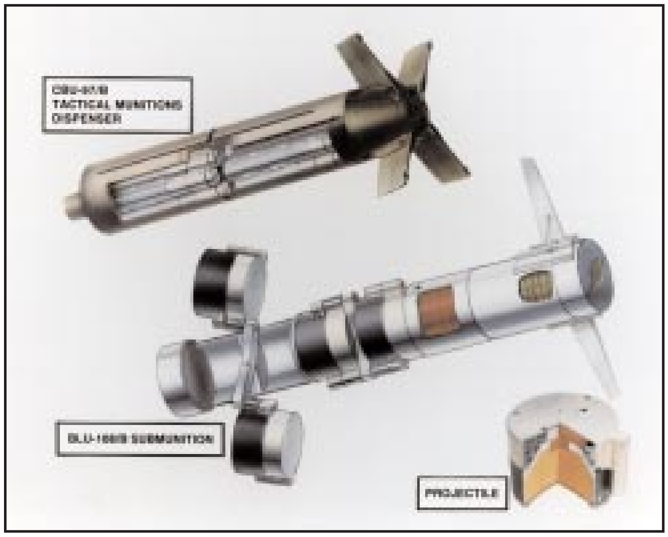
■ *The X-31 in flight.*

The DARPA X-31 Demonstrator Aircraft Program was initiated in conjunction with the German Air Force to develop, build, and test a fighter aircraft that demonstrated the feasibility of poststall flight and defined an aggressive maneuvering envelope. The X-31 was employed to establish and demonstrate these capabilities in a close-in air combat environment. The results were a success, with the X-31 achieving a ten to one aggregate exchange ratio against a conventionally matched F-18.

The X-31 includes a diverse array of technically and operationally significant "firsts" in aeronautics. The X-31 pioneered a technology suite that includes an advanced flight control system integrating conventional aerodynamic control with a multiaxis thrust vectoring system. The resultant capability allows the X-31 to maneuver aggressively beyond the normally feared aerodynamic stall barrier, and also provides other unique performance attributes that can be exploited throughout the conventional flight envelope. To facilitate improved situational awareness in the unusual flight environment that accompanies dynamic poststall flight, an advanced helmet-mounted display incorporating own-ship orientation displays and other performance parameters was developed. The X-31 also demonstrated the feasibility of tailless flight under a variety of conditions, including supersonic speeds.

SENSOR FUZED WEAPON (CBU-97/B)

The Air Force Sensor Fuzed Weapon (SFW) is an air-to-ground munition designed to meet the Air Force requirement for a general-purpose weapon that provides multiple kills per pass; can be employed over a wide area; functions under adverse weather conditions, at night, in an electronic countermeasures environment; and can be deployed from frontline fighters and bombers. It entered the Air Force inventory in 1994.



■ *Sensor Fuzed Weapon (CBU-97/B).*

DARPA began work in advanced weapons concepts for the Sensor Fuzed Weapon in the Assault Breaker Program as the Skeet Delivery Vehicle (SDV). In that program and related programs, DARPA developed and demonstrated a warhead and a simple infrared sensor concept leading to a 5.25-inch warhead, a more sophisticated sensor with target discrimination software, and a BLU launching/dispersal system.

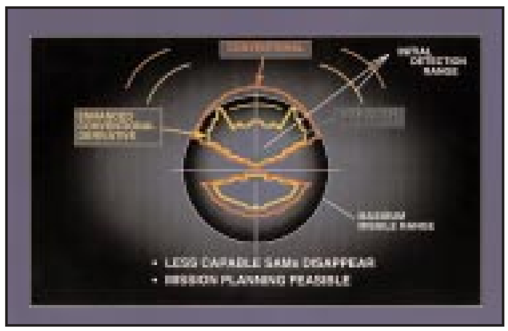
The smart projectile is a sensor fuzed warhead comprised of an infrared sensor, a safe and arming device, a thermal battery, and a copper liner. The infrared sensor detects the target and fuzes the warhead to explosively form the copper liner into a kinetic energy projectile that can defeat both armored and soft vehicle targets.

The smart projectile is a sensor fuzed warhead comprised of an infrared sensor, a safe and arming device, a thermal battery, and a copper liner.

STEALTH FIGHTER

TRANSITIONS TO THE AIR FORCE

This very successful Stealth Fighter, Air Force F-117, was developed from technology demonstrated by a DARPA prototype, the HAVE BLUE aircraft.



- *Top: The Stealth Fighter Air Force F-117.*
- *Center: Radar Signature Reduction.*
- *Bottom: The HAVE BLUE aircraft.*

Early efforts by DARPA led to the development of the Air Force F-117 tactical fighter that was so successful in the Desert Storm operation, flying 1,271 sorties without a single aircraft loss, successfully penetrating air defenses, and delivering 2,000 tons of ordnance to account for some 40% of all targets with an 80%-85% hit rate.

In the early 1970s a study by DARPA, the Air Vehicle Observables workshop, brought to light the extent of the vulnerabilities of U.S. aircraft and their on-board equipment to detection and attack by our adversaries. Based on the study and encouragement from Office of the Secretary of Defense and others, DARPA embarked on a program to develop the technologies for stealthy aircraft. Under a codeword program, "HAVE BLUE," two aircraft were built, and first flight occurred successfully in April 1977. Technologies addressed by DARPA included the reduction of radar cross section through a combination of shaping to form a limited number of radar return spikes designed to be less detectable by ground-based radars, radar absorbent materials, infrared shielding, heat dissipation, reduced visual signatures, low-probability-of-intercept (LPI) radar, active signature cancellation, and inlet shielding, exhaust cooling and shaping, and windshield coatings.

In November 1978, the Air Force initiated a program for the F-117 based on the HAVE BLUE demonstrations and the DARPA-developed technologies. First flight of the F-117 was in June 1981 and the aircraft became operational in October 1983. A total of 59 aircraft were built, and 36 were deployed to Saudi Arabia in late 1990, from which they were highly successful in F-117 Nighthawks attacks against high-value Iraqi targets.

STEALTH BOMBER

TRANSITIONS TO THE AIR FORCE

Early research and development by DARPA led to the design and fabrication of the TACIT BLUE low observable stealth aircraft. Most notably, it was the first aircraft to demonstrate a low radar cross section using curved surfaces, along with a low probability of intercept radar and data link. As such, the DARPA TACIT BLUE Program contributed directly to the development of the B-2 Stealth Bomber so successfully deployed by the Air Force.

■ *The B2 Stealth Bomber.*

Building on the success of the HAVE BLUE prototype Stealth Fighter, DARPA supported a second demonstrator, TACIT BLUE, which provided the curved surface stealth technology base for the B-2 Stealth Bomber.

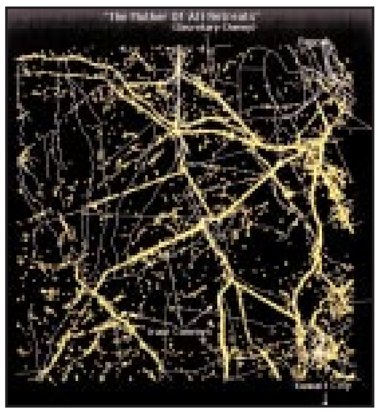
In the early 1970s a study by DARPA, the Air Vehicle Observables workshop, brought to light the extent of the vulnerabilities of U.S. aircraft and their on-board equipment to detection and attack by our adversaries. After the successes of the DARPA HAVE BLUE Stealth Fighter Program, DARPA initiated the TACIT BLUE Technology Demonstration Program, an effort to demonstrate that a low observable surveillance aircraft with a low probability of intercept radar and other sensors could operate close to the forward line of battle with a high degree of survivability. TACIT BLUE first flew in February 1982 and accumulated 135 flights over a three-year period.

■ *TACIT BLUE.*

Other technologies addressed by DARPA included the reduction of radar cross section through a combination of shaping to form a limited number of radar return spikes designed to be less detectable by ground-based radars, radar absorbent materials, infrared shielding, heat dissipation, reduced visual signatures, low-probability-of-intercept (LPI) radar, active signature cancellation, and inlet shielding, exhaust cooling and shaping, and windshield coatings.

JOINT STARS

TRANSITIONS TO THE AIR FORCE



The concept and technology for Joint STARS were products of DARPA research under the Assault Breaker Program. STARS was successful in Desert Storm and is being acquired by the Air Force and international allies.

- *Top left: Airborne operators stations.*
- *Top right: The E-8C JSTARS aircraft.*
- *Bottom: Ground target tracks.*

DARPA and the Air Force jointly developed an airborne target acquisition weapon delivery radar program, Pave Mover, under the DARPA Assault Breaker Program. The Pave Mover system was the demonstrator and became the basis for the Joint STARS airborne target detection and weapon assignment program so successful in Operation Desert Storm as real-time support to the commanders for both battle area situation assessment and targeting roles. The system is now under production and will be operated by the Air Force.

Early DARPA-sponsored technology in low minimum detectable velocity (MDV) moving target indication (MTI) radar became the basis for the Pave Mover/Joint STARS concept. A spot area synthetic aperture radar (SAR) was added to analyze areas for which the MTI radar no longer detected a moving target, and the processing for detection of helicopters and even rotating antennas was included. DARPA sponsored the initial work, which led to the Surveillance and Control Data Link (SCDL) for Joint STARS. Also a part of Pave Mover was a weapon guidance mode that was to guide the weapon to the target coordinates. Though both the radar and the weapon guidance were demonstrated in the DARPA Assault Breaker Program, the weapon guidance was later dropped from the Joint STARS Program.

X-29 FORWARD SWEPT WING AIRCRAFT TECHNOLOGY

TRANSITIONS TO THE AIR FORCE

■ *The X-29 aircraft.*

The DARPA X-29 Technology Demonstrator Program proved successful in demonstrating the ability of a forward swept wing aircraft to operate at high angles of attack and also demonstrated the viability of advanced technologies such as a unique fly-by-wire digital flight control system, aeroelastic tailoring on a thin, forward swept, composite materials, supercritical wing, and the use of close-coupled canards or foreplanes for pitch control. Technology breakthroughs, particularly digital flight control systems for unstable aircraft, and carbon fiber wing technology made possible the manufacture of a supersonic fighter class aircraft with a forward swept wing.

Designed to explore flight regimes unreachable by conventional aircraft, the X-29 demonstrated that an aerodynamically unstable aircraft could be stabilized by unique flight controls and light-weight composite materials.

The X-29 Forward Swept Wing Aircraft Technology Demonstrator began as a DARPA-NASA joint program in 1976 after some design problems occurred in the Highly Maneuverable Aircraft Technology Testbed (HiMAT), and a proponent expert on forward swept wing design became interested in the problem. The expert joined DARPA to become the program manager, and the initial study effort verified the aerodynamic performance of the forward swept wing design.

By 1979, DARPA-funded research had made clear that use of lightweight composite materials could overcome the divergence problems associated with previous forward swept wing designs. DARPA and the Air Force Flight Dynamics Laboratory decided to apply the forward swept wing concept to an experimental aircraft program. Two X-29s were developed, and first flight occurred in December 1984. Subsequently, in March 1985, the program was turned over to the Air Force, and by April 1990 some 279 flights had been completed.

PILOT'S ASSOCIATE

TRANSITIONS TO THE AIR FORCE

■ *The Pilot's Associate system thinks along with the pilot, handling routine tasks.*

The DARPA Pilot's Associate (PA) Program has successfully developed techniques for improved situational awareness for the pilot of the future by a combination of advanced computerized systems using artificial intelligence technology. Although the program was targeted for the beyond-2000 Air Force and Army aircraft, technology elements of the PA Program are now being inserted into the Air Force F-22 aircraft, and the Army will apply PA in its rotorcraft program.

The PA Program began at DARPA in 1986 as a joint effort with the Air Force, originally to demonstrate the feasibility of using artificial intelligence in future single-seat fighter aircraft. Unlike today's avionics systems that can overload the pilot with data, the PA will use an intelligent interface with the pilot that prioritizes data and gives the pilot timely information for making the correct decisions.

The Pilot's Associate will use an intelligent interface with the pilot that prioritizes data and gives the pilot timely information for making the correct decisions.

In 1988 Phase I demonstrations began with two contractors working to establish the functionality and methodology of the PA system. Phase II demonstrations in 1989 produced a demonstrator that would run in real time based on a generic advanced tactical fighter and laid the groundwork for follow-on laboratory environment testing. In 1992 a series of further tests with F-15 pilots occurred, followed by further maturation and application programs.

MATERIALS TECHNOLOGIES FOR THE F-15 AND F-16

Rapid Solidification Rate (RSR) technology enables realization of high temperature resistant metal alloys for critical parts of the F-100 engine.

The primary fighter aircraft in today's Air Force inventory, the F-15 and F-16, owe much of their performance advancements to materials technologies that emerged from DARPA programs conducted in the 1970s and early 1980s. Of substantial significance is the utilization of a nickel-based superalloy in the ring seals of the new F-100-PW-220 engine that powers both the F-15 and F-16. This alloy extends the useful life of hot engine sections 100-fold because of its high strength and improved oxidation resistance, and it can only be produced by the rapid solidification rate (RSR) processing, a revolutionary materials processing technique developed by DARPA. Equally significant, DARPA, in conjunction with the Air Force Materials Laboratory, developed a new methodology termed "Retirement for Cause" (RFC), which integrated nondestructive testing with probabilistic fracture mechanics, logistics, and economics. The Air Force is now using RFC methodology for its maintenance and logistics related to the F-100 engine and also has incorporated RFC into its standards for all Air Force aircraft engine design and maintenance. As of 1990, a participant estimated $1.2 billion in life cycle savings because of parts procurement reduction and reduced maintenance time, both directly resulting from the use of RFC.

■ *The F-15 fighter aircraft.*

■ *The F-16 fighter aircraft.*

Other important DARPA technologies that contribute to the superior performance of the fighters include the following:

■ Rare earth permanent magnets, specifically Sm_2Co_{17}, exhibit a low enough temperature coefficient to allow operation over the entire military temperature range of -55°C to +125°C. These are a new part of the traveling wave tubes in the AN/ALQ-135 EW system, permitting operation of the F-15 to 70,000 feet in altitude.

■ Titanium carbide-coated metal ball bearings, the outgrowth of a program in solid lubricated ceramic technology, provide improved performance, increased operational life, and enhanced factory yields for the F-16 gyroscopes.

LOW PROBABILITY OF INTERCEPT AIRBORNE RADAR

TRANSITIONS TO THE AIR FORCE

The program generated a design and a prototype radar that provided next-generation waveforms, beam-forming techniques, frequency agility, and power management.

A DARPA program to develop and demonstrate a low-probability-of-intercept (LPI) radar as a part of the DARPA HAVE BLUE stealth demonstrator provided critical insights for the design of the B-2 radar, as well as the DARPA/Air Force TACIT BLUE surveillance radar. The successful demonstration that a radar useful for air intercept and ground target detection could be built so as to be undetectable by state-of-the-art radar warning receivers is key to future stealth aircraft programs.

As the HAVE BLUE stealth aircraft program began, it became clear that emitting sensor and communication systems would compromise the stealth and could actually be used to track the aircraft. Several analyses were conducted, and a DARPA program was initiated to attack the most difficult emitter, the aircraft radar. The program generated a design and a prototype radar that provided next-generation waveforms, beam-forming techniques, frequency agility, and power management. The resulting LPI radar was tested in a roofhouse against some very capable radar warning receivers. The radar was not detected. The technologies for LPI radar were transitioned from this DARPA program to the B-2 and the TACIT BLUE surveillance aircraft technology demonstration program.

ADVANCED CRUISE MISSILE

TRANSITIONS TO THE AIR FORCE

A DARPA program, TEAL DAWN, developed key technologies and a design later incorporated into the Air Force Advanced Cruise Missile (ACM). In the early 1980s, the Air Force assumed responsibility for the ACM Program and successfully managed the system through concept demonstration; engineering and manufacturing development; production; and development.

The TEAL DAWN Program involved a series of studies and developments related to the development of a long-range stealthy strategic cruise missile. DARPA experience in low observables was incorporated into the design of the low-signature engine inlet and nozzle. Other technologies included the unique aerosurface sweep angles that provided a benefit to the aerodynamic performance.

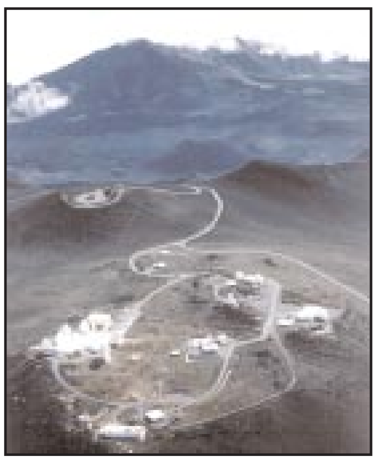
DARPA experience in low observables was incorporated into the design of the low-signature engine inlet and nozzle.

Clearly recognized performance goals (signature, range, flight profile) were successfully demonstrated during the DARPA phase of the program. Wind tunnel and radar ranges testing also were accomplished by the Air Force under DARPA sponsorship. The follow-on Air Force program could then focus on operational test and evaluations (OT&E) and manufacturing objectives with a high degree of confidence that program objectives would be realized.

ARPA MAUI OPTICAL STATION

TRANSITIONS TO THE AIR FORCE

This DARPA facility and equipment, transitioned to the Air Force in 1984, has been used for precise tracking of space objects in the infrared and optical spectra. It also was used for ICBM warhead reentry measurements and for compensated imaging and laser illumination of space objects.



- *Top: Twin infrared telescopes.*
- *Bottom: AMOS site, Mt. Haleakala.*

The ARPA Maui Optical Station (AMOS) initially served as a unique facility for operational measurements and research and development related to space object identification and tracking from the early 1960s. AMOS twin infrared telescopes were transferred to the Air Force in the late 1970s and are now one of the primary sensors of the Air Force Space Tracking System.

AMOS was initiated by DARPA in 1961 as an astronomical-quality observatory to obtain precise measurements and images of reentry bodies and decoys, satellites, and other space objects in the infrared and optical spectrum. By 1969, the quality and potential of AMOS had been demonstrated, and a second phase began in which the Air Force became the DARPA Agent and began to support projects to measure properties of reentry bodies at the facility under its Advance Ballistic Reentry System (ABRES) Project. In the late 1970s, successful space object measurements continued in the infrared and visible ranges, and laser illumination and ranging were initiated. Other developments such as the compensated imaging program were tested successfully at AMOS, located at nearly 10,000 feet atop Mt. Haleakala, Maui, Hawaii. By 1984, AMOS had become a highly automated system, and DARPA transferred it to the Air Force as one of the primary sensors of the Air Force Space Tracking System.

MATERIALS TECHNOLOGIES FOR THE TITAN

TRANSITIONS TO THE AIR FORCE

■ *The Titan rocket.*

The Air Force's primary rocket booster, the Titan, contains important materials technologies that are the result of materials research programs undertaken at DARPA.

DARPA developed the technology for the aluminum/lithium (Al/Li) alloy used for a launch-adapting structure that goes on the front end of the Titan missile. By using the Al/Li, 10% of the weight of this large structure is saved, resulting in a launch cost reduction of $8 million per launch.

Another DARPA-developed technology, explosive forming, is used to fabricate the Titan "manhole" covers.

DARPA development of the aluminum/lithium alloy and its application to Titan yielded a 10% structural weight reduction and $8 million per launch cost reduction.

OVER-THE-HORIZON RADAR

TRANSITIONS TO
THE AIR FORCE

DARPA-sponsored research during a seventeen year period led to the successful deployment of Air Force and Navy radars.

■ *Over-the-Horizon Radar.*

The DARPA program for Over-the-Horizon (OTH) radar technology led to major capabilities for missile launch detection. The DARPA technology work directly influenced major systems, including the Air Force FPS-118 OTH-B radar, continental United States (CONUS) defense system, the Navy Over-the-Horizon Radar (OTH-R), the Stanford Wide Aperture Research Facility (WARF), and the Australian OTH system. The results of the experimental projects affected later decisions on siting and orientation of CONUS OTH air defense radars generally away from auroral regions.

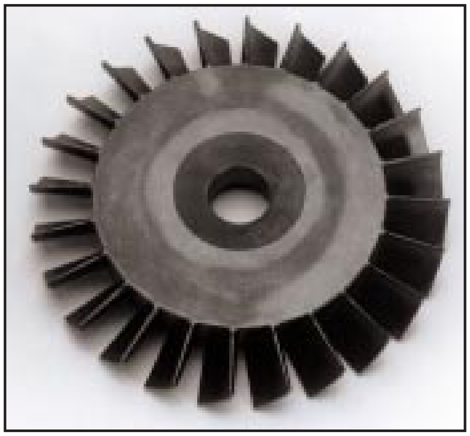
In 1958 DARPA began to support exploratory, high-risk research and development (R&D) on a wide range of OTH techniques and problems, such as antennas and receivers, ionospheric propagation, signal formats, management of interference, and ionospheric sounders. Because of the high priority of ballistic missile defense and DARPA's broad responsibilities and funding under Project DEFENDER, all OTH R&D was coordinated by DARPA.

The DARPA program focused, in the early 1970s, on the problem of evaluating risks for OTH detection of aircraft at higher latitudes, with the singular auroral and polar cap ionospheres, strongly motivated by the fact that CONUS air defense would have to deal with this northern section.

Increasing appreciation of the air threat to CONUS provided motivation for the Air Force to go ahead with OTH backscatter radar systems for CONUS defense in 1975, when DARPA transferred its OTH Program to the Air Force.

EXTENDED LONG-RANGE INTEGRATED TECHNOLOGY EXPERIMENT

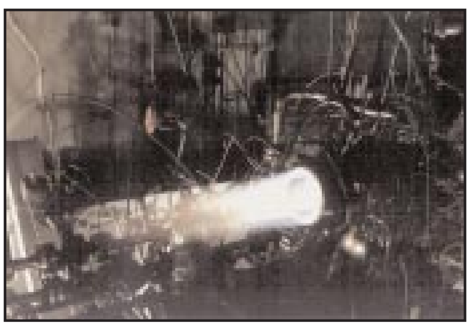
TRANSITIONS TO THE AIR FORCE



■ *Carbon-carbon turbine blades.*

DARPA, in the Extended Long-Range Integrated Technology Experiment (ELITE), pioneered the development of carbon-carbon technologies for higher temperature engines (3,600 °F). The higher temperature engines provide greatly improved efficiency for fuel quantity-critical applications. The technology work started at DARPA is the basis for further work under way at the Air Force Wright Laboratories.

A DARPA technology program, ELITE, conducted a significant amount of development of carbon-carbon (a high-temperature material). The work culminated in the demonstration of carbon-carbon turbine blades under the Wright Lab Expendable Turbine Engine Concept technology program. A great deal was learned in the program, and Wright Labs is now developing new application engines using the DARPA-initiated carbon-carbon materials technologies under the Joint Expendable Turbine Engine Concept Program. Improvements of 100% in thrust per air flow, reduction of 40% in specific fuel consumption, and a reduction of 60% in cost are the goals.



■ *High-temperature turbine engine firing.*

High-temperature turbine engines using DARPA-developed carbon-carbon turbine blades have goals of 100% improvement in thrust per air flow, 40% reduction in specific fuel consumption, and 60% reduction in cost.

ADVANCED MEDIUM RANGE AIR-TO-AIR MISSILE

■ *AMRAAM launch from an Air Force F-16.*

This follow-on to the AIM-7 Sparrow missile is faster, lighter weight, and has improved low-altitude target capability. Development benefited from DARPA research on a Light-Weight Radar Missile (LWRM) using solid state radar.

■ *Model of AMRAAM.*

The Advanced Medium Range Air-to-Air Missile (AMRAAM) was influenced by the DARPA Light-Weight Radar Missile (LWRM) program in the early 1970s when DARPA initiated the program based on a tri-service technology base program in solid state radar.

Both DARPA and the Air Force funded the original studies and limited technology development work. DARPA studies showed that a high-speed, countermeasures-resistant, launch and leave, active radar missile with significant performance would not fit into the AIM-9 Sidewinder missile size and weight, which was DARPA's desire. The Air Force was willing to accept a larger size consistent with the AIM-7 Sparrow missile launch stations, and the program proceeded on that basis.

The AMRAAM is a new generation missile and became the follow-on to the AIM-7 Sparrow missile series. It is faster, lighter, and has an improved low-altitude target capability. The AMRAAM began its conceptual phase in 1979 when the U.S. Air Force selected two of five competing contractors to continue into the validation phase. The validation phase ended in December 1981, and the full scale missile was deployed in late 1991. With an inertial midcourse guidance and an active radar terminal guidance, the $400,000 missile can operate at ranges greater than twenty miles.

MATERIALS TECHNOLOGIES FOR THE SR-71

TRANSITIONS TO THE AIR FORCE

■ *The SR-71.*

The high-flying SR-71 gave the United States invaluable intelligence information. Its ability to achieve heretofore unobtainable performance parameters rests on innovations in many technology areas. New materials technologies played a substantial role.

DARPA's materials program in explosive forming provided the technology for SR-71 afterburner rings.

The explosive forming technology also has found extensive use in other DoD projects. It has been used to make jet engine diffusers for Rohr, Titan "manhole" covers, rocket engine seals, P-3 Orion aircraft skin, tactical missile domes, jet engine sound suppressors, and heat shields for turbine engines. The reason for the widespread use of explosive forming technology in DoD systems is its relatively cost-effective means for obtaining tight tolerances for complex shapes for a large variety of engineering metals and alloys.

New materials technology in critical subsections allow the SR-71 to fly higher, faster, and farther.

NUCLEAR TEST MONITORING SATELLITES

TRANSITIONS TO THE AIR FORCE

Satellites for detection of nuclear tests in space and the upper atmosphere were developed by DARPA in the early 1960s and transferred to the Air Force in 1970.

■ *The VELA satellite.*

In 1959, the High-Altitude Detection Panel of the President's Science Advisory Committee recommended that a satellite system be used to detect nuclear tests in space and in the atmosphere as part of the overall basis for verification of a future nuclear test ban treaty. The first such satellites, known as VELA HOTEL satellites, were launched by DARPA in 1963 and were very successful, with performance cost and lifetime far better than expected. This success also provided interim monitoring capability in support of the Limited Test Ban Treaty, which banned nuclear tests in the earth's atmosphere and in space. In 1970, after six VELA HOTEL satellite pairs had been launched successfully and had operated successfully in orbit, the project was taken over by the Air Force.

The objective of the DARPA VELA HOTEL Program was to develop satellite technology and global background data to detect nuclear explosions taking place in space, and eventually also in the earth's atmosphere. The program developed x-ray, neutron, electromagnetic pulse (EMP), and gamma ray detectors, and instruments to measure background radiation. Some subsequent satellites were fitted with an optical signature detector called the "bhangmeter." Later nuclear detection systems, such as the global positioning system/nuclear detection system (GPS/NDS) and integrated navigation and nuclear explosion detection satellites, are based on the detector technologies developed at DARPA.

PHASED ARRAY RADARS

TRANSITIONS TO THE AIR FORCE

■ *The PAVE PAWS radar network system.*

DARPA pioneered the construction of large ground-based phased array radars such as the FPS-85 with a program called Electronically Steered Array Radar (ESAR). The FPS-85 phased array radar had a range of several thousand miles and could detect, track, identify, and catalog earth-orbiting objects and ballistic missiles. The FPS-85 quickly became part of the Air Force SPACETRACK system and is operational today.

In 1957 a President's Science Advisory Committee panel and many other experts had pointed out the need in ballistic missile defense (BMD) and space surveillance to detect, track, and identify a large number of objects incoming or moving at very high speeds.

Responding to these needs, DARPA initiated a design competition for design and construction of a large experimental two-dimensional phased array with beam steering under computer control known as the ESAR Program. The program's focus was to develop low-cost, high-power tubes and phase shifters, extend component frequency ranges, increase bandwidth, apply digital techniques, and study antenna coupling.

The Air Force, enthused by the success of the DARPA ESAR, began a follow-on, larger, high-power phased array radar program for space tracking based largely on the ESAR technology. ESAR's successful performance also accelerated a DARPA program of phased array components that has affected all subsequent large phased array systems, including the Air Force PAVE PAWS, and the Navy AEGIS Phased Array Radars.

Early DARPA research under the DEFENDER Program led to the development of a large phased array radar (ESAR) and supporting components. This technology was key to the development of the Air Force FPS-85 and other operational phased array radars.

TRANSITIONS TO THE ARMY

1990s

Enhanced Survivability for the HMMWV
MELIOS Improvement
Signal Processing Technologies for the OH-58D
Comanche ANN-Based ATR
SOLDIER 911
X-Rod Guided Projectile
Shaped Charge Warheads
Cermet Materials for Armor
Hand-Emplaced Wide Area Munition

1980s

Close Combat Tactical Trainer
Javelin
Uncooled IR Sensors
Head-Mounted Displays
Body Armor
No Tail Rotor for Single Rotor Helicopters
Precision Emitter Location

1970s

Copperhead
Army Tactical Missile Systems
Mini-Remotely Piloted Vehicles
Brilliant Anti-Tank Munition

1960s

M16 Assault Rifle
SPRINT
Camp Sentinel Radar

ENHANCED SURVIVABILITY FOR THE HMMWV

TRANSITIONS TO THE ARMY

DARPA-developed armor kits provided an 80% solution at one-tenth the cost and one-quarter the weight of the Army Enhanced Armor HMMWV.

■ *The High Mobility Multipurpose Wheeled Vehicle.*

In late 1992, DARPA initiated a program to examine advanced survivability for the High Mobility Multipurpose Wheeled Vehicle (HMMWV). The intent was to provide both ballistic and mine protection to crew members in the lightest configuration possible. In addition, the protection had to be modular, retrofittable, and low cost. Mobility and survivability, as well as mission adaptability, were the operational drivers.

In July 1993, several U.S. soldiers riding in HMMWVs were killed by mines and sniper fire in Somalia. As a result, DARPA received an urgent request to provide any near term force protection technologies that could help U.S. and UN forces in Somalia. DARPA had sixteen prototype HMMWV armor kits delivered. These kits provided an 80% solution at one-tenth the cost and one-fourth the weight of the Army Enhanced Armor HMMWV. These kits also have been used successfully in patrolling sections of Haiti during PROVIDE PROMISE and in the peacekeeping missions in Sarajevo, Bosnia.

MELIOS IMPROVEMENT

TRANSITIONS TO THE ARMY

■ *The Melios.*

This program addressed a need for precise location of targets and the ability to wirelessly transmit formatted reconnaissance information to headquarters. It significantly decreased the time and increased the accuracy of dismounted reconnaissance personnel reporting and also formatted reports such as Call For Fire while in the field. It also decreases time on the radio and prevents the operator from being located and identified. The MELIOS, an existing piece of equipment, was modified so the soldier does not have to carry additional weight and the logistics system does not have additional part numbers to track. These upgrades are easily made in a depot, and are low cost, low weight, and high value-added.

DARPA-developed modifications to MELIOS provided precise location of targets and rapid reporting from the field.

The DARPA program was initiated to investigate the ability to modify a hand-held laser rangefinder (MELIOS) developed by the U.S. Army Program Manager (PM) for Night Vision. A memorandum of understanding was signed with the PM for Night Vision to cooperate on the project. As functionality improvements were demonstrated, the PM for Night Vision funded his contractors to incorporate the changes in MELIOS. The upgraded equipment is accomplished through an engineering change proposal to the existing MELIOS contract.

SIGNAL PROCESSING TECHNOLOGIES FOR THE OH-58D

Gallium arsenide integrated circuits endow the OH-58D with speedier acquisition of targets by synchronizing visible and infrared images.

■ *The OH-58D.*

The OH-58D, the Army's primary scout helicopter, will incorporate DARPA-developed signal processing technology into its next upgrade. Designed to find targets rapidly and laser designate them for destruction by attack helicopters, the OH-58D needs the highest speed signal processors to achieve swift sensor data fusion to acquire and assess targets.

DARPA initiated gallium arsenide (GaAs) integrated circuit (IC) development in 1975. GaAs as a semiconductor held the promise of providing higher speed and lower power consumption for digital electronics as opposed to traditional silicon-based ICs. Once initial laboratory results had demonstrated the performance potential of the technology, DARPA's efforts concentrated on producibility and insertion of the technology into fielded military systems. In the next upgrade of the OH-58D, a GaAs digital signal processor (DSP) will be processing the data from the helicopter's mast-mounted site sensors. This will, for the first time, provide side-by-side television images in both visible and infrared that are precisely matched with respect to fields of view. The simultaneous display of visible and infrared images substantially enhances rapid target acquisition and evaluation.

COMANCHE ANN-BASED ATR

TRANSITIONS
TO THE ARMY

■ *The Comanche.*

The Army's new reconnaissance helicopter, the Comanche, will deploy an artificial neural network (ANN)-based aided target recognition (ATR) system. In the first two comprehensive Army blind tests on Comanche forward looking infrared (FLIR) imagery, the ANN achieved factors of two to sixfold reduction in detection error, identification error, and false alarm rate over the competing template-matching algorithm. These results enable the Comanche performance specifications to be achieved, while the template matcher failed to meet those specifications.

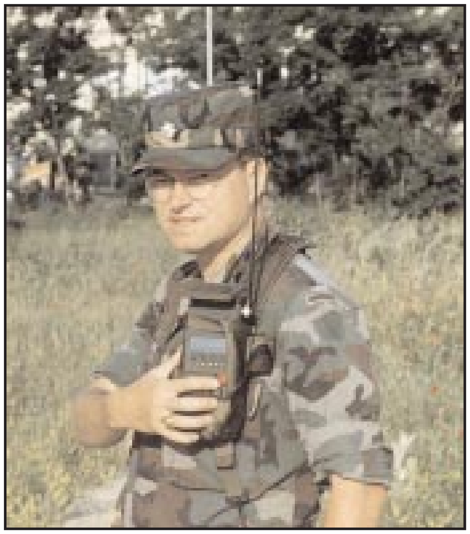
DARPA initiated a major ANN program in 1989. One of its goals was to determine the potential applicability of the ANN algorithms to military signal processing tasks. DARPA developed an ANN-based ATR system and compared its performance to that of its standard template matcher, an algorithm that had seen twenty years of development. As a result of the ANN's successful test runs, key portions of the code are now being programmed onto the Comanche array processor. The ANN ATR classifier has now also been delivered for testing to other major users: RISTA, ASTAMIDS, TAATD, TSSA, Color ATR, and MSAT-Air.

Artificial neural networks (ANN) technology provides the Comanche with a man-in-the-loop aided target recognition system (ATR) that enables the Comanche to operate and be survivable on the battlefield within the threat engagement timelines.

SOLDIER 911

TRANSITIONS TO THE ARMY

DARPA GPS multichip module in the GPS emergency radio provides field soldier position location and emergency call for assistance.



■ *Army officer with his finger on the 911 button.*

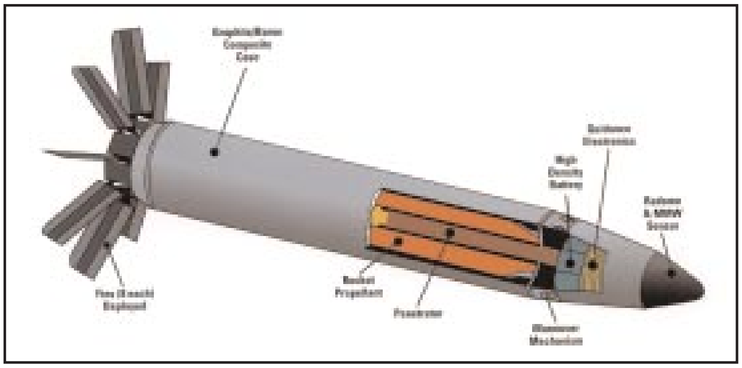
SOLDIER 911 is a personal emergency radio that monitors the position of the wearer, and if the soldier approaches a restricted area, the radio alerts the soldier and his or her chain of command. The radio also contains an emergency call button whereby the wearer can call for immediate assistance (hence the "911" name), and a geolocation network report-back system.

SOLDIER 911 responded to an immediate need identified by the Commander-in-Chief (CINC), Europe, to alert peacekeepers in Macedonia when they were approaching the Serbian border. It has also has been requested by the CINC U.S. Forces Korea and deployed in a limited test to assist soldiers and airmen there. SOLDIER 911 is based on the Motorola GPS-112 emergency radio (which is an upgrade of the PRC-112 that incorporates the DARPA Global Positioning System multichip module).

X-ROD GUIDED PROJECTILE

TRANSITIONS
TO THE ARMY

The X-Rod, developed jointly between DARPA and the Balanced Technology Initiative (BTI) Program, is a long- range, millimeter-wave guided, rocket-boosted, kinetic energy antiarmor tank projectile. The X-Rod Program was transitioned to the Army in 1992, while still in the technology demonstration stage. The Army is currently competing the X-Rod against its Staff system with a downselection scheduled for FY 1998.



■ *The X-Rod "smart" tank munition.*

DARPA developed and managed the X-Rod Program and selected the best combination of technologies to accomplish Army mission goals for such a system. The objective of the X-Rod Program was to develop a long-range tank round that would respond to a recommendation of the 1985 Defense Science Board (DSB) Summer Study to increase the battlespace by increasing the ranges at which targets can be acquired and attacked with direct fire weapons. Studies had shown that defending forces (such as NATO) did much better if they could engage effectively from further away than exposed attackers (such as the Warsaw Pact). The Army was developing a long-range, rocket-boosted tank projectile known as RAKE (Rocket Assisted Kinetic Energy). However, there were concerns that at extreme ranges (such as three or more kilometers) the accuracy requirements would be too stringent for it to be highly effective. This concern was addressed by the X-Rod program (which one might describe as "Guided RAKE") when funding from the BTI became available in FY 1987.

The Army is currently competing the X-Rod against its Staff system with a downselection scheduled for FY 1998.

SHAPED CHARGE WARHEADS

TRANSITIONS
TO THE ARMY

Most anti-tank weapons rely on shaped charge technology. DARPA technology helps keep them viable.

■ *Tube Launched, Optically Tracked Wire Guided Anti-Tank Missile (TOW).*

Three shaped charge warheads and a number of technologies were transitioned to the Army at the close of the Armor/Antiarmor Joint Program at DARPA in 1993 (they are receiving Army research and development (R&D) funding). One is a precursor warhead for the Tube Launched, Optically Tracked Wire Guided Anti-Tank Missile (TOW) follow-on, another is a classified concept for a Javelin preplanned product improvement, and the third is a tandem warhead precursor concept.

The Shaped Charge Warhead Program, conducted under the DARPA-led Armor/Antiarmor Program, developed chemical energy warhead and explosively formed penetrator (EFP) technologies. Two paths were taken to accomplish this. In the first, industrial teams developed and demonstrated advanced designs and material applications. Two of these warheads were adopted by the Army for development toward integration into fielded or developmental missiles. Definitive work was done in depleted uranium liners, the dynamic shaping of EFPs, and a unique low-density liner for a precursor. Along the way a large volume of analytical and experimental data was collected toward future advancements. The second path was dedicated to basic technology investigations to expand warhead design parameters by exploring and applying advanced high-risk concepts. For example, the Lawrence Livermore National Laboratory produced extremely fast jets for countering reactive armors, multipoint warhead initiation schemes, tungsten liners, and state-of-the-art diagnostic instrumentation. Perhaps their most impressive contribution was the development of a computer-aided design technique that enabled the optimization of the liner through a series of iterative designs undergoing simulated tests, resulting in extremely efficient designs that are receiving Army R&D funds for consideration as a TOW follow-on precursor warhead.

CERMET MATERIALS FOR ARMOR

■ *A marine adds DARPA/DSO ceramic armor appliqués to a light armored vehicle.*

The Lanxide cermet (ceramic/ metallic) process discovered by M. Newkirk at Lanxide Corporation has resulted in hundreds of patents. Variations have been successfully used as appliqué armor for the Marine Corps' Light Armored Vehicles (LAV) in Operation Desert Storm (particularly for roof protection from artillery). This insertion was funded by the DARPA ceramic Insertion Program. Seventy-five LAVs were up-armored. M-9 ACE also employed this lightweight armor, which was adopted in 1993. Other variations have been used for cockpit armor by the Air Force in the C-130, C-141, and C-14 aircraft in Bosnia. The Lanxide material has also been employed as high-power density heat sinks for the F/A-18 and F-16 radars, turbine tip shrouds, commercial satellite heat sinks, very stiff parts for semiconductor lithography machines, and as vehicle brake components.

The Lanxide cermet material has been inserted as armor in many Army and Air Force applications.

DARPA's role, in addition to support of advanced materials development, was to identify technology for this application. All the military and civil uses of Lanxide evolved directly from DARPA's program. The military uses were examined in a preliminary laboratory-based manner under DARPA support, and then transitioned to Army and Air Force Programs.

HAND-EMPLACED WIDE AREA MUNITION

TRANSITIONS TO THE ARMY

Command, Control, Communications (C^3) technology allows for positive control of a wide area mine field.

The Army Wide Area Munition (WAM) is an unattended antiarmor device with a lethal radius of 100 meters. It can attack nearby targets without demanding direct contact to trigger a fuse. Providing that device with basic Command, Control, Communications (C^3) capabilities allows a controller to turn the minefield on and off. The controller also autonomously creates a "map" of the minefield, showing where each device is located. Finally, it allows easy retrieval, locating each mine electronically.

DARPA's role was to develop the C^3 for the WAM, allowing mines to communicate with a controller unit and, eventually, with each other. The first infusion of this technology will be accomplished through an engineering and manufacturing development in FY 1996 for a WAM Product Improvement Program. The next step in the process is the development of truly "intelligent" minefields, where communications between WAMs and more capable computers will combine to generate simple tactics involving several devices automatically, as well as create the capability to deactivate the mines after some time.

CLOSE COMBAT TACTICAL TRAINER

TRANSITIONS TO THE ARMY

■ *SIMNET workstation.*

SIMNET stands for networked simulation. It represents the technology that permits trainees to interact from separate simulators. These simulators may be in the same facility (such as the armored vehicle training range at Fort Leavenworth), or located around the world. Using Protocol Data Units (PDUs), simulators share state change updates with other networked simulators, which have been previously initialized with the same data, so that only changes need to be transmitted among the participating systems. In the Synthetic Theater of War 97 (STOW 97) program, up to 50,000 entities (tanks, planes, etc.) will be interacting dynamically in a realistic synthetic environment. SIMNET also includes semiautomated opposing forces.

Networked simulation permits large-scale training with "sweaty palms" realism.

SIMNET is a breakthrough training technology that transitioned to the Army as Battlefield Distributed Simulation-Developmental. Its technology underlies the Combined Arms Tactical Trainer, which is currently being procured. SIMNET permits interaction of trainees under free play conditions, leading to enhanced realism in training. In addition, results from networked simulations may be incorporated into constructive simulations so that the larger simulation may be based on actual human interaction, rather than computer projections. Advanced distributed simulation also may be used to try operational concepts for developmental hardware systems, informing performance trade-offs during the design phase, when they are least expensive and most appropriate.

JAVELIN

TRANSITIONS
TO THE ARMY

DARPA mercury-cadmium telluride (MCT) manufacturing technology enabled low-cost production of infrared arrays.

■ *Army Javelin Missile system.*

The forty-nine-pound Javelin is a human-portable anti-tank missile system that is to replace the Dragon missile in the Army's inventory, with production buys from 1995 through 2009. The Javelin provides high lethality against conventional and reactive armor. The Javelin was derived from a DARPA concept called Tank Breaker during the late 1970s and early 1980s. It featured a top-attack warhead (conceived to strike the tank on its vulnerable top area), an imaging focal plane array seeker, and lock-on before launch. DARPA developed this approach in the face of increasingly tougher frontal armor found on Soviet tanks. It was accepted by the Army in the mid-1980s and advertised for further development and production under a program called Anti-Armor Weapon System–Medium (AAWS–M).

DARPA also provided the manufacturing technology for Javelin's thermal (long-wave infrared) target acquisition and the missile's seeker arrays. While DARPA and the Services have supported technology development in mercury-cadmium-telluride (MCT) imagers for two decades, it was DARPA's MCT Manufacturing Technology Program that achieved the needed discipline in infrared (IR) imaging array production to obtain acceptable manufacturing yield. This was achieved despite the very stringent specifications required by the Javelin IR imaging arrays. The high yields allowed a 100x reduction in the cost of both the 240 x 2 scanning arrays used for target acquisition and the 64 x 64 seeker arrays. This cost reduction made the Javelin IR subsystem affordable.

UNCOOLED IR SENSORS

TRANSITIONS TO THE ARMY

■ *Uncooled IR Sensor.*

The U.S. military has "owned the night" because of generations of cryogenically cooled infrared (IR) sensors. These sensors were a major reason for the ground victory in Desert Storm. Unfortunately, the high cost of cooled sensors has precluded wide distribution to combat troops' human-portable applications. Although the performance of uncooled IR sensors is below that of the cooled sensors, they are superior (in nearly all circumstances) to light intensification equipment that is today's low-cost alternative. The uncooled IR technology has been accepted into the Army as a prototype and awaits production for fielding.

The Low-Cost, Uncooled Sensor Program (LOCUSP) at DARPA initially developed, fabricated, and demonstrated this new technology. Two new Technology Reinvestment Project development efforts are exploiting microbolometers and advanced ferroelectric technologies. These efforts will accelerate the entry of uncooled IR technologies into the commercial market, and will contribute to sustain the research and development and manufacturing bases necessary for affordable, high-performance military systems. Specifically, the program addresses cost reduction and performance improvement of major elements of the uncooled night vision sight and provides prototypes for several important applications.

The DARPA Low-Cost, Uncooled Sensor Program (LOCUSP) has advanced this technology and has yielded low-cost, high-performance uncooled infrared sensors.

HEAD MOUNTED DISPLAYS

DARPA's head-mounted display technology is being integrated into the Army's Land Warrior Program and the Generation II soldier.

■ *Head-mounted display.*

This program provided the capability for soldiers to view information from a head-mounted sensor and also from a wearable computer. It developed a capability that never before existed and was not expected to exist until well into the twenty-first century. There is an upgrade path to meet the needs of the future. Current demands are greater than the supply. In a business area where the Japanese dominate 95% of the market, this technology can be procured domestically for military purposes.

DARPA awarded separate development contracts for miniature displays and an integrated head-mounted display system. All contractors worked together in a technology development and integration effort. DARPA's head-mounted subsystem is being integrated into the Army's Land Warrior Program and the Generation II soldier. Both these Army programs also plan to upgrade their systems with DARPA-developed display technologies.

BODY ARMOR

TRANSITIONS TO THE ARMY

■ *Top and bottom: Concealable body armor.*

Because current Army and Marine flak jackets are ineffective against all machine gun and sniper rifle bullets (e.g., 7.62 mm armor piercing bullets), DARPA developed jacket inserts to improve soldier survivability against sniper attack. The insert is composed of ceramic material developed under the DARPA Armor/Anti-Armor Program. In a separate case, Special Forces purchased sixty ballistic breastplates of DARPA-developed Lanxide cermet (DIMOX-HTTM) for insertion into their body armor systems. Plates were of a unique design and employed cermet as a hard face to fracture projectiles.

DARPA hosted a demonstration of its body armor insert at Aberdeen Proving Ground. The vest insert is 40% lighter than the current ranger body armor insert. The insert stopped several rounds, thereby validating its utility against sniper fire. Special Operations Command (SOCOM) representatives were extremely impressed and immediately initiated a procurement of the DARPA Inserts. Another SOCOM unit also began a separate procurement of these vest inserts.

DARPA's vest insert using Lanxide cermet (DIMOX-HTTM) is 40% lighter than current armor and is effective against sniper fire where current armor is not.

NO TAIL ROTOR FOR SINGLE ROTOR HELICOPTERS

TRANSITIONS TO THE ARMY

Quiet helicopters increase survivability and effectiveness.

■ *The NOTAR series of helicopters.*

No Tail Rotor (NOTAR) helicopters are the world's quietest helicopters, which translates into decreased helicopter detection. NOTAR is incorporated into three new production helicopters by McDonnell Douglas Helicopter systems. The light, single-engine versions are the MD 520N and the MD 600N, and the medium, twin-engine version is the MD 900 Explorer. The NOTAR system was also incorporated into McDonnell Douglas' entry into the Army's RAH-66 Comanche competitive procurement. There are more than 100 NOTAR-equipped helicopters currently flying worldwide.

The current MD 520N, MD 600N, and MD 900 Explorer directly evolved from the NOTAR demonstrator aircraft program run by DARPA and demonstrated in the early 1980s. Without DARPA's support to show the operational advantages of the NOTAR flying demonstrator, the NOTAR series of helicopters would not be flying today. The NOTAR system is considered to be the first successful fundamental configuration change to the single-rotor helicopter since the incorporation of the turbine engine in the late 1950s and early 1960s.

PRECISION EMITTER LOCATION

TRANSITIONS TO THE ARMY

■ *The Guardrail SIGINT aircraft.*

DARPA-developed technologies for the near real-time precision location of communications emitters provided a major breakthrough in this difficult problem. The technology was developed in conjunction with the Air Force and, later, the Army and is currently fielded in the Army Communications High-Accuracy Airborne Location System (CHAALS) aboard the Guardrail Signal Intercept (SIGINT) aircraft, as the only airborne high-accuracy communications emitter location capability in the Military Services.

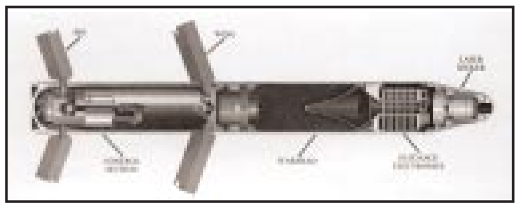
The technique exploiting time-difference-of-arrival (TDOA) and differential doppler (DD) technologies enable rapid targeting of enemy command and control elements.

A DARPA-initiated demonstration program carried algorithms developed by the Air Force to a demonstration phase called Mini-Emitter Location System (Mini-ELS). The technique exploited time-difference-of-arrival (TDOA) and differential doppler (DD) techniques using long baseline aircraft receivers. The TDOA and DD technologies provide the first major improvement in emitter location accuracies for intelligence and targeting purposes.

COPPERHEAD

TRANSITIONS TO THE ARMY

Precision artillery attack of mobile hard targets.

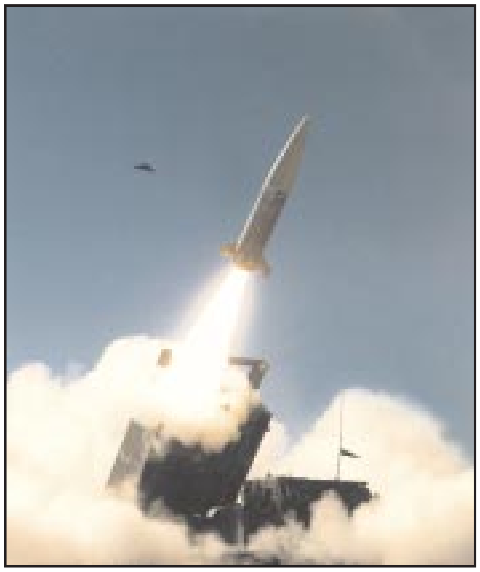


- *Top left: Copperhead approaching tank.*
- *Top right: Direct hit.*
- *Bottom: Copperhead round.*

Copperhead is a semi-active laser (SAL) guided artillery round that has been in the Army's inventory since the 1980s. It was remarkable in that the guidance and fuzing system successfully sustained over 8,000 g's during launch. The round proved to be an extremely accurate way to deliver munitions to a point target.

DARPA sponsored the development and subsequent g hardening of the SAL seeker through a contract with what is now Lockheed Martin. The concept was proven through demonstrations of the Laser Aided Rocket System (LARS) using the 2.75-inch rocket. The success of LARS led to the development of the Tri-Service prototype SAL seekers in 1971 and 1972. This led to the Army's Cannon-Launched Guided Projectile (CLGP) Program in 1972-1975. After cannon testing, CLGP became Copperhead in 1975. At one time, production rates exceeded 500 rounds per month. Production ended in 1989, after 27,000 rounds had been produced.

ARMY TACTICAL MISSILE SYSTEMS



■ *The Army Tactical Missile System (ATACMS).*

The Army Tactical Missile System (ATACMS) is the centerpiece of the Army's precision strike modernization effort. It is a long-range, quick-response surface-to-surface artillery rocket system with all-weather, day and night capability to be deployed against a wide range of targets, including critical mobile targets. It saw action during Desert Storm, where it was used to neutralize or destroy several surface-to-air missile sites, a logistics site, a refueling point, vehicles on a pontoon bridge, and other targets. A feature of the ATACMS is the ability to carry a variety of warheads, including many deployable submunitions, such as antipersonnel/antimaterial (APAM) and Brilliant Antiarmor Submunition (BAT) warheads. The ATACMS Block I is currently in its fourth year of full-scale production, with Block II scheduled to enter production in 1999.

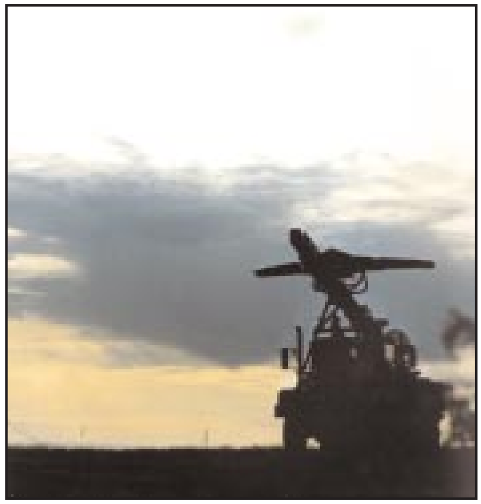
DARPA Assault Breaker Program demonstrated the feasibility of multiple kills from submunitions carried by a single delivery weapon.

The parent program to ATACMS was DARPA's Assault Breaker, which was conducted during the late 1970s. DARPA combined several of the emerging technologies of the time—Synthetic Aperture Radar with Moving Target Indication capability, intelligence fusion (BETA project), and terminally guided submunitions—into a system of systems that demonstrated in principle the capability to kill multiple mobile hard targets at standoff ranges with a single delivery system. This delivery system became the ATACMS missile and was made compatible with the Army's workhorse Multiple Launch Rocket system. Assault Breaker's missile system demonstrated submunitions with infrared seekers and shaped charge and explosively formed projectile warheads.

MINI-REMOTELY PILOTED VEHICLES

TRANSITIONS TO THE ARMY

DARPA pioneered the development of Mini-RPVs starting in the 1960s.



■ *AQUILA.*

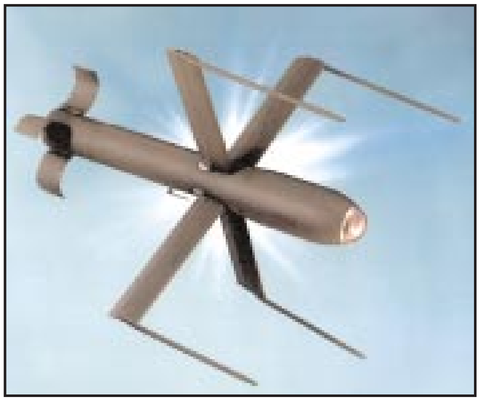
DARPA pioneered in the development of Mini-Remotely Piloted Vehicles (Mini-RPVs), transitioning technologies to many later Unmanned Aerial Vehicle and RPV programs in all Services. In addition to aerial vehicle development, DARPA was very active in the development of payloads, with the first major effort being to develop payloads for the Navy drone anti-submarine helicopter (DASH), including communications and guidance packages, day and low-light-level television, moving target indication radar, a hypervelocity gun, a laser designator rocket system, and a variety of other weapons under the NITE PANTHER and NITE GAZELLE programs. The NITE PANTHER was used in test and operational missions in Vietnam.

In the early 1970s, DARPA initiated efforts to develop air vehicles and compact, high-performance and lower cost electro-optical sensor systems. DARPA also began, in 1972, an effort to develop a lightweight, compact, low-cost sensor/laser designator combination that had been recommended by the Defense Science Board (DSB). The resulting RPV had exchangeable modular payloads, the RPV carrying the daytime television-laser target designator configuration called PRAEIRE, and the same RPV carrying the lightweight forward-looking infrared and laser target designator called CALERE. The first flight of PRAEIRE, a 75-pound RPV powered by a modified lawn mower engine, occurred in 1973 in a joint Army-DARPA effort. The Army AQUILA RPV evolved from this technology.

In the early 1970s, DARPA and the Air Force began work on an expendable mini-RPV, capable of loitering and attack, called AXILLARY, from which the Air Force initiated the Tacit Rainbow system. In a related technology effort, DARPA undertook the long-endurance, high-altitude RPV program Amber in 1983, taking advantage of new advances in materials, computers, propulsion, communications, and sensor capabilities.

BRILLIANT ANTI-TANK MUNITION

TRANSITIONS TO THE ARMY



■ *The Brilliant Anti-Tank Munition (BAT).*

The Brilliant Anti-Tank Munition (BAT) is a terminally guided anti-armor munition originally intended to be carried aboard the Tri-Service Standoff Attack Missile. It has dual seekers to minimize spoofing, including a novel acoustic sensor that can cue on the sound of running tank engines. Low-rate initial production of BAT is planned to start the first quarter of FY 1998.

DARPA and the Army's Fort Belvoir Research, Development and Engineering Center ran a series of concept studies in the early 1970s to define requirements for the Terminally Guided Anti-Armor Indirect Fire Weapon System. Technology development funding provided industry with the confidence that the future would contain a terminally guided Anti-Armor Indirect Fire Weapons System, thereby justifying corporate investments in BAT. The BAT Program transition path occurred when people with experience and knowledge they had gained through DARPA programs became key players in the BAT Program.

Joint DARPA/Army technology efforts provided a confidence level to proceed with the Brilliant Anti-Tank Munition.

M16 ASSAULT RIFLE

TRANSITIONS
TO THE ARMY

■ *The M-16 rifle.*

DARPA-sponsored field evaluation of the Colt AR-15 rifle led to adoption of the lightweight high-velocity 5.56 mm-round M16 rifle.

The M16 Assault Rifle is the standard issue shoulder weapon in the U.S. military. It marks a departure from normal ballistics in that it uses a smaller, high-velocity round (5.56 mm caliber vs. 7.62 mm). This results in a smaller and lighter weapon as well as smaller ammunition, thereby significantly decreasing combat load.

The M16 is based on a design (the Colt AR-15) that had already been rejected by the Chief of Staff of the Army in favor of the heavier 7.62 mm M14. Colt brought the weapon to DARPA in 1962. Through Project AGILE, DARPA purchased 1,000 AR-15s and issued them to combat troops in Southeast Asia for field trials, to prove that the high-velocity 5.56 mm round had satisfactory performance. The subsequent DARPA report, documenting the lethality of the AR-15, was instrumental in motivating the Secretary of Defense to reconsider the Army's decision and eventually adopt a modified AR-15 as the U.S. military individual weapon of choice. The weapon was first deployed to the Air Force's Air Police and later adopted by the Army. The move to high-velocity 5.56 mm was also subsequently adopted by the Israelis, the Soviets, and our NATO allies. DARPA's most significant contribution to this program was its willingness to "think outside of the box" and try something new.

SPRINT

TRANSITIONS
TO THE ARMY

■ *SPRINT Launch.*

High-acceleration missiles with precision guidance could make feasible the interception and destruction of inbound nuclear missiles, enabling point defense of hardened ground targets, such as missile silos. This defense would enhance deterrence by making a disarming nuclear first strike less feasible. High Booster Experiment/ UPSTAGE (HIBEX) was a DARPA development that roughly paralleled the Army's SPRINT high-velocity interceptor program. HIBEX outperformed SPRINT (which was designed for near-term deployment), and was later incorporated into the Army's Low Altitude Defense (LoADS) Program (LoADS did not develop a first stage, but assumed one with performance similar to HIBEX). UPSTAGE was a maneuvering second stage interceptor. It was later incorporated into the HEDI Program, the Strategic Defense Initiative's High Endoatmospheric Defensive Interceptor missile.

The DARPA HIBEX Program developed extremely high specific impulse solid propellants that provide the enabling technology for terminal intercept missiles against ICBMs.

HIBEX developed new solid propellants that could provide extremely high specific impulse while resisting structural deformation and cracking during multi-axial loading during acceleration. In general, HIBEX achieved Mach 8 velocities with one-second burn times, with 400 g peak axial and 60 g lateral accelerations. UPSTAGE incorporated a ring laser gyroscope (which requires no "spin up") that had been developed partly with DARPA funding. It also used jet thrust vector control, achieving 300 g lateral acceleration. Its responsiveness made high-precision, nonnuclear kills appear feasible.

CAMP SENTINEL RADAR

TRANSITIONS TO THE ARMY

This DARPA-developed foliage penetration radar proved the feasibility of military base intrusion detection in Vietnam-like environments.

■ *Camp Sentinel Radar.*

The Camp Sentinel Radar penetrated foliage to detect infiltrators near U.S. deployments and was a near-term, Vietnam-era development of advanced technology. Camp Sentinel responded to a military need for intruder detection with enough accuracy to direct fire. DARPA recommended a foliage penetration radar, which was completed within two years at a direct cost of $2 million. Camp Sentinel radar prototypes were field tested in Vietnam and retained by the troops for use. Further technical refinement was conducted by the Army's Harry Diamond Laboratories.

Camp Sentinel pioneered the development of radar in hostile jungle conditions, which feature absorption and refraction by foliage in high-clutter environments, with multipath returns caused by the ground-based application. Camp Sentinel developed clutter rejection processing techniques that were also later used by commercial acoustic detection intruder detectors.

TRANSITIONS TO THE NAVY

1990s

Non-Penetrating Periscope
Unmanned Undersea Vehicle
Materials Technologies for the F/A-18
Hydrodynamic/Hydroacoustic Technology Center
Shallow Water Multi-Static Active Sonar

1980s

Sea Shadow

1970s

Surveillance Towed Array Sensor System
Aircraft Undersea Sound Experiments
MK 50 Torpedo Propulsion System
MIRACL Anti-Ballistic Missile Defense

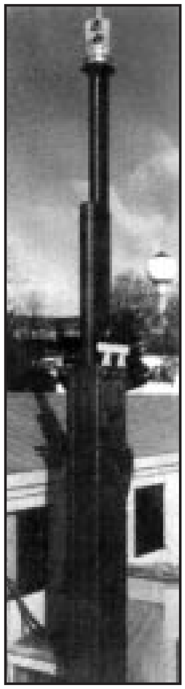
1960s

Satellite Navigation System
Tomahawk Cruise Missile Engines
Relocatable Over-the-Horizon Radar

NON-PENETRATING PERISCOPE

TRANSITIONS
TO THE NAVY

Using fiber optic data transmission, the new telescoping mast eliminates the requirement for fifty feet of hull penetrating optics tube.



■ *The Non-Penetrating Periscope.*

The Non-Penetrating Periscope (NPP) is a revolutionary step forward in submarine mast development and is planned for use on the Navy's newest submarine, the NSSN. Using fiber optic data transmission, the new telescoping mast eliminates the requirement for the deep well and the fifty feet of hull penetrating optics tube that is installed on our current generation of submarines. A prototype system employing commercial visible and infrared spectrum cameras was built and successfully demonstrated on the submarine USS MEMPHIS in 1992. The Navy has continued to build upon this demonstration to enable photonics sensors technology. The NPP also allows greater flexibility in hull design and use of space.

The NPP is one of ten full-scale technology demonstrations that successfully transitioned out of the DARPA Advanced Submarine Technology (SUBTECH) Program to the Department of the Navy between 1989 and 1994. An additional fifty-four projects, falling into the categories Partial Scale Technology Demonstration (sixteen), Capabilities (seventeen), and Knowledge Base (twenty-one), have transitioned or are on the verge of transition. The DARPA SUBTECH Program was the result of specific direction by Congress to establish a program to develop new hull, mechanical, and electrical technology outside of normal Navy research and development channels and transfer them for use as quickly as possible.

UNMANNED UNDERSEA VEHICLE

TRANSITIONS TO THE NAVY

■ *The Unmanned Undersea Vehicle.*

There are a number of Navy missions in the littoral that cannot be performed safely by a full-sized, staffed platform. These include mine location and avoidance as well as remote surveillance. In 1988, a joint DARPA/Navy Unmanned Undersea Vehicle (UUV) Program was initiated, with the goal of demonstrating that UUVs could meet specific Navy mission requirements. The program started with a memorandum of agreement between DARPA and the Navy that specified the design and fabrication of test-bed autonomous vehicles, the independent development of mission packages, and their subsequent integration.

The Unmanned Undersea Vehicle addresses the Navy's objective of developing a tethered shallow water mine reconnaissance vehicle for littoral warfare.

The Navy initially pursued a submarine-launched UUV that would either guide the submarine through an area that might be mined or search an area for mines. As a result of the end of the Cold War, the Navy revised the program with the objective of developing a tethered shallow-water mine reconnaissance vehicle for littoral warfare. A system will be demonstrated in the Joint Mine Countermeasures Advanced Concept Technology Demonstration (ACTD) in 1998.

MATERIALS TECHNOLOGIES FOR THE F/A-18

TRANSITIONS TO THE NAVY

Advanced materials find multiple uses in important subsystems of this Navy fighter.

■ *Top: The Navy F/A-18.*

■ *Bottom: The F/A-18 cockpit.*

The F/A-18A entered operational service in 1983 and is the most reliable, easy-to-maintain tactical aircraft that the Navy and Marine Corps have ever had in their inventories. The aircraft includes many technologies developed under DARPA sponsorship:

■ Titanium aluminum alloy is used in the gun blast diffuser on the M61A1 Gatling Gun.

■ Zinc selenide (ZnSe), with appropriate low-absorption coatings, was adapted for the Ford AN/AAS-38 forward-looking infrared windows. ZnSe windows replaced germanium windows, which could not stand up to the operational needs of the aircraft.

■ Titanium carbide-coated metal ball bearings, also used in the F-16, increased operational life and provided improved performance in the gyrocompasses of the Litton inertial navigation system.

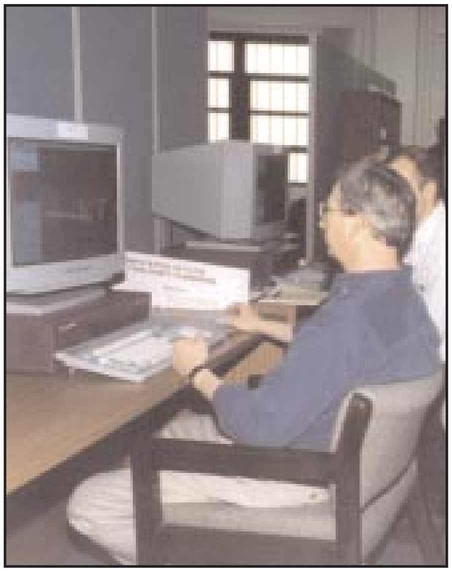
■ Silicon carbide-reinforced aluminum heat sinks facilitate heat removal from the SMUG and power supply subsystem, an outgrowth of fundamental research into ceramic composites.

■ Carbon-carbon composites are being evaluated for use in the repair of damaged brakes. The Naval Air Systems Command has shown that the use of this process, in lieu of discarding all damaged brake material, will save $28 million over the life of the F/A-18 as well as $4 million over the life of the F-14.

In every one of these applications, the Materials Sciences Program at DARPA was responsible for developing or taking advantage of technological breakthroughs in metallurgy, ceramics, composites, and coatings and adapting them to the needs of war-fighting systems.

HYDRODYNAMIC/HYDRO-ACOUSTIC TECHNOLOGY CENTER

TRANSITIONS TO THE NAVY



■ *Hydrodynamic/Hydroacoustic Center at Carderock.*

Maintaining the "acoustic advantage" that is continuing to improve performance in successive generations of submarines is technologically challenging and very expensive. Conventional, empirical design methods were evaluated to have achieved their limits with SEA WOLF. New design tools were necessary not only for the design of the New Attack Submarine but for examining the dynamics of weapon and Unmanned Undersea Vehicle separation from the launch platform.

The program incorporated a network of computers and promoted design tools for stealthy submarines.

As part of its Advanced Submarine Technology Program, DARPA commissioned the development of an advanced design capability. It incorporated a network of computers and promoted the development of computational algorithms and integrated design tools for the purpose of building high-performance, stealthy submarines. The result was the establishment of the Navy's Hydrodynamic/ Hydroacoustic Center (H/HTC) at the Naval Surface Warfare Center, Carderock. H/HTC provides a critical service to the Navy's NSSN and other submarine-related programs and is used by Navy labs, academia, and industry.

SHALLOW WATER MULTI-STATIC ACTIVE SONAR

Broadband low frequency acoustic sources and an automatic processor were built and successfully demonstrated.

The U.S. Navy has not been able to adequately solve the shallow-water antisubmarine warfare (ASW) problem. The detection of small target strength, low Doppler diesel submarines in high clutter remains a critical littoral issue. In response, DARPA initiated the Multi-Static Active in Adverse Environments (MSA/AE) and Autonomous Multistatic Active/Passive Processing System (AMAPPS) programs. The goals of these programs included but were not limited to design, development, and demonstration of the following:

- Operationally useful shallow-water ASW capabilities that use low-frequency active sonar signals.
- Acoustic processing, display, and scene management that can perform automated detection and classification of diesel submarines in adverse acoustic conditions.
- Acoustic sources that generate broadband impulsive signals.

Broadband low-frequency acoustic sources and an automatic processor were built and successfully demonstrated during a series of exercises, including SPAWAR's Littoral Surveillance Exercise (LSE 94) in the Mediterranean Sea. During this exercise, a distributed surveillance field was successfully activated with the MSA/AE sources, and an operational target was detected, classified, and tracked at significant ranges using the prototype processor. Impulsive source designs and the automated algorithms also transitioned to the Naval Air Systems Command (NAVAIRSYSCOM) (PMA-264) Improved Extended Echo Ranging (IEER) Program. Efforts in 1996 included testing the processing system in conjunction with the AN/SQR-19 surface ship tactical towed array system during a littoral Ship ASW Readiness Effectiveness Measurement Program (SHAREM) exercise.

SEA SHADOW

TRANSITIONS TO THE NAVY

■ *The SEA SHADOW.*

Antisurface ship weapons of increasing sophistication and affordability are proliferating world-wide and are becoming more difficult to defend against with current shipboard combat systems. In all cases, the antisurface-ship weapons' launch platform acquisition and terminal homing effectiveness is dependent upon some aspect of surface ship signature. Signature includes radar reflection, infrared profile, electronic or acoustic emission, wake, and magnetic field. Great emphasis has been placed on the development of new shipboard combat systems to a point that enhances shipboard combat systems' effectiveness. Enhancement occurs in several ways. When the enemy launch platform acquisition range is reduced, it becomes more vulnerable to prelaunch counterdetection. Reduced signatures also enhance the performance of decoys and countermeasures against the weapons themselves.

When the enemy launch platform acquisition range is reduced, it becomes more vulnerable to prelaunch counterdetection.

In April 1993, the Navy unveiled SEA SHADOW, a formerly classified prototype surface ship designed to investigate the limits of signature control, sea keeping, ship control, and automation. SEA SHADOW was built in the mid 1980s as part of a joint DARPA/Navy program to provide proof of concept for technologies that can apply to future Navy combatants such as SC-21 and the Arsenal Ship. The black, SWATH–hulled SEA SHADOW employs a faceted shape similar to that of the F-117 to achieve reduced radar cross section, while the twin hull construction contributes to wake reduction and increased sea-keeping capability. Radar cross section reducing modifications to the DDG-51 superstructure in the form of angled surfaces, rounded edges, and a single lightweight mast are the direct results of the SEA SHADOW Program. The sea-keeping capability of the SWATH hull design is also found in USNS VICTORIOUS (T-AGOS-19), a ship meant to work in difficult sea states in higher latitudes.

SURVEILLANCE TOWED ARRAY SENSOR SYSTEM

The DARPA LAMBDA Program demonstrated the utility of long aperture towed acoustic array for undersea surveillance.

■ *SURTASS-equipped SWATH ship.*

Surveillance Towed Array Sensor System (SURTASS) is the Navy's surface ship towed array undersea surveillance capability and has been in nearly continuous fleet operational use since its Initial Operational Capability (IOC) in 1984. There are currently eight SURTASS dedicated T-AGOS monohull ships deployed across the Atlantic and Pacific Oceans, as well as one twin-hull (SWATH) ship. The success of the SURTASS Program has been made possible in part by DARPA research under the Large Aperture Marine Basic Data Array (LAMBDA) Program.

The LAMBDA Program had two important impacts on the development of SURTASS:

1. The LAMBDA experiment demonstrated the utility of long aperture towed acoustic arrays for undersea surveillance.

2. When the Navy's acoustic array telemetry technology failed to mature quickly enough to support the SURTASS program development schedule, the Navy switched to the proven seismic array technology used in the LAMBDA array and demonstrated under a team effort with the Office of Naval Research's (ONR) Long Range Acoustic Propagation Program (LRAPP). This telemetry technology was used for the remainder of the SURTASS development effort.

AIRCRAFT UNDERSEA SOUND EXPERIMENTS

Reports of submerged, long line array acoustic detections of patrolling aircraft prompted the need to investigate whether the detections could be an exploitable phenomenon. There were two potential operational payoffs:

1. Development of capability for our submarines to avoid detection by aircraft.
2. Development of tactics to prevent our own patrol aircraft from alerting Soviet submarines.

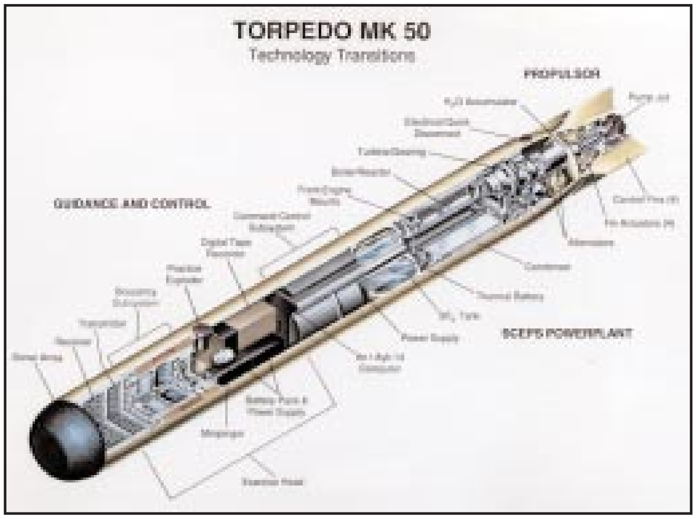
The AUSEX demonstration contributed to the subsequent development of automatic aircraft detection algorithms integrated within the submarine.

In response, DARPA initiated a program in 1974 to explore the limitations of the capability to acoustically detect aircraft using underwater sensors. The program goals were to identify and understand the physics of the detections and to demonstrate technical feasibility. The primary achievements of the Aircraft Undersea Sound Experiments (AUSEX) program were:

1. Validation of a physical model of airborne sound propagation through the air/surface interface.
2. Demonstration of the feasibility of tactical exploitation.
3. Development of the narrow band signal processing techniques to detect and track aircraft.

The demonstration contributed to the subsequent development of automatic aircraft detection algorithms integrated within the submarine sonar processing systems. The capability is currently referred to as the Navy Autonomous Threat Overflight Monitoring System (ATOMS).

MK 50 TORPEDO PROPULSION SYSTEM (SCEPS)



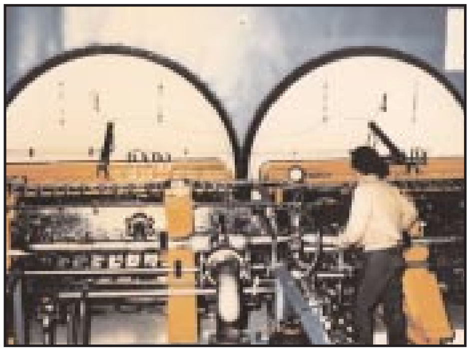
■ *MK 50 torpedo.*

In 1969, ARL/Penn State began work, under Navy sponsorship, on a lithium-based thermal energy system for torpedo application. The system, called SCEPS, featured a reaction of lithium (Li) metal with a sulfur hexafluoride oxidizer (SF6) as a closed Rankine-cycle power plant applicable to the high-power, short-duration mission of a torpedo.

DARPA subsequently selected the Li/SF6 heat source coupled to a Brayton-cycle engine as one propulsion plant candidate for a long-endurance undersea vehicle. One of the engineering obstacles that was overcome in the DARPA adaptation of the heat source was the development of long-life SF6 injectors that could survive in the molten Li bath. The Navy SCEPS Program, which had also been experiencing some difficulty with injectors, adapted the DARPA technology. Today SCEPS is the power plant for the MK 50 Torpedo. Navy work continues, using DARPA-developed concepts, to build and demonstrate a long endurance Li/SF6-powered Stirling engine for undersea vehicle use.

The system features a reaction of lithium metal with sulfur hexafluoride oxidizer for the short duration mission of a torpedo.

MIRACL ANTI-BALLISTIC MISSILE DEFENSE



■ *Chemical Laser.*

In the mid-1970s high-energy lasers showed great promise for antiair warfare and in particular anti-ballistic missile defense. DARPA supported many technology and early system concepts for tactical high-energy lasers. This support culminated in DARPA funding the development of the Baseline Demonstration Laser (BDL) and jointly funding with the Navy the Navy DARPA Chemical Laser. Concurrent with these systems programs, DARPA funded the Special Laser Technology Development Program, which led to many advanced components and concepts.

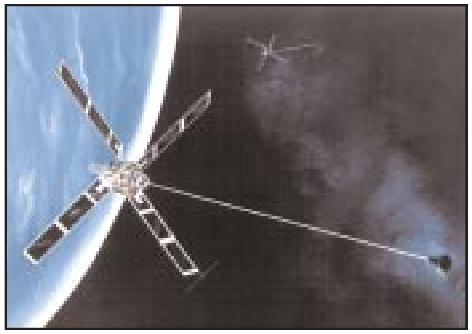
DARPA/Navy joint support of chemical laser research led to the MIRACL, which has been successfully demonstrated.

These concepts formed the bases for several developmental laser systems. Most noteworthy are the Mid-Infrared Advanced Chemical Laser (MIRACL) and the Chemical Oxygen-Iodine Laser (COIL). The latter forms the basis of the Air Force's Airborne Laser (ABL); the former recently shot down a live, short-range rocket at White Sands Test Range. The success has led to initiation of an operational system concept study to develop a Theater High-Energy Laser (THEL), which will lead to developing a fieldable system.

SATELLITE NAVIGATION SYSTEM

TRANSITIONS TO THE NAVY

DARPA support of Transit technology and provision of launch support accelerated development of this early navigation satellite system.



■ *The Satellite Navigation System.*

Transit was the world's first satellite navigation system. The initial satellite was launched in 1959, and by 1968 a fully operational constellation was in place. Thirty-six satellites have been launched, providing accurate, all-weather navigation to both military and commercial vessels, including the Navy's ballistic missile submarine force. Although it is being replaced by the Global Positioning System (GPS) after 28 years of service, Transit established the basis for wide acceptance of satellite navigation systems.

The Transit proposal was brought to DARPA in 1958 by the Applied Physics Laboratory/Johns Hopkins University (APL/JHU) after the Navy declined to support the program because of expense and high risk. Realizing the potential, DARPA responded with the funding to demonstrate the feasibility of the system. The APL built both the satellite and ground stations, while DARPA itself worked on providing the launch systems. The strength of the DARPA support and a streamlined management system permitted the system to proceed easily through feasibility testing and to go operational. The Navy assumed funding responsibilities in the early 1960s.

TOMAHAWK CRUISE MISSILE ENGINES

■ *The TOMAHAWK cruise missile.*

The cruise missile engines evolved from early (1960s) DARPA/Army research on an Individual Mobility System (IMS).

At the onset of Operation Desert Storm, long-range cruise missiles were employed with great effectiveness against high-priority targets in Iraq. Navy TOMAHAWK cruise missiles were launched from destroyers, cruisers, and submerged submarines, while Air Force AGM-86C cruise missiles were launched from B-52s flying 14,000-mile sorties. Propelled by turbofan engines and traveling hundreds of miles at low altitude, these missiles demonstrated high reliability and precision. Cruise missiles were subsequently employed against additional targets in Iraq and in Bosnia as instruments of U.S. policy.

DARPA played a key role in the early development of the turbofan cruise missile engine. The Individual Mobility System (IMS) Project (1965-1969) was a joint effort with the Army. The purpose was to extend the range and endurance of the Bell Rocket Belt developed for the Army in the 1950s. With DARPA funding, Bell replaced the vertical lift rocket system with a compact, highly efficient, turbofan engine being developed by Williams Research Corporation. The DARPA project helped bring the WR-19 engine into full development. It also brought it to the attention of the Air Force, for which it demonstrated excellent horizontal flight characteristics. The engine was adapted for use in the new Air Force cruise missile program. The Navy also became interested in the Williams Research engines as it adapted cruise missiles for maritime applications. Improved versions of the Williams engine (now the F107 series) power all the air, surface, and subsurface launched cruise missiles in the Navy and Air Force inventories.

RELOCATABLE OVER-THE-HORIZON RADAR

TRANSITIONS TO THE NAVY

Derived from extensive research by DARPA on Over-the-Horizon Radar technology.

■ *Relocatable Over-the-Horizon Radar.*

Both the Air Force and the Navy had requirements for the capability to conduct long-range radar surveillance for air and surface threats. Taking advantage of ionospheric reflection of high-frequency electromagnetic waves and improved processing systems, the Department of Defense has fielded at least three high-frequency (HF) over-the-horizon early warning radars. They are the Air Force 440L, an early warning system that was introduced in 1966 and was retired in 1975; the Air Force FPS-118, a continental United States (CONUS)-based air defense system; and the Navy's Relocatable Over-the-Horizon Radar (ROTHR), which is in current use in the drug wars searching for airborne drug carriers.

DARPA became involved in Over-the-Horizon Radar work in 1958. As part of Project DEFENDER, the CONUS ballistic missile defense system, the Agency was given the responsibility for coordinating the development of the technology. Several efforts were already under way in the Navy and Air Force. Besides the coordination responsibility, DARPA aggressively supported the high-risk research and development needed to ensure overall program success.



1990s

Predator Missile
Enhanced Armor for LAV (LAST)

PREDATOR MISSILE

TRANSITIONS TO THE MARINE CORPS

The Predator is a low-cost, shoulder-fired anti-tank rocket that features a unique guidance system.

- *Top: The Predator missile being fired.*
- *Bottom: The Predator missile.*

A low-cost, shoulder-fired antitank rocket, the Short-Range Anti-Armor Weapon (SRAW), also known as Predator, features a unique guidance system, which yielded impressive accuracies for this class of weapon. This unique characteristic, combined with a warhead that adjusts to different kinds of targets, makes the SRAW an innovative and valued weapon in the Marine Corps arsenal.

SRAW was principally funded through the Balanced Technology Initiative Program and was managed by DARPA. The development program began in the mid-1980s and was taken over by the Marine Corps in 1993.

ENHANCED ARMOR FOR LAV (LAST)

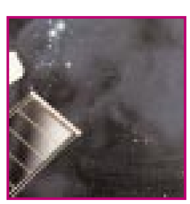
■ *Cermet Materials for Armor.*

In the fall of 1990, the U.S. military buildup in the Kuwaiti theater of operations was continuing. There was concern about Iraqi artillery (especially the South African 155 mm cannon) which in some cases could outrange ours. The top of the Marine Corps Light Armored Vehicle (LAV) was insufficiently protected from fragments that might be delivered by Iraq's large arsenal of artillery. The Light Appliqué System Technology (LAST) armor provided a solution for this problem and was mounted on 75 LAVs that were tested and held ready for Desert Storm. Although the vehicles were too late to enter combat, the armor system is still being considered for adoption. In the meantime, the Canadian forces adapted the LAST system to their vehicles (similar to the LAV, but called the "Grizzly"). Their vehicles with LAST have served in Bosnia. Among the benefits of LAST are its ability to stop fragments at very low arieal density, quick application and removal, and fast repair. Because of the quick application, vehicles and armor can be transported separately and rejoined upon arrival.

Utilizing Lanxide cermet material stops fragments at very low arieal density and is capable of quick application and repair.

DARPA's Armor/Anti-Armor Joint Program sponsored work in two areas that resulted in LAST armor. The first of these was an adaptation of Lanxide cermet material, developed under the DARPA materials program. The product is a ceramic metallic composite that was produced by a unique material manufacturing process (see "Cermet Materials for Armor"). The other technology was a rugged fabric with hooks and loops similar to Velcro. It is sufficiently strong to hold in place 3/8-inch armor tiles on a combat vehicle that is driven across country at high speeds (during Marine Corps practice maneuvers, one LAST-equipped LAV ran over an arroyo, breaking an axle, but losing none of the armor tiles). Other vehicles that received this armor were helicopters and transport aircraft.





OTHER TRANSITIONS

1990s

Microwave and Millimeter Wave Monolithic Integrated Circuits Technology

1980s

Ball Bearing Technology

1970s

Tethered Aerostat Radar System (TARS)
Antenna Booms
Nuclear Monitoring Seismology Technology

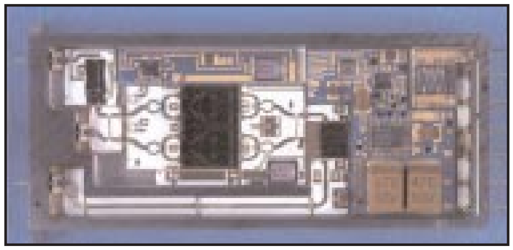
1960s

National Astronomy and Ionospheric Center
F-1 Engine
Saturn V Space Launch Vehicle

1950s

Meteorological Satellite Program (TIROS)
CENTAUR Program

MICROWAVE AND MILLIMETER WAVE MONOLITHIC INTEGRATED CIRCUITS TECHNOLOGY



■ *MIMIC brass board for Generic Expendable Decoy (GEN-X).*

The cost of realizing microwave functions has been reduced by over an order of magnitude.

The development of Microwave and Millimeter Wave Monolithic Integrated Circuits (MIMIC) technology has made possible the realization of numerous military systems within their cost, volume, and power constraints. Of particular significance are the Navy/Air Force High-Speed Anti-Radiation Missile (HARM); the Army's Multi-Option Fuse for artillery (MOFA) and Sense and Destroy Armor (SADARM) system; the Navy/Air Force Advanced Medium-Range Air-to-Air Missile (AMRAAM); the Generic Expendable Decoy (GEN-X), rushed into production for Operation Desert Storm; and Global Positioning System (GPS) receivers. The same technology is now finding a use in civilian applications such as the Forewarn radar system that alerts school bus drivers of the presence of children in "blind" areas surrounding the bus and in AT&T's 900-MHz cordless telephone system that incorporates spread spectrum techniques to prevent undesired interception of transmitted information.

DARPA's MIMIC Program, conducted from 1988 to 1995, concentrated on developing the technologies that would make microwave circuits affordable. It advanced the state of the art for microwave and millimeter wave materials, computer aided design (CAD), device and circuit technologies, manufacturing disciplines, and packaging and testing. Significant advances in these areas have made possible over an order of magnitude cost reduction per given microwave function.

BALL BEARING TECHNOLOGY

■ *Silicon nitride rolling elements for long life, low friction, high speed ball-bearings.*

In the early 1980s, DARPA funded basic research in ceramic ball bearings and solid lubricants. Advanced solid lubricated ceramic technology for moving mechanisms has produced major benefits for numerous DoD weapons systems. Titanium carbide ceramic coated metal ball bearings and silicon nitride ceramic ball bearings have enhanced factory yields, shown better performance, and prolonged life in many applications.

Low-friction, ceramic ball bearings are vital to gyros in DoD's navigation guidance systems.

Titanium carbide ceramic coated metal ball bearings are used in gyroscopes for the following:

- Standard Navigation-Guidance systems of F-18, AV-8, and F-16 production aircraft
- Standard Navigation-Guidance systems of several different helicopters
- Navigational-Guidance systems for the Mark 48 Torpedo and the ASW SEA Lance Program

More recent research advances in silicon nitride ball bearings are demonstrating utility in programs for cryogenic fuel and oxidizer pumps, the life-limiting components in heavy-lift launch chemical propulsion systems, and gimbal bearings for spacecraft precision pointing systems. Flight test data show tenfold improvement in mean time between failures (MTBF) for ceramic bearings. Aircraft fleet retrofits are being contemplated, since these bearings can be substituted without system design changes.

TETHERED AEROSTAT RADAR SYSTEM (TARS)

OTHER TRANSITIONS

Large balloon-borne, high-power, long-range MTI radar detects air and ground moving targets.

■ *Tethered Aerostat Radar System.*

Large balloon-borne, high-power, long-range moving target indication (MTI) radar (detects air and ground moving targets) and communications systems are operated by the Air Force, with participation by the Coast Guard, Army and U.S. Customs Service for southern U.S. border surveillance against low flying intruders and drug smugglers. CARIBALL (Caribbean Balloon) operations began in 1985, and SOWRBALL (Southwest Radar Balloon) operations have been ongoing since 1988.

TARS evolved directly from DARPA tethered aerostat projects Egyptian Goose (radar balloon payloads) and Grand View (communications balloon payloads) in the late 1960s; and Pocket Veto and SEEK SKYHOOK in the early 1970s. Pocket Veto and SEEK SKYHOOK established continuous early tethered aerostat radar surveillance from Cudjoe Key, Florida, across the Caribbean to monitor Cuban flight activities.

ANTENNA BOOMS

■ *The Hubble Space Telescope.*

The National Aeronautics and Space Administration's (NASA) Hubble Telescope takes the clearest images of the universe and, upon command, transmits these to earth via its antennas.

From 1978 to 1980 DARPA funded the design, fabrication, delivery to NASA, and installation of two antenna booms for the Hubble Space Telescope (HST) to demonstrate the advantages of metal matrix composites. These booms, made out of a graphite-fiber/aluminum matrix, permit radio frequency conduction at the same time they serve as low stiffness per unit weight structural supports. This dual use of one composite material resulted in a 60% weight savings over the use of graphite epoxy mechanical load-bearing beams, to which aluminum waveguides would be attached. Antennas for communicating with the HST are attached to the ends of long waveguide booms. Because this particular metal matrix composite also has a low coefficient of thermal expansion, the misalignment drift of the two antennas with temperature excursions is also minimized by use of the composite. NASA's design requirements of light weight, stiffness, and dimensional stability were met by this new materials technology.

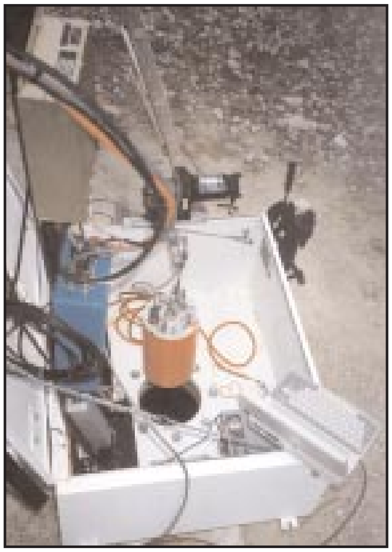
DARPA also contributed to the Hubble's superclear images. Hubble incorporates the algorithms and concept of the deformable mirror for wave front correction, a concept that was pioneered by DARPA's Directed Energy Program in the late 1970s and early 1980s.

Metal matrix composites, pioneered by DARPA, provide the light weight, stiffness and dimensional stability needed for structures in space.

NUCLEAR MONITORING SEISMOLOGY TECHNOLOGY

OTHER TRANSITIONS

DARPA deployed the first World Wide Standardized Seismograph Network (WWSSN), which has had a great impact on seismology as well as detection and identification of underground nuclear explosions.



■ *Installing a seismometer in a borehole at the TXAR array.*

DARPA, under the VELA UNIFORM Project, conducted research in seismology and other techniques for the detection and identification of underground nuclear explosions. As part of this program, DARPA deployed the first World Wide Standardized Seismograph Network (WWSSN), which has had a great impact on seismology and its applications for our understanding of earthquakes and to geology, as well as on the problem of detection and identification of underground nuclear explosions. WWSSN was essentially complete in 1963 and has more than 100 stations in 54 countries, at a cost of some $9 million.

The DARPA solution to the problem of long-period seismic noise made a thoroughly successful transition to operations. It, and the instrumentation developed by DARPA for its implementation, remain an integral part of the U.S. Atomic Energy Detection System (USAEDS), employed at all the USAEDS sites. Most recently, DARPA's design for a high-frequency, low-cost seismic array for explosion monitoring at distances out to a few thousand kilometers has been selected for use in the new International Monitoring System for monitoring compliance with the Comprehensive Test Ban Treaty.

Subsequent to the completion of the initial system, DARPA continued to upgrade the technology of the WWSSN, notably toward becoming more digital. In the late 1960s DARPA sponsored the development and installation of ten high-gain, long-period seismographs which were later augmented with short-period instruments. In 1973 DARPA and the U.S. Geological Survey jointly developed and deployed thirteen Seismic Research Observatories, which included a new broadband borehole seismometer and an advanced digital recording system.

In 1964 DARPA began construction of a Large Aperture Seismic Array (LASA) that was completed in five months and operated until 1978. In 1967 DARPA undertook the cooperative construction, with the Norwegians, of the Norwegian Seismic Array (NORSAR), a second-generation large array at a location outside Oslo. NORSAR commenced full operation in 1971 and is still being used. A subarray of NORSAR, NORESS, has been outfitted with the most modern seismographs and data handling systems and may be regarded as a prototype international seismographic monitoring station.

NATIONAL ASTRONOMY AND IONOSPHERIC CENTER

■ *The National Astronomy and Ionospheric Center (NAIC).*

The Arecibo Ionospheric Observatory, renamed the National Astronomy and Ionospheric Center (NAIC) in 1971, is operated by Cornell University for the National Science Foundation. It has been used for ionospheric physics studies, radar and radio astronomy, aeronomy and dynamics of the earth's upper atmosphere, and has assisted the National Aeronautics and Space Administration in selection of lunar landing sites as well as Viking planetary mission landing sites. It continues to be in use.

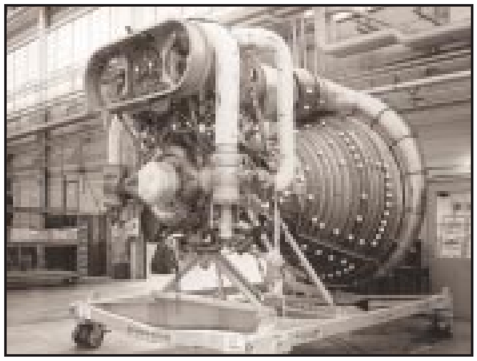
Development of the Arecibo facility was initially supported by DARPA in the 1960s as part of the DEFENDER Program, a broad-based missile defense program. It was intended for study of the structure of the upper ionosphere.

The NAIC, developed by DARPA as the Arecibo Ionospheric Observatory, has been used for ionospheric physics studies, radar and radio astronomy, aeronomy and dynamics of the earth's upper atmosphere.

F-1 ENGINE

OTHER TRANSITIONS

Development of the F-1 engine was supported by DARPA as a means of catching up with the large space booster of the Soviet Union.



■ *The F-1 engine.*

The 1.5 million pound thrust F-1 engine in a cluster of five became the first stage propulsion unit for SATURN V, the booster used for National Aeronautics and Space Administration (NASA) lunar missions.

Recognizing the need for a major step in engine thrust to support future space missions and to compete with the Soviet large thrust engine technology, DARPA initiated development of a one million pound thrust engine, later uprated to 1.5 million pound thrust, which entered test firings at Edwards Air Force Base in 1959. The F-1 engine was transferred to NASA as part of the SATURN transfer in 1960.

SATURN V SPACE LAUNCH VEHICLE

OTHER TRANSITIONS

■ *The Saturn V Space Launch Vehicle.*

The SATURN V Space Launch Vehicle used for staffed cislunar and lunar landing missions evolved from early high-thrust booster work sponsored by DARPA.

In 1958 DARPA initiated a cluster engine development program (eight engines of the Intermediate Range Ballistic Missile [IRBM] class, each with a 150,000 pound thrust), at the Army Ballistic Missile Agency. This development was to support a SATURN IB space launch vehicle program that would be performance-competitive with the projected SPUTNIK Soviet booster. Growth versions of the SATURN, including the SATURN IC (later designated SATURN V by NASA) would have a cluster of F-1 (1.5 million pound thrust) engines in the first stage with growth liquid oxygen and liquid hydrogen (LOX LH2) upper stage. This subsequently became the SATURN launch vehicle that carried the first astronauts to the moon. Large upper stages and a CENTAUR-class stage would be integral parts of the space booster. This program was transferred to NASA in early 1960.

The initiation of clustered high-thrust engine technology by DARPA led to the development of the Saturn V Space Launch Vehicle that carried the first astronauts to the moon.

METEOROLOGICAL SATELLITE PROGRAM (TIROS)

The early launch of TIROS I in 1959 was successful and produced 23,000 pictures of the earth and its cloud cover.

■ *The TIROS satellite.*

The TIROS meteorological satellite program at NASA became the developmental prototype for the current National Oceanographic and Atmospheric Administration's (NOAA) global system that is used for weather reporting and forecasting.

The TIROS Program was initiated by DARPA in 1958 and transferred to NASA in 1959. The early launch of TIROS I in 1959 was successful and produced 23,000 pictures of the earth and its cloud cover over two months' time.

CENTAUR PROGRAM

OTHER TRANSITIONS

■ *The RL-10 LOX/LH2 engine used on the CENTAUR stage.*

The CENTAUR LOX/LH2 upper stage has been used extensively on the ATLAS and Titan booster stages for many high-energy satellite missions such as twenty-four-hour communication satellites as well as deep space missions. It was transferred to NASA in late 1959.

The CENTAUR Program was initiated at DARPA in 1958, along with the development of the Pratt & Whitney RL-10 LOX/LH2 engine for powering the stage. Taking advantage of the high specific impulse of this propellant combination, it allowed existing inventory first and second stage launch vehicles to extend their mission performance. The CENTAUR provided the vehicle for proving the liquid oxygen and liquid hydrogen (LOX/LH2) technology, which was subsequently incorporated into upper stages for the SATURN launch vehicle.

The CENTAUR Program, initiated by DARPA in 1958, was the first upper stage to use LOX/LH2 propellants.

SUMMARY

The Defense Advanced Research Projects Agency, contrary to some government organizations created in response to an immediate need, has persisted and enjoyed a growing acceptance and respect not only within the Defense Department but governmentwide, by the Congress and the industrial and academic communities.

This report documents many of the noteworthy achievements which have found acceptance and have been exploited by the Military Departments, other departments of government, and the industrial community. A modest investment in terms of the total government research and development funding has fostered major advances in defense capabilities.

The factors contributing to successful transition of technology, pointed out in the Executive Summary (pp 20-22), are widely recognized by the Military Departments, the industrial and academic partners. The Agency has aggressively sought transition modes and techniques which have yielded successful transition. The process has been a shared experience with the Military Departments and its success is a mutual accomplishment.

While the Report highlights and illustrates some of the more prominent and recognizable transitions, there are many embedded transitions which cannot be so clearly presented. In the fields of microelectronics, advanced materials, electronic devices, computer science and information processing much of the DARPA technology is seamlessly transitioned by becoming embedded in military or industrial developed systems.

In the Appendix, which follows, the association of DARPA Technology Thrusts with the Selected Technology Transitions presented in the Report is tabulated. The association of transitions explicitly with a given DARPA Thrust is beyond the scope of the Report, however, the DARPA Thrusts reflect the recognition of military needs by the DARPA organization. The continuing flow of technology transitions testify to the Agency's successful perception of these needs.

DARPA plans to establish a data recovery system which will capture these technology transitions as they occur. This will provide an enduring record and a continuing opportunity to adjust and improve the technology transition process.

APPENDIX

DARPA'S TECHNOLOGY THRUSTS AND TECHNOLOGY TRANSITIONS

An interesting view of this assessment is to examine successful transitions by decade against the major technological thrusts of the Agency. The transition process is usually extended and nonuniform. A Military Service has to examine the technology in various formats, match it up with its operational requirements, and compare it with alternatives before participating in extending the technology into field or prototype demonstrations. It was in recognition of these considerations that DARPA in the mid-1970s created a research and development (R&D) category called Experimental Evaluation of Major Innovative Technology (EEMIT). This thrust and the recommendation of the Packard Commission in the mid-1980s have helped to accelerate the transition process. These recommendations have been extended in the 1990s by the Advanced Concept Technology Demonstration (ACTD) Program.

The following tables associate selected transitions by decade with the major thrusts (R&D projects) of the Agency.

In Table I, the two years of DARPA's existence in the 1950s (1958-59) are grouped with the 1960s decade. The earliest transitions (1959) were the TIROS Meteorological Satellite, the CENTAUR LOX/LH2 space launch vehicle upper stage, and associated RL-10 LOX/LH2 engine development. Programs transferred to DARPA when it was established in 1958 include the Air Force SAMOS and MIDAS Programs, and the Army NOTUS Program. These programs were returned to the respective Services in 1959 by direction of the Secretary of Defense. Since DARPA activities on these programs were mainly studies, they are not included in the transition history. The early 1960s saw the transition of the R-1 rocket engine and the SATURN space launch vehicle to NASA as part of the nationalization of the space program established by NASA. The transition of the Arecibo Ionospheric Observatory to the National Science Foundation also occurred in the early 1960s. The balance of those technologies shown in Table 1 transitioned in the mid to late 1960s. These transitions are associated with the technology thrusts of the Agency, as shown.

Table 1

DARPA's TECHNOLOGY THRUSTS OF THE LATE 1950s AND 1960s AND TECHNOLOGY TRANSITIONS

DARPA's TECHNOLOGY THRUSTS	TECHNOLOGY TRANSITIONS
▪ Outer Space	▪ Phased Array Radars
▪ Ballistic Missile Defense	▪ M-16 Assault Riffle
▪ Solid Propellant Chemistry	▪ SPRINT
▪ Materials Science	▪ Camp Sentinel Radar
▪ Nuclear Test Detection	▪ Satellite Navigation System (Transit)
▪ Command and Control Information	▪ Tomahawk Cruise Missile Engine
▪ AGILE (counterinsurgency R&D)	▪ Relocatable Over-the-Horizon Radar
▪ Advanced Sensors	▪ National Astronomy and Ionospheric Center
	▪ F-1Engine
	▪ SATURN Space Launch Vehicle Meteorological Satellite Program
	▪ CENTAUR Program

The transfer of space programs to NASA and the Military Departments in 1960, the transfer of DEFENDER to the Army later in the decade, and the termination of the AGILE activities as a consequence of the end of the Vietnam War in the early 1970s helped reshape the technology thrusts of the Agency in the 1970s. The Materials Science Program spun off the materials research laboratories to the National Science Foundation, but more applied programs continue to this day. Nuclear Test Detection continued to be of high interest, especially with the prominence of the Nuclear Test Ban Treaty talks and the need to discriminate possible treaty violations by de-coupled underground testing. The residue of AGILE and the Advanced Sensors activity were merged into a new overall thrust of Tactical Technology. The stealth technology evolved from this thrust. The Strategic Technology thrust was created after the transfer of DEFENDER and addressed a broad range of science and technology aimed at retention of the U.S. deterrence posture. Activities included surveillance from space, directed energy technology such as high-energy lasers and particle beam accelerators. Also receiving support in this period was advanced Antisubmarine Warfare. During the 1970s, Information Processing Technology received increasing budget growth, emphasizing command and control, packet switching, and parallel processing.

A summary of these technology thrusts and the technology transitions achieved in the 1970s is shown in Table 2.

Table 2

DARPA'S TECHNOLOGY THRUSTS OF THE 1970S
AND TECHNOLOGY TRANSITIONS

DARPA's TECHNOLOGY THRUSTS	TECHNOLOGY TRANSITIONS
■ Materials Science	■ ARPA Maui Optical Station
■ Nuclear Test Detection	■ Materials Technologies for the Titan
■ Tactical Technology	■ Over-the-Horizon Radar
AGILE	■ Balloon-Borne Radar Surveillance
Advanced Sensors	■ ELITE
Other	■ Advanced Medium Range Air-to-Air Missile (AMRAMM)
■ Strategic Technology	
Large Space Optics	■ Materials Technologies for the SR-71
Anti-Submarine Warfare	■ Nuclear Test Monitoring Satellite
■ Information Processing Technology	■ Copperhead
	■ Army Tactical Missile Systems (ATACMS)
	■ Brilliant Anti-Tank (BAT Munition)
	■ Surveillance Towed Array Sensor System (SURTASS)
	■ Aircraft Undersea Sound Experiments (AUSEX)
	■ MK 50 Torpedo Propulsion System (SCEPS)
	■ UNIX
	■ Simulators/Computer Graphics
	■ VLSI Design
	■ Internet/Milnet
	■ Tethered Aerostat Radar System (TARS)
	■ Antenna Boom
	■ Nuclear Monitoring Seismology Technology
	■ Large-Scale Data Processing
	■ Computer Workstation

Technology transitions and Technology Thrusts in the 1980s are shown in Table 3.

Table 3

DARPA's TECHNOLOGY THRUSTS OF THE 1980s
AND TECHNOLOGY TRANSITIONS

DARPA's TECHNOLOGY THRUSTS	TECHNOLOGY TRANSITIONS
■ Materials Science	■ Stealth Fighter
■ Microelectronics Technology	■ Stealth Bomber
■ Electronics Systems Technology	■ Joint STARS
■ Nuclear Test Detection	■ X-29 Forward Swept Wing Aircraft Technology Demonstrator
■ Tactical Technology (Air, Land, and Naval Warfare)	■ Pilot's Associate
■ Aerospace Technology (Advanced Air and Space Vehicles)	■ Materials Technologies for F-15 and F-16
■ Information Processing Technology	■ Low Probability of Intercept (LPI) Airborne Radar
	■ Advanced Cruise Missile
	■ Close Combat Tactical Trainer (CCTT)
	■ Javelin
	■ Uncooled infrared Sensors
	■ Head-Mounted Displays
	■ Body Armor
	■ No Tail Rotor for Single Rotor Helicopter (NOTAR)
	■ Precision Emitter Location
	■ SEA SHADOW

The DARPA technology thrusts in the 1990s continue to support the Materials and Electronics Processing Project including advanced structural, electronic, and magnetic materials. The Information Processing Technology thrust has given increasing support to the High-Performance Computing and Communication Initiative, intelligent systems and software. Demonstration programs in experimental evaluation of major innovative technologies (EEMIT) have been stepped up in the areas of critical mobile targets, advanced simulation, global grid communications, and classified programs (including some transfers from the Office of the Secretary of Defense).

Technology transitions and Technology Thrusts in the 1990s are shown in Table 4.

Table 4

DARPA'S TECHNOLOGY THRUSTS OF THE 1990S
AND TECHNOLOGY TRANSITIONS

DARPA's TECHNOLOGY THRUSTS	TECHNOLOGY TRANSITIONS
■ Materials Science	■ Taurus Launch Vehicle
■ Electronic Sciences and Systems	■ Pegasus Air Launched Vehicle
■ Tactical Technology (Naval Warfare, Advanced Land System Components)	■ Endurance Unmanned Air Vehicle
■ Information Processing Technology	■ Affordable Short Takeoff, Vertical Landing (ASTOVL)
■ Sensor Technology	■ Schottky IR Imager for the B-52 (Replacements for the AAQ-6)
	■ Materials Technology for the F-22
	■ Technologies for Transport Aircraft
	■ Affordable Tooling for Rapid Prototyping
	■ X-31 Aircraft
	■ Sensor Fuzed Weapon (CBU-97/B)
	■ Enhanced Survivability for HMMWV
	■ MELIOS Improvement
	■ Signal Processing Technologies for the OH-58D
	■ Comanche ANN-Based ATR
	■ SOLDIER 911
	■ X-Rod
	■ Shaped Charged Warhead
	■ Hand-Emplaced Wide Area Munition
	■ Non-Penetrating Periscope
	■ Unmanned Undersea Vehicle
	■ Materials Technologies for the F/A-18
	■ Hydrodynamic Computational Workstation

The Nuclear Test Monitoring thrust was transferred to the Office of the Secretary of Defense in FY 1996, after phasing out of DARPA in the mid-1990s. The Tactical Technology thrust continues at a moderate level with some growth in the last half of the decade in Naval Warfare, Advanced Land Systems, and Advanced Component technologies. The Aerospace thrust has phased out. A new initiative in the 1990s is Sensor Technology. The major activity in this thrust is directed toward sensor improvements for detection, location, and tracking of airborne threat vehicles such as cruise missiles and aircraft.

In the late 1980s and early 1990s there was substantial increase in the DARPA budget associated primarily with technology demonstration projects, computer science and a new initiative, the Technology Reinvestment Project (TRP). The TRP sought to stimulate a merging of defense and commercial industrial bases to ensure DoD access to critical defense-related technologies at a cost kept low by joint interests. Transitions evolving from this activity are not discussed in this report. An excellent discussion of this activity is contained in "The Technology Reinvestment Project,Dual-Use Innovation for a Stronger Defense," published by the National Technology Transfer Center (Reference 4).

GLOSSARY AND REFERENCES

GLOSSARY

AALPS - Advanced Air Load Planning System
AAWS–M - Anti-Armor Weapon System-Medium
ABL - Airborne Laser
ABMDA - Army Ballistic Missile Defense Agency
ABRES - Advance Ballistic Reentry System
ACE - Armored Combat Earthmover
ACM - Advanced Cruise Missile
ACP - Affordable Composites Program
ACTD - Advanced Concept Technology Demonstration
AEDS - Atomic Energy Detection System
AICBM - Anti-Intercontinental Ballistic Missile
AIRMS - Advanced Infrared Measurement System
ALV - Air-Launched Vehicle
AMAPPS - Autonomous Multistatic Active/Passive Processing System
AMOS - ARPA Maui Optical Station
AMRAAM - Advanced Medium-Range Air-to-Air Missile
ANN - Artificial Neural Network
AP - Armor Piercing
APAM - Antipersonnel/Anti-Material
APL/JHU - Applied Physics Laboratory/Johns Hopkins University
ARPA - Advanced Research Projects Agency
ASAT - Defense Against Satellites
ASTAMIDS - Airborne Standoff Minefield Reconnaissance and Detection System
ASTOVL - Affordable Short Takeoff, Vertical Landing
ASW - Anti-Submarine Warfare
ATACMS - Army Tactical Missile System
ATD - Advanced Technology Demonstration
ATFE - Advanced Tactical Fighter Engine
ATM - Asynchronous Transfer Mode
ATOMS - Navy Autonomous Threat Overflight Monitoring System
ATR - Automatic Target Recognition
AUSEX - Aircraft Undersea Sound Experiments

BAT - Brilliant Antitank Munition
BDL - Baseline Demonstration Laser
BMD - Ballistic Missile Defense
BMDO - Ballistic Missile Defense Organization
BTI - Balanced Technology Initiative

C^3 - Command, Control, Communications
CAD - Computer Aided Design
CALF - Common Affordable Lightweight Fighter
CARIBALL - Caribbean Balloon
CATT - Combined Arms Tactical Trainer
CATT/CCTT - Combined Arms Tactical Trainer and Close Combat Tactical Trainer
CCD^2 - Charged Coupled Devices ^{2}
CCTT - Close Combat Tactical Trainer
CERT - Computer Emergency Response Team
CHAALS - Communications High-Accuracy Airborne Location System
CLGP - Cannon-Launched Guided Projectile
CMM - Capability Maturity Models
CMOS - Complementary Metal Oxide Semiconductor
COIL - Chemical Oxygen-Iodine Laser
CONUS - Continental United States
CTOL - Conventional Takeoff and Landing

DARO - Defense Airborne Reconnaissance Office
DARPA - Defense Advanced Research Projects Agency
DD - Differential Doppler
DDR&E - Director, Defense Research and Engineering
DISA - Defense Information System Agency
DISN - Defense Information System Network
DISN LES - Defense Information System Network Leading Edge Service
DoD - Department of Defense
DoE - Department of Energy
DSB - Defense Science Board
DSP - Digital Signal Processor

EEMIT - Experimental Evaluation of Major Innovative Technologies
EFP - Explosively Formed Penetrator
ELITE - Extended Long-Range Integrated Technology Experiment
EMP - Electromagnetic Pulse
EO/IR - Electro-Optical/Infrared
ESAR - Electronically Steered Array Radar
EW - Electronic Warfare

FFRDC - Federally Funded Research and Development Centers
FLIR - Forward-Looking Infrared

GCCS - Global Command and Control System
GEN-X - Generic Expendable Decoy
GPS - Global Positioning System
GPS/NDS - Global Positioning System/Nuclear Detection System
H/HTC - Hydrodynamic/Hydroacoustic Technology Center
HALO - High-Altitude Large Optics
HARM - High-Speed Antiradiation Missile
HEDI - High Endoatmospheric Defensive Interceptor
HF - High Frequency
HIBEX - High Booster Experiment
HiMAT - Highly Maneuverable Aircraft Technology
HMMWV - High Mobility Multi-Purpose Wheeled Vehicle
HP - Hewlett Packard
HPC - High-Performance Computing
HPF - High-Performance Fortran
HST - Hubble Space Telescope

IC - Integrated Circuit
ICBM - Intercontinental Ballistic Missile
IEER - Improved Extended Echo Ranging
IMS - Individual Mobility System
IOC- Initial Operational Capability
IR - Infrared
IR&D - Independent Research and Development
IRBM - Intermediate Range Ballistic Missile
ISAR - Inverse Synthetic Aperture Radar

JSF - Joint Strike Fighter
JSTARS - Joint Surveillance and Target Attack Radar System

KREMS - Kiernan Reentry Measurements System

LAMBDA - Large Aperture Marine Basic Data Array
LARS - Laser Aided Rocket System
LASA - Large Aperture Seismic Array
LAST - Light Appliqué System Technology
LAV - Light Armored Vehicles
LoADS - Low Altitude Defense
LOCUSP - Low-Cost, Uncooled Sensor Program
LODE - Laser Technology, Large Optics
LPI - Low-Probability-of-Intercept

LRAPP - Long-Range Acoustic Propagation Program
LSE - Littoral Surveillance Exercise
LWRM - Light-Weight Radar Missile

MCT - Mercury-Cadmium-Telluride
MDV - Minimum Detectable Velocity
MIMIC - Microwave and Millimeter Wave Monolithic Integrated Circuits
Mini-ELS - Mini-Emitter Location System
Mini-RPVs - Mini-Remotely Piloted Vehicles
MIPS - Millions of Instructions Per Second
MIRACL - Mid-Infrared Advanced Chemical Laser
MIT - Massachusetts Institute of Technology
MOFA - Multi-Option Fuse for Artillery
MOSIS - Metal Oxide Semiconductor Implementation Service
MSA/AE - Multi-Static Active in Adverse Environments
MTBF - Mean-Time-Between-Failure
MTI - Moving Target Indication

NAIC - National Astronomy and Ionospheric Center
NASA - National Aeronautics and Space Administration
NASP - National Aerospace Plane
NAVAIRSYSCOM - Naval Air Systems Command
NAVSEA 92-R - Navy Advanced Submarine Research and Development Office
NOAA - National Oceanographic and Atmospheric Administration
NORSAR - Norwegian Seismic Array
NOTAR - No Tail Rotor
NPP - Non-Penetrating Periscope
NSA - National Security Agency
NSA MISSI - National Security Agency/Multilevel Information Security
NSF - National Science Foundation
NSWC - Naval Surface Warfare Center

ONR - Office of Naval Research
OMG - Object Management Group
OS - Operating System
OSD - Office of the Secretary of Defense
OT&E - Operational Test and Evaluation
OTH - Over-the-Horizon
OTH-B - Over-the-Horizon-Backscatter
OTH-R - Over-the-Horizon Radar

PA - Pilot's Associate
PDU - Protocol Data Unit
PEGSAT - Pegasus Satellite
PM - Program Manager
PRESS - Pacific Range Electromagnetic Systems Studies

R&D - Research and Development
RAID - Redundant Array of Inexpensive Devices
RAKE - Rocket-Assisted Kinetic Energy Tank Round
rf - Radio Frequency
RFC - Retirement for Cause
RFP - Request for Proposals
RISC - Reduced Instruction Set Computing
RISTA - Reconnaissance, Intelligence, Surveillance and Target Acquisition
ROTHR - Relocatable Over-the-Horizon Radar
RPV - Remotely Piloted Vehicle
RSR - Rapid Solidification Rate
RSVP - Resource reSerVation Protocol

SAC - Strategic Air Command
SADARM - Sense and Destroy Armor
SAL - Semiactive Laser
SAR - Synthetic Aperture Radar
SCDL - Surveillance and Control Data Link
SCEPS - Stored Chemical Energy Propulsion System
SDIO - Strategic Defense Initiative Organization
SDV - Skeet Delivery Vehicle
SFW - Sensor Fuzed Weapon
SGI - Silicon Graphics Incorporated
SHAREM - Ship ASW Readiness Effectiveness Measurement Program
SIGNET - Signal Intercept
SIMNET - Networked Simulation
SIPRNet - Secure IP Router Network
SOCOM - Special Operations Command
SONET - Synchronous Optical Network
SOWRBALL - Southwest Radar Balloon
SPAWAR - Space and Naval Warfare Systems Command
SRAW - Short-Range Antiarmor Weapon
SRO - Seismic Research Observatories
SSLV - Small Standard Launch Vehicle
STOVL - Short Takeoff, Vertical Landing

STOW 97 - Synthetic Theater of War 97
SUBTECH - Submarine Technology
SURTASS - Surveillance Towed Array Sensor System

TARS - Tethered Aerostat Radar System
TCP/IP - Transmission Control/Internet Protocol
TDOA -Time-Difference-of-Arrival
THEL - Theater High-Energy Laser
TOW - Tube Launched, Optically Tracked Wire Guided Antitank Missile
TRP - Technology Reinvestment Project

UAV - Unmanned Aerial Vehicle
UN/NATO - United Nations/North American Treaty Alliance
USAEDS - U.S. Atomic Energy Detection System
USMC - United States Marine Corps
UUV - Unmanned Undersea Vehicle

VLSI - Very Large-Scale Integration

WAM - Wide Area Munition
WARF - Wide Aperture Research Facility
WDM - Wave Division Multiplexing
WWSSN - World Wide Standardized Seismograph Network

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LIST OF CONTRIBUTORS

LIST OF CONTRIBUTORS

Listed below are those organizations that provided technology transition information.

DEPARTMENT OF DEFENSE

Defense Commercial Communications Office
Defense Electronic Supply Center
Defense Finance and Accounting Service
Defense Information Systems Agency
Defense Intelligence Agency
Defense Logistics Agency
Defense Mapping Agency
Defense Nuclear Agency
Department of Defense, Ballistic Missile Defense Organization (BMDO)
Office of the Under Secretary of Defense (Acquisition and Technology)

UNITED STATES AIR FORCE

46 Test Wing (Chicken Little)
Air Force Aeronautical Systems Center/XR
Air Force Human Systems Center
Air Force Institute of Technology
Air Force Office of Scientific Research
Air Force School of Aerospace Medicine
Air Force Technical Applications Center
Armstrong Lab–Human Systems Center
Department of the Air Force, Aeronautical Systems Center
Department of the Air Force, HQ 46th Test Group
Department of the Air Force Space and Missile Systems
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UNITED STATES ARMY

Aberdeen Proving Ground—Support Activity
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UNITED STATES NAVY

Naval Air Systems Command
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UNITED STATES MARINE CORPS

Marine Corps Systems Command (MCSC)

OTHER GOVERNMENT

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